Papers

25th

SUSTAINABILITY DRIVING THE FUTURE

Int'l. Fertilizer Technology Conference & Exhibition

July 9-11, 2012

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25th AFA International Fertilizers Technology Conference
Sustainability Driving the Future

July 09 – 11, 2012

Program


Registration & Help Desk:

- **Sunday: July 8th, 2012**: 09 hr:30 - 16 hr:00
- **Monday: July 9th, 2012**: 08 hr:30 - 14 hr:00
- **Tuesday: July 10th, 2012**: 09 hr:30 - 14 hr:00

Committees Meeting: Restricted to members only

Sunday: July 8th, 2012

- 10 hr:00  AFA Technical Committee Meeting
- 11 hr:00  AFA Economic Committee Meeting
- 12 hr:00  AFA HSE Committee Meeting

14 hr:00 - 15hr:30 Lunch (Restricted to Committees Member)
Hosted by: AFA General Secretariat
Program

DAY 1: Monday: July 9th, 2012

10:00 Opening Ceremony
- Welcome addresses:
  - Mr. Mohamed Rashid AL-Rashid, AFA Chairman
  - Dr. Shafik Ashkar, AFA Secretary General

10:30 Session I
1- From flaring to environmental friendly ammonia firing and that even done in an economical way
   Joey Dobrée, Licensing Manager, Stamicarbon, Netherlands
2- Energy efficient cooling of fertilizer with the Coperion bulk solids heat exchanger BULK-X-CHANGE®.
   Harald Nigsch - Sales Manager Thermal Processes, Coperion, Germany
3- “GPIC Sustainability Reporting Approach in line with the Global Reporting Initiatives (GRI) Framework”
   Hussam Al Asadi, Planning Engineer, GPIC, Bahrain
4- Qatar Fertilizer Company Commitment to Health & Safety and Environmental Stewardship
   Iftikhar Hussain Turi, HOS A2/ AHOS Urea-2-, QAFCO, Qatar

12:00 Networking Coffee / Tea

12:30 Session II
Chairperson: Dr. Julian Hilton - Chairman, Aleff Group - UK
1- How Automation Improves Operational Efficiency of Nitrogen-based Fertilizer Plants
   Brendan Sheehan, Chemical Marketing Manager, Honeywell Process Solutions, Turkey
2- Energy Conservation Study for Ammonia Urea Complex
   Anthony Conning – Business Unit Manager, ABB - UK
   Magdy Mohamed Ali - Senior Process Engineer - Projects Division, FERTIL - UAE
3- Catalysing profit margin with LK-853 FENCE™: A new generation of Topsoe low methanol LTS catalyst
   Kristina Svennerberg, General Manager, Marketing Synthesis, Haldor Topsoe, Denmark
4- Elimination of radioactive sources in Ruwais Fertilizer Industries Co.
   Ahmed Al-Awadhi – Sr. Instrument Engineer, FERTIL, UAE

14:00 Networking Lunch

17:00 Dubai City Tour
DAY 2 Tuesday: July 10th, 2012

10:00 Session III

Chairperson: Dr. Nadim Fuleihan - President, Senior Consulting - Ardaman & Association - USA

1- Safe, Sustainable Phosphate Production
   Julian Hilton – Chairman, ALEFF GROUP, UK

2- Phosphogypsum Management and Use: Opportunities and Issues
   Julian Hilton – Chairman, ALEFF GROUP, UK

3- Utilization of Low grade rocks by optimizing operation parameters in manufacturing Phosphoric acid with Better Efficiency
   G M Patel, Technical Director, CFIC, India

4- Smart fertilizers for sustainable agriculture: The state of the art and the recent developments
   Youssef ZEROUAL, Research & Development Direction Industrial Pole, OCP Group, Morocco

5- Enhancement of Hot leach plant Operational Sustainability
   Ala'a Al Omari, Senior Process Engineer, APC, Jordan

12:00 Networking Coffee / Tea

12:30 Session IV

Chairperson: Eng. Faisal Dodun - General Manager - I C – Jordan

1- KBR PURIFIERTM Technology and Project Execution Options for Ammonia Plants
   Avinash Malhotra - Director, Technology Fertilizers & Synthesis Gas, KBR, USA

2- Application of ALSTOM’s Chilled Ammonia Process in the Fertilizer Industry
   Gianluca Di Federico - Director Sales, ALSTOM, Germany

3- Sustainable ammonia plant operations: The impact of shift operation
   Yaqoob Kamal, Johnson Matthey, UK

4- Online Installation of New Exchanger for Sustained Production
   Faisal F. Al-Shahrani, SF4 Operation Manager, SAFCO, S. Arabia

5- Economics of synthesis gas generation concepts for substantial capacity enlargements of ammonia plants
   Joachim Johanning, Head of Product Development Group Ammonia & Urea Division, Uhde GmbH, Germany

14:00 Networking Lunch

17:00 Dubai City Tour
DAY 3: Wednesday, July 11th, 2012

10:00 Session V

Chairperson: Dr. Abdelhak Kabbabi - Head of Department Environment - OCP - Morocco

1- The Way to achieve Zero Liquid Discharge at Abu Qir Fertilizers Co.
   Fatma Badawy - Utilities Sectors Head, Abu Qir, Egypt

2- Challenges Experienced in Phasing out Radioactive Source Level Measurement in Urea Reactor at Albayroni
   Hassan Al-Khulaif - Process Engineer, Bayroni, S. Arabia

3- “GPIC Initiative to obtain Responsible Care® Certification as full member of GPCA”
   Mohamed Al Hashemi, GPIC, Bahrain

4- Composite fertilizers including Urea+ and NPK production in High Speed Drum Granulator
   Danil Safonov, International Affairs Manager, R&D Institute of Urea (NIIK) – Russia

12:00 Closing Session

13:00 Networking Lunch
1. From flaring to environmental friendly ammonia firing and that even done in an economical way
   Joey Dobrée, Licensing Manager, Stamicarbon, Netherlands

2. Energy efficient cooling of fertilizer with the Coperion bulk solids heat exchanger BULK-X-CHANGE®.
   Harald Nigsch - Sales Manager Thermal Processes, Coperion, Germany

3. “GPIC Sustainability Reporting Approach in line with the Global Reporting Initiatives (GRI) Framework”
   Hussam Al Asadi, Planning Engineer, GPIC, Bahrain

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From flaring to environmental friendly ammonia firing and that even done in an economical way

Joey Dobrée
Licensing Manager, Stamicarbon
Netherlands
From flaring to environmental friendly ammonia firing and that even done in an economical way

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1. Abstract

The reduction of ammonia emission from urea plants has always been an important qualifier for technology licensors in order to comply with World Bank or derivative standards and our own responsibility to strive for a sustainable future. Technology development does provide solutions to design urea plants in such way that ammonia venting is made absent, but economical feasibility and environmental sensibility remain a hurdle to take.

In the meanwhile tightening local emission regulations and the avoidance of ammonia smell to the plant surroundings require solutions to bridge the gap to the future. One of the options for the bridging is the flaring of ammonia containing off-gasses. But is it an actual solution or just a poor man’s solution?

This paper focuses specifically on the environmental consideration to use an off-gas treatment system for the elimination of ammonia emissions in the urea melt plant. It explains how ammonia venting to the atmosphere can environmentally wise be benchmarked against the alternatives of incineration, heating and combustion technologies. The paper explains Stamicarbon’s objections regarding the use of flare systems as environmental mitigation strategy in the urea melt plant and clarifies the most environmental and economical sensible solution available in Stamicarbon’s technology portfolio: the thermal treatment and catalytic DeNOx.

An example case of a world scale urea plant is used for quantification and the outcome of the paper reveals Stamicarbon’s bridge that connects today to tomorrow.
2. Introduction

The reduction of the ammonia emission from urea plants is an important qualifier for licensors to comply with international and local standards. Still there is a heavy tendency to tighten the emission regulations and the avoidance of ammonia smell to the plant surroundings requires solutions to completely eliminate the ammonia in the tail gases from the urea plant.

This paper focuses on a new developed opportunity to eliminate the ammonia emission from continuous emission sources in urea plants except from the finishing sections. It explains how to eliminate the ammonia in an environmental and economical friendly way. The developed alternative is explained by considering the CO2 stripping process as an example but the application of this alternative vent gas treatment system is not only limited to this process design.
3. Continuous ammonia emission sources in a CO₂ stripping plant

In urea plants inert from the feed stocks ammonia and carbon dioxide, air injection for passivation of the materials in the synthesis to prevent corrosion and air ingress in vacuum systems like the evaporation sections have to be vented. To minimize the ammonia in these vapours, the stream is treated in absorbers before to be released into the atmosphere. Still, even after the absorption treatment, the vented vapour contains a limited although minimum amount of ammonia.

The breathing system of atmospheric storage tanks is another emission source to be considered since the out breathing air contains ammonia and is usually discharged via the main stack into the atmosphere. In general the continuous ammonia emission sources in a modern CO₂ stripping process are limited to:

- Vent gases from the low-pressure absorber.
- Vent gases from the atmospheric absorber.
- Breathing system of the atmospheric storage tanks.
4. Existing commercial available treatment possibilities to eliminate the ammonia in tail gases

In certain locations where plants are built close to populated areas, the governmental legislation requests to avoid any nuisance and therefore any smell of ammonia have to be avoided. Currently there are three commercial available treatment options to be considered:

- Flaring
- Acidic scrubbing
- Heating with flare

All these available treatment options are expensive and have their own specific disadvantages.

4.1 Flaring

Flaring of the vented vapor from continuous emission sources needs a continuous flare. To prevent oxygen ingress a continuous nitrogen purge is needed. The application of nitrogen needed to do this is substantial to ensure a positive flow of each emission source to the flare at all circumstances and to ensure an oxygen concentration of the vented vapor below 5 % of volume at the tip of the flare as required from safety considerations and usually also requested by the flare vendors. Also natural gas fuel needs to be added as the ammonia concentration in the off-gas of continuous emissions is very low; and since air and or air/nitrogen mixtures do not burn, additional fuel gas has to be supplied to the flare in order to make a flame in which the ammonia can be combusted. This continuous supply of fuel gas has to be considered as it impacts utilities and variable costs.

By flaring, ammonia and part of the present nitrogen, due to the involved high temperatures, is converted to nitric oxides. The amount of formed nitric oxides can be minimized by using special burners (CONOX). However the application of these special burners will not prevent the nitric oxide formation completely and thus will create a solid basis for global warming potential, acidification, tropospheric ozone formation and ozone depletion potential.

So, summarizing, considering the environmental pollution, the nitric oxide emission, formed by flaring, has even a more negative impact for the environment than the ammonia emission itself.

4.2 Acidic scrubbing

Acidic scrubbing of the continuous vent gases is environmentally a good method to eliminate the present ammonia urea plant vented off-gases. This method is suitable if there is a possibility to get rid of the formed ammonium containing salt at site. The formed amount salt formation however is very small due to the relative low gaseous ammonia emissions and thus this method is economically not optimal at locations where the formed ammonium salt by-product is wasted.
4.3 Heating with flare

The use of a flare system to heat the ammonia containing off-gasses to ensure that the ammonia is transported to higher layers in the atmosphere is applied in some urea plants. The heating with a flare will only reduce the nuisance of ammonia in the direct vicinity of the plant. This approach does not eliminate the ammonia emission and increases the environmental load of the continuous emissions by the NO$_X$ formation. Additionally, it requires the capital investment for the installation of a flare and operational costs to ensure the heating. This option is therefore considered as relatively useless as it does not contribute to sustainable plant management and can be made redundant with proper design of the vents.
5. Description of the Stamicarbon environmental friendly and economical alternative

The ammonia containing inert vapors from the continuous emission sources are subjected to an environmental friendly elimination device comprising:
- Combustion step.
- \( \text{NO}_x \) Thermal reduction step (Selective Non Catalytic Reduction SNCR).
- Flue gas cooling step.
- \( \text{NO}_x \) Catalytic reduction step (Selective Catalytic Reduction SCR).

The ammonia elimination device is schematically illustrated in figure 1.

![Figure 1 - Stamicarbon’s ammonia elimination technology](image)

The ammonia containing vapor leaving the low-pressure absorber from the urea plant enters the combustion chamber of the ammonia elimination device. Natural gas is supplied as a fuel and is fired in the combustion chamber by a burner. The combustion chamber operates at a positive pressure of about 300 mm water column in order to overcome the involved pressure drop of the downstream operation steps in the device. The temperature control in the combustion chamber of the device is done by supplying air. By controlling this temperature the ammonia is converted into nitrogen and nitric oxide, as described in the next chapter. The formed nitric oxide comprises a variety of components like nitrogen dioxide, nitrogen monoxide and is generally characterized as \( \text{NO}_x \).
The hot flue gases leaving the combustion chamber of the ammonia elimination device are subjected to the thermal reduction step. The thermal reduction step (SNCR) is a post combustion nitric oxide reduction method that reduces the majority of the formed nitric oxide in the flue gas by adding anhydrous ammonia to these flue gases. The amount of anhydrous ammonia used as reducing component in the thermal reduction step is controlled in such extend that the formed NO\textsubscript{x} components in the combustion chamber is reduced to nitrogen and water to almost completeness. The optimal temperature to reduce the nitric oxide components to nitrogen and water in the thermal reduction step is in between 900 and 1100 °C and is controlled by supplying air to this section.

The air supply to control the required air in the combustion chamber, as well as to control the temperature in the thermal reduction step is typically coming from the absorbers and atmospheric storage tanks as a continuous out breathing of these tanks. However, the configuration can change depending on the available emission sources. The vapor is pressurized to about 300 mm water column by the application of a fan that conveys the vapor to the ammonia elimination device. Part of this vapor is generally directed to the combustion chamber of the device while the remainder is directed to the thermal reduction step of this device.

Schematically the ammonia containing inert vapors to be subjected to the ammonia elimination device is illustrated in figure 2.

*Figure 2 - architecture of Stamicarbon’s ammonia elimination technology*
The flue gas leaving the thermal reduction step is cooled down to approximately 350°C necessary to operate the downstream catalytic reduction step (SCR). By cooling down this flue gas temperature, saturated steam at a pressure of about 12 bar is generated. A conventional flue gas type boiler is incorporated in the device. The formed steam is returned to the steam system of the urea plant.

The catalytic reduction, downstream the flue gas convection step, is a fine control to reduce the remaining left nitric oxide components in the flue gas. This catalytic reduction utilizes anhydrous ammonia mixed with air as a reducing component and reacts with a catalyst to reduce the nitric oxides to nitrogen and water to values less than 10 % of the formed nitric oxide formation, corresponding typically 100 parts per million by volume. The ammonia slip in the released flue gas will be less than 5 parts per million by volume.

References of the thermal treatment technology are among others available at Miteni and Brystol Myers Squibb in Italy, Sword Laboratories in Ireland and Mobin Petrochemical Company in Iran.
6. Environmental considerations

From environmental point of view four independent international standards, applied to the energy and industry sector to assess emissions, are considered to quantify and benchmark the emission of a urea melt plant. The benchmark is focused on emission of ammonia into the atmosphere by the incineration of ammonia by thermal treatment, combustion via flaring, heating via flaring and acidic scrubbing of vent gases.

Benchmark indicators
The benchmark provides insights on the impact of ammonia and NOx emission and creates a solid basis to make a well considered decision on the most suitable solution. Considered are the global warming potential, acidification, tropospheric ozone formation potential and ozone depletion potential of gasses:

The global warming potential (GWP)\(^1\) indicates the contribution of a specified gas mass to global warming by comparison with reference gas carbon dioxide. The GWP has been defined as the ratio of the time integrated warming effect from the instantaneous release of a kilogram of a specified gas, compared to that of a kilogram of reference gas carbon dioxide. The GWP value represents the global warming potential of the gas over one hundred years.

Acidification is used to describe the loss of nutrient bases in ground or water through the process of leaching and their replacement by acidic elements. The acidification is indicated by the acid equivalent\(^2\). The acid equivalent is a measure to determine the environmental impact of the acidifying substances, which are mainly caused by sulfur and nitrogen based molecules. The equivalent determines the degree of acidity of a substance per mole.

The tropospheric ozone forming potential (TOFP)\(^3\) equivalent indicates the formation of ozone in the troposphere, causing radiative forcing. The troposphere is defined as the lowest part of the atmosphere from the surface to about ten kilometer in altitude in mid-latitudes where clouds and “weather” phenomena occur. Ozone is formed by two preceding pollutants in the presence of ultraviolet sunlight: volatile organic compounds and nitrogen oxides. TOFP uses ratios to convert emission masses to masses of the TOFP equivalent.

\(^1\) Intergovernmental Panel on Climate Change, 2007: Forster, P., Ramaswamy V., et al., Fourth Assessment Report, Changes in atmospheric constituents and in radiative forcing, Ch 2

\(^2\) MIRA/VMM, 2009: Brouwers. J., Milieureport Vlaanderen

\(^3\) Intergovernmental Panel on Climate Change, 2001: Houghton, J.T., et al., Climate Change 2001: The Scientific Basis, Ch 6
The ozone depletion potential (ODP) equivalent indicates the ability of a specified gas to destroy stratospheric ozone by reaction with the ozone to oxygen. The ODP has been defined as the ratio of the total amount of ozone destroyed due to a kilogram of specified gas and the amount of ozone destroyed by a kilogram of reference refrigerant gas CFC-11 (CCL3F).

The described commercial available vapor treatment possibilities on the environmental impact considering the indicators are illustrated in the next figure 3.

![Environmental impact of solutions](image)

**Figure 3 - Overview of the intensity of environmental contribution for different solutions**

---


10.
7. Principle of combustion and DeNO\textsubscript{x} system

The purpose of the thermal treatment system is to convert all the ammonia in the off-gas stream into nitrogen. The oxidation however is not complete and a certain amount of NO\textsubscript{x} is formed. Sources of NO\textsubscript{x} formation are atmospheric nitrogen (N\textsubscript{2}) and the ammonia. NO\textsubscript{x} formation and emission are difficult to predict from purely thermodynamic and kinetic considerations depending upon the following factors:

- Temperature
- Fuel/air ratio
- Residence time
- Fuel type and composition
- Gas flow and mixing
- Concentration of free radicals in the flame and post flame zone

NO\textsubscript{x} formation occurs by three different routes:

- Thermal NO\textsubscript{x}.
- Fuel NO\textsubscript{x}.
- Prompt NO\textsubscript{x}.

Thermal NO\textsubscript{x} are produced from oxidation of nitrogen present in the combustion air. The process is strongly enhanced by the high temperature. Fuel NO\textsubscript{x} comes from oxidation of nitrogen compounds in the fuel gas. They are released at relative low temperature. Prompt NO\textsubscript{x} are formed in the flame front by reaction of nitrogen molecules with free radicals produced from the combustion. The proportion by the different NO\textsubscript{x} routes is visible from the following figure 4.

![Figure 4 - Different NO\textsubscript{x} sources as function of temperature](image)

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5 Pollution control technologies-Vol. II-Control of Nitrogen Oxides-S.Zandarya & A.Buekens
Fuel and thermal NOX are dominant, where thermal NOX are prevalent at very high temperature and when burning a fuel with low nitrogen. Fuel NOX is only dominant when combustibles contains significant amount of organic nitrogen which is not the case in the considered case.

The reactions that take place are the following:

\[
\begin{align*}
N_2 + O_2 \rightarrow & \ 2NO \\
NO + \frac{1}{2}O_2 \rightarrow & \ NO_2 \\
4NH_3 + 3O_2 \rightarrow & \ 2N_2 + 6H_2O \\
4NH_3 + 5O_2 \rightarrow & \ 4NO + 6H_2O \\
4NH_3 + 7O_2 \rightarrow & \ 4NO_2 + 6H_2O
\end{align*}
\]

Nitrogen oxides formed during combustion contain typically 5-10% of NO2.

A part of nitrogen that was converted into NOX has to be removed since NO2, formed in contact to the atmosphere from the oxidation of NO, may give rise to the formation of nitric acid that contributes at the formation of acidification and ozone formation.

A reduction of NOX could be done either by reducing them at the source during the combustion by CONOX burners and/or reducing downstream the burner source. Two different ways to control NOX emission downstream the combustion chamber could be applied:

- Thermal DeNOX or Selective Non Catalytic Reduction, SNCR.
- Catalytic DeNOX or Selective Catalytic Reduction, SCR.

Each one could be used as standalone, but a combination of both implies a higher efficiency than SNCR and uses less catalyst than SCR, respectively alone. Both require a reducing component from outside typically ammonia (NH3) or urea ((NH2)2CO). The choice is moving towards ammonia as it is more selective. The reactions that take place are:

\[
\begin{align*}
4NO + 4NH_3 + O_2 \rightarrow & \ 4N_2 + 6H_2O \\
6NO + 4NH_3 \rightarrow & \ 5N_2 + 6H_2O \\
2NO_2 + 4NH_3 + O_2 \rightarrow & \ 3N_2 + 6H_2O \\
6NO_2 + 8NH_3 \rightarrow & \ 7N_2 + 12H_2O
\end{align*}
\]

In addition also side reactions take place, which require an additional consumption of ammonia. For this reason, the reduction system works with an excess of ammonia.
This process is effective within a specified temperature range of 900 – 1100°C that is specific for each application, but depends also from reagents mass ratio, mixing and contact time. For these reasons, in the plant different points of reducing agent injection are provided in order to have ammonia at the optimal point as indicated in figure 5.

Figure 5 - SCNR Process

This thermal DeNO\textsubscript{x} solution has the following advantages:
- Simple design based on available experience and know-how.
- No catalyst or specific reagent required.
- No space required to introduce catalyst.
- Is applicable in a wide range of temperatures.

In the Catalytic DeNO\textsubscript{x} the reactions that take place are the same as for Thermal DeNO\textsubscript{x}, but at lower temperature range of 250 – 350°C due to the presence of catalyst that reduces activation energy. A SCR catalyst is fabricated into a monolithic with the shape of flat-plate or honeycomb characterized by low pressure drops and by high specific surface.

It is made by vanadium pentoxide (V2O5) or tungsten trioxide (WO3) active sites impregnated into porous titanium dioxide (TiO2) carriers. The life time is generally around 2-5 years.

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6 Selective Non Catalytic Reduction(SNCR) for controlling NOx emissions- SNCR COMMITTEE INSTITUTE OF CLEAN AIR COMPANIES, INC-May 2000
Contrary to thermal treatment, heating flares and flare systems are not suitable for the use of NO\textsubscript{x} removing systems, as it combusts the off-gas in an open air environment, which consequently makes the excess NO\textsubscript{x} emission unavoidable and thus an uncontrolled emission source.
8. Lay out options

The ammonia elimination device comprises the following modules:
- The combustion chamber and thermal reduction step.
- The flue gas cooling and heat recovery systems.
- The catalytic reduction step.
- The stack.

Usually these modules are horizontally built to keep the pressure drop in the system minimal and to avoid structures necessary for operation and maintenance. These modules can be positioned in such a way that fits in any available plot area of the plant. An example is schematically shown in the top view figure 6 and the side view of the ammonia elimination device is schematically illustrated in figure 7.

*Figure 6 - Top view of installed equipment*
At locations where space area is limited i.e. existing plant locations, the system can be build vertically. A structure is part of the unit to ensure access for maintenance and operability, but the required area can be reduced to only 4 by 4 meters. Consequently the pressure in the combustion chamber is for these systems somewhat higher to overcome the additional pressure drop.
9. Safety and nuisance consideration

9.1 Safety consideration
By definition a plant has to be designed safe always. The difference between the off-gas treatment alternatives to achieve a safe design lies in the difference of the safety principle that is applied. An overview of the principles used for safe design for the off-gas treatment systems is available in table 1.

Table 1: Applied principles for safe design

<table>
<thead>
<tr>
<th>Type of treatment</th>
<th>Principle for safe design</th>
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<tr>
<td>Venting (standard design)</td>
<td>Pressure delta, dispersion, elevated stack</td>
</tr>
<tr>
<td>Flaring</td>
<td>Complex process design, separation of pressure regimes, high elevated stack, shielding, safe guarding</td>
</tr>
<tr>
<td>Heating with flare</td>
<td>Dispersion, elevated stack, safe guarding</td>
</tr>
<tr>
<td>Thermal treatment</td>
<td>Smart process design, low stack, safe guarding</td>
</tr>
</tbody>
</table>

It is important to realize that the addition of a thermal treatment or flare system does not make a urea plant safer or unsafer, because all emission treatment systems require their own specific safety approach in order to achieve an intrinsically safe plant design. The choice to vent, heat, incinerate or combust can therefore never be a safety issue, but only a pollution and nuisance prevention philosophy or authority requirement. The choice does give the opportunity to choose the best suitable option for the plant and local circumstances.

9.2 Nuisance consideration
The nuisance consideration is based on specific local requirements, which are present due to the physical location of the plant, the neighbourhood and local governmental regulations. Off-gas treatment systems in urea melt plants are in most cases installed for this reason, because the ammonia smell is detectable by human nose at concentrations higher than 5 parts per million.

However, this consideration is mostly applicable to discontinuous emissions, which may be associated with substantial volumes and high ammonia concentrations. In case of continuous emissions, the nuisance consideration is hardly required as the ammonia concentrations from continuous sources by far do not reach the limit of 5 parts per million on ground level outside the fence. It is for this reason that none of Stamicarbon urea plants currently apply thermal treatment or flare systems for continuous emission of ammonia containing off-gasses for the solely purpose of nuisance control.
A solution that is occasionally known to be provided is the application of a flare to heat the ammonia containing continuous off-gasses. However, this approach increases the environmental load of the continuous emission. It can therefore only be considered from nuisance point of view as it is more harmful for the environment than venting and thermal treatment, as it emits additional NOX without reducing ammonia emissions.
10. Example case: World scale urea melt plant

10.1 Treatment of continuous off-gasses

In this example the entire ammonia emission of all continuous emission sources in the urea melt plant are needed to be treated in order to achieve zero ammonia emission and replaces the venting of off-gasses. It is demonstrated that the consideration of a flare system is an environmental burden and will show that the best alternative to obtain zero ammonia emission at lowest environmental impact and without formation of side products is the new thermal treatment as proposed.

It also shows that this new solution significantly reduces capital investment and operation costs compared to flaring. The example case is calculated for a typical world scale 3,500 metric tons per day urea melt plant.

The flare system used for the comparison is simplified illustrated in figure 8. The entire system is maintained as an oxygen free environment to avoid oxygen ingress and risk of explosive mixtures. A nitrogen dosage system is for that purpose added to all connected vessels. The lines to the continuous flare are continuously flushed with condensate or steam to prevent blockage and nitrogen to control oxygen concentration. The blow-off separator is used to recover process liquids.

Figure 8 – Flare system example case for continuous emissions
The ratio of support gas necessary to combust the ammonia in the emitted gas stream is determined by quality and quantity of the off-gas from the emission source. The components of urea melt plant off-gas typically include: ammonia, carbon dioxide, hydrogen, nitrogen, oxygen and water. The total heating value of the off-gas is determined by the net heat of combustion of the components. The theoretical net heat of combustion is shown in table 3.

Table 3: Net heat of combustion of gasses typical for urea melt plant

<table>
<thead>
<tr>
<th>Gas</th>
<th>Net heat of combustion (Btu/scf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia – NH₃</td>
<td>365</td>
</tr>
<tr>
<td>Carbon dioxide – CO₂</td>
<td>0</td>
</tr>
<tr>
<td>Hydrogen – H₂</td>
<td>275</td>
</tr>
<tr>
<td>Nitrogen – N₂</td>
<td>0</td>
</tr>
<tr>
<td>Oxygen – O₂</td>
<td>0</td>
</tr>
<tr>
<td>Support gas – CH₄</td>
<td>913</td>
</tr>
<tr>
<td>Water – H₂O</td>
<td>0</td>
</tr>
</tbody>
</table>

Typically the heating value of the off-gas is minimal, because the percentage of ammonia present during normal operation is on average below 1 mole % and the rest of the off-gas consists for 99 mole % of nitrogen, oxygen and water. It almost looks like an attempt to burn air. The lack of heating value requires the insertion of support gas to cross the threshold value of 200 Btu/scf that is required for proper combustion of the ammonia. This threshold value is regarded as a typical rule-of-thumb value of flare vendors.

The amount of support gas that is required to combust all ammonia is determined by calculating the difference in heat value between the off-gas mixture plus the added nitrogen and the threshold value. The support gas to ammonia mass ratio is calculated and indicates the relation of the ammonia that requires combustion and the support gas that is required to combust the total off-gas of which the ammonia is part of. It must be considered that the required amount of support gas on standby is substantial. The required support gas is shown in table 4.

Subsequently the nitrogen consumption is calculated, which is required to ensure a positive flow to avoid the risk of explosive mixtures caused by oxygen ingress via the flare tip. In addition, all connected vessels are to be operated under nitrogen atmosphere in order to avoid oxygen ingress during in breathing scenarios. The required nitrogen is shown in table 4. Dilution with support gas is not considered, because the use of support gas results in an unpredictable distribution thereof through the process in presence of excess oxygen and ignition sources.

7 Perry’s chemical engineers’ handbook, 6th edition, 1984: Perry, R.H., Green, D., Table 9-30 Combustion constants
8 The John Zink Combustion Handbook, 2000: Baukal, Jr, C.E., Ch 20
Table 4: Required support gas and nitrogen for continuous emission sources as ammonia mass ratio for flaring.

<table>
<thead>
<tr>
<th>Ratios</th>
<th>Required mass ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Support gas (CH₄) : Ammonia (NH₃)</td>
<td>140:1</td>
</tr>
<tr>
<td>Nitrogen (N₂) : Ammonia (NH₃)</td>
<td>600:1</td>
</tr>
</tbody>
</table>

10.2 Replacement of flare system by thermal treatment

The introduction of the thermal treatment with Catalytic DeNOₓ is a game changer with respect to our existing perception on the end-of-pipe solutions for continuous emission sources in the urea melt plant. The new solution makes flare systems an inconvenient memory of the past from environmental and investment point of view. As the thermal treatment system is identified as the best alternative for a flare system from the perspective of absolute emissions, the example case will highlight the replacement of a flare system by the thermal treatment system.

The integrated solution for thermal treatment reduces the required equipment to a small incinerator and catalyst bed at ground level right next to the urea plant. It makes the need for complex process design, necessary to deal with the backpressure of the flare in an atmospheric environment, redundant. It also does not need long distance and large diameter piping to a safe location, typically located at an elevated structure at 90 meters or at hundreds of meters distance from the plant at ground level. The height of the flare structure or its distance from the plant is required as a safety provision in case of ignition failure and shielding from heat and harmful UV light, but these issues do not apply for the thermal treatment system.

The configuration of the thermal treatment system is displayed in figure 1 and figure 2. The unique advantage of thermal treatment is from this perspective expressed by the reduction of number and dimensions of equipment.

10.3 Environmental relief

The environmental relief is mainly expressed by the reduction of the natural gas consumption and the corresponding NOₓ emission. The reduction of the nitrogen requirement and therefore the costs for nitrogen production on site or import is for this paper not taken into account. The reduction of natural gas consumption in existing plants can be reduced with more than 90%, as calculated later on in this paper. Grass root plants can be designed in such way that the natural gas consumption is reduced to the consumption of your central heating at home. The consequence is a significant relief of the environmental load with respect to the four benchmark indicators and sustainable plant performance.
10.4 Capital investment analysis

The main differentiator between a flare system and a thermal treatment system is the efficiency of combustion between incineration and flaring, and the possibility to catch the NO\textsubscript{X} emission. Other main differentiators are the capital investment and operational costs. The impact of the investment costs related to flare systems is in practice often underestimated. An important reason behind the underestimation is the use of petrochemical expertise to handle low or zero emission standards for ammonia containing off-gasses.

The common practice of flaring seems, from the perception of the petrochemical expertise, an easy and cheap solution for urea plants facing emission issues with local governments. These petrochemical originated assumptions has proven not to be applicable to the urea melt plant, as it has the potential to cause major headache during design and engineering phase as well as complications during operations.

The reason why flare systems are difficult to implement is related to the type of emission sources that need to be treated. The continuous emission sources from the urea melt plant come from low or atmospheric pressure with ambient oxygen concentrations and only traces of unwanted ammonia. The origin of these sources results in four major issues:

1. Safety provisions are required to separate pressure regimes, as the backpressure of the flare can cause fatal equipment failure in atmospheric or low pressure sections of the plant and storage vessels.
2. Ambient oxygen concentration in the off-gas require insertion of nitrogen in order to:
   a. Avoid the possibility of an explosive mixture in the flare system by guaranteeing positive flow to avoid oxygen ingress via the flare tip.
   b. Guarantee the lifetime of the flare tip and avoid unscheduled plant shutdown due to flare tip failure at high altitude in the plant.
3. Continuous availability of large quantities of natural gas and nitrogen to facilitate full combustion of the ammonia traces, which has proven to be an expensive utility and loss of natural gas that could also have been utilized for the production of urea.
4. No return on investment.

The capital investment of a flare system is impressive and often under estimated. The main costs for the installation of the flare system are due to the numerous pieces of instrumentation required to operate the flare system in a safe way, while ensuring the full combustion of ammonia. Additional the investment costs are related to the large piping diameters required, the need to locate the flare tip at an elevated or distant location, support structures for vessels, piping and flares. An overview of an in-house budget estimate is available in table 5 and a typical breakdown of costs is available in table 6.
Table 5: Capital budget cost comparison

<table>
<thead>
<tr>
<th>Type of treatment</th>
<th>CAPEX ±40% [Million US$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flaring</td>
<td>15</td>
</tr>
<tr>
<td>Thermal treatment</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 6: Breakdown of investment costs for flare system

<table>
<thead>
<tr>
<th>Type of investment</th>
<th>Breakdown CAPEX Flare system [%]</th>
<th>Breakdown CAPEX Thermal treatment [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment costs</td>
<td>15</td>
<td>65</td>
</tr>
<tr>
<td>Structure, pipe racks, shielding, fencing</td>
<td>45</td>
<td>5</td>
</tr>
<tr>
<td>Instrumentation, piping</td>
<td>40</td>
<td>30</td>
</tr>
</tbody>
</table>

The budget estimate shows that the installation of a flare system is approximately eight times as expensive from capital investment point of view, which is a significant saving as the investment in a flare system shows no return on investment. The breakdown of the costs shows the effect of the secondary requirements of a flare system. The consequence is that the bulk of the investment costs are given by items like instrumentation, piping and support structures. In the case of the thermal treatment option the majority of the investment costs solely come from the unit itself.

10.5 Utility requirements

Another important objection against flaring is the utility requirement. From utility perspective it is important to distinguish flaring for heating of off-gasses and flaring to eliminate ammonia emission. In heating case only a small amount of natural gas and no nitrogen is required, but it does not eliminate the ammonia emission. For the utility comparison we will only compare the options that will result in full elimination of the ammonia emission from the urea melt plant.

The figures for flaring as mentioned before in table 4 have been updated with the calculated consumption figures for the thermal treatment system in table 7. The consumption figures for the thermal treatment system are indicated for two cases. The most favorable case based on plants running at minimum oxygen content in the urea synthesis. In this case it is possible to fully utilize the hydrogen imported with the CO2 from battery limits and recover the heat value. Besides this optimal case, alternatively the technology can be applied in plants with passivation air intake as is common practice in most existing urea plants. As a result of the controlled incineration of the off-gasses, no nitrogen is required for dilution to avoid the presence of explosive mixtures.
Table 7: Required support gas and nitrogen for continuous emission sources as ammonia mass ratio for thermal treatment.

<table>
<thead>
<tr>
<th>Ratios</th>
<th>Required mass ratios for the options</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flaring</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Support gas (CH$_4$) : Ammonia (NH$_3$)</td>
<td>140:1</td>
</tr>
<tr>
<td>Nitrogen (N$_2$) : Ammonia (NH$_3$)</td>
<td>600:1</td>
</tr>
</tbody>
</table>

The utility consumption overview shows that the optimal performance is achieved at operating conditions where the hydrogen is utilized as feedstock for the thermal treatment. As a consequence the hydrogen convertor is to be removed, which can only be the case for low air dosage to the synthesis.

10.6 Steam generation

Another positive side effect of the thermal treatment system is also allows to recover the heat value of the hydrogen and methane used to incinerate the ammonia. In the example case it can be calculated that around 1500 kilogram of medium pressure steam at 12 bars is generated per hour. The generated medium pressure steam can be utilized in the urea melt plant to consumers as the second stage evaporator, ejectors and tracing.

These medium pressure steam consumers are normally served by depressurizing high pressure steam imported from the ammonia plant. Therefore it reduces the required high pressure steam import and the energy consumption of the urea plant. At an average production cost of EUR 30,- per ton of high pressure steam, the benefit can be quantified as a cost saving of approximately EUR 400.000,- per year.

This unique benefit results in a payback period for capital investment of around 5 years. This is remarkable good for an investment with the main purpose to meet environmental regulation requirements.

10.7 Recap of the example case

Earlier in this paper it has been proven that flaring in general has a negative consequence with respect to global warming, tropospheric ozone formation and ozone depletion. The remaining acidification motivation can be justified when ammonia is replaced by NO$_x$ in a mass ratio up to 1:3. The outcome of the example case shows that for continuous emission sources the ratio requirements of 140 kilogram support gas per kilogram of emitted ammonia tremendously exceeds the justifiable ratio.

---

9 Plant operating at low oxygen contents with no hydrogen convertor.
The replacement of ammonia by nitrogen dioxide results in a higher environmental load and can therefore not be justified from acidification and thus environmental point of view.

In case the elimination of ammonia containing off-gasses is considered, the option of thermal treatment is a clear improvement with respect to the environmental load. The thermal treatment system is even creating an attractive return on investment by the generation of medium pressure steam, which is pleasantly unusual for an end-of-pipe solution. This feature allows for a justification not only from environmental, but also from capital investment and operational cost point of view and can be integrated in any urea melt plant.
11. Conclusion

Based on the safety, nuisance and environmental considerations, and the example case the following can be concluded:

1. Safety is not a consideration for the choice of off-gas treatment.

2. Flaring of continuous emission sources can eliminate ammonia emission, but cannot be justified from environmental point of view.

3. Heating the off-gas is suitable to avoid ammonia nuisance in the vicinity of the urea melt plant, but it is not preferred as it does not eliminate the ammonia emission and increases the environmental load.

4. The thermal treatment in combination with Catalytic DeNOx is the best practice, in case all ammonia is to be eliminated, with respect to the environmental impact, capital investment and operational costs. By the application of this proposed system no undesired side products as ammonia salts are formed.
25th AFA International Fertilizers Technology Conference  
Sustainability Driving the Future  
July 09 – 11, 2012  

Energy efficient cooling of fertilizer with the Coperion bulk solids heat exchanger BULK-X-CHANGE®.  

Harald Nigsch  
Sales Manager Thermal Processes, Coperion  
Germany
Energy efficient cooling of fertilizer with the Coperion Bulk Solids Heat Exchanger BULK-X-CHANGE®

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Abstract

The bulk materials heat exchanger from Coperion already successfully placed in the plastics industry is now on the way to demonstrate the benefit if applying in the fertilizer production.

Caused by the hygroscopic nature of many fertilizer types the fertilizer granules have to be treated after production to avoid problems during storage like caking of the granules.

One important method to prevent caking is the gentle and controlled cooling of the fertilizer pellets after production before it is sent to the warehouse for storage or bagging. Conventional used methods as drum or fluid bed coolers have the disadvantage of consuming lots of operation energy and creating huge emissions.

A new method demonstrates the bulk materials heat exchanger BULK-X-CHANGE® from Coperion which is operating based on a gravity mass flow of the product. This cooler type needs only a small amount of operational energy, is nearly emission and maintenance free and offers the advantage of gentle and controlled thermal treatment.

The vertically arranged BULK-X-CHANGE® heat exchanger is a simple device based on a well approved round design which offers a lot of advantages like

- residual free material flow 
- compact design 
- purge gas system to prevent condensation 
- simple clean and maintenance

First applications and experiences with the BULK-X-CHANGE® in the fertilizer field have been made with an Ammonium Sulphate production plant where all benefits could be verified. The clients experience with this new fertilizer cooler device will be shown and presented. Further applications have been made with NPK and CAN plants and intensive tests have been performed to demonstrate also the excellent operation characteristics for UREA fertilizer.
1) Coperion company profile and products

Coperion is the worldwide market and technology leader in compounding & extrusion, materials handling and service - as well as being a partner for global corporations and small to medium-sized enterprises in the plastics, chemicals, food and aluminium industries. As an integrated technology provider, we use our comprehensive system and process expertise to implement individual solutions for compounding technology and bulk materials handling. This includes extruders, compounders, pneumatic conveying systems as well as components for bulk material handling. This includes extruders, compounders, pneumatic conveying systems as well as components for bulk material handling.

1.1 Close Cooperation of the 3 Competence Centres

With our total of 29 locations and more than 30 sales representatives around the globe, a network exists that ensures direct contact to our customers

![Compounding & Extrusion, Bulk material handling, Global service](image)

Fig. 1: Coperion technologies applied in plastics, chemical, food and aluminium industries
1.2 Global presence in the plastics, chemical, food and aluminum industries

![Schematic of a polyolefin plant](image1)

![Schematic of a compounding plant](image2)

![Material handling at an aluminium production plant](image3)

Fig. 2: Different fields of Applications

1.3 Key figures of Coperion

<table>
<thead>
<tr>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compounding systems installed worldwide, over</td>
<td>10,000</td>
</tr>
<tr>
<td>Bulk materials handling systems installed worldwide, over</td>
<td>8,000</td>
</tr>
<tr>
<td>Employees worldwide, over</td>
<td>1,900</td>
</tr>
<tr>
<td>Network of locations worldwide</td>
<td>29</td>
</tr>
</tbody>
</table>
2) Coperion Bulk-X-Change ® bulk solids heat exchanger

2.1 Different Concepts of the Coperion Bulk-X-Change ®

<table>
<thead>
<tr>
<th>Concept</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BULK-X-CHANGE® Gravity</td>
<td>The originally developed concept is intended for free flowing granulate and coarse powder. Within that concept the bulk solids is flowing through vertical pipes from top to bottom caused by gravity. Cooling or heating is supplied on the shell side of the heat exchanger and is flowing from bottom to top through around the pipes on the shell side.</td>
</tr>
<tr>
<td>BULK-X-CHANGE® Inline Gravity</td>
<td>This concept can be used in case there is not enough vertical space within the existing layout. Product feed is based on using a pneumatic conveying system and possibly also the discharge. The product is separated in the hood and move through the heat exchanger tubes by gravity. The conveying air is bypassed from inlet to the outlet of the heat exchanger in an external pipe. At the product discharge (rotary valve) the bypassed air is taking-up the thermally treated product and the pneumatic conveying is continuing its way.</td>
</tr>
<tr>
<td>BULK-X-CHANGE® Inline</td>
<td>This concept was developed especially for fine powders. Main principle of this new patented design is the direct integration of the BULK-X-CHANGE® in a vertical pneumatic conveying line. The pneumatically conveyed powder is in this way is flowing from bottom to top.</td>
</tr>
</tbody>
</table>

Fig. 3: Three different Concepts of the Coperion Bulk-X-Change ®

BULK-X-CHANGE® Gravity
The originally developed concept is intended for free flowing granulate and coarse powder. Within that concept the bulk solids is flowing through vertical pipes from top to bottom caused by gravity. Cooling or heating is supplied on the shell side of the heat exchanger and is flowing from bottom to top through around the pipes on the shell side.

BULK-X-CHANGE® Inline Gravity
This concept can be used in case there is not enough vertical space within the existing layout. Product feed is based on using a pneumatic conveying system and possibly also the discharge. The product is separated in the hood and move through the heat exchanger tubes by gravity. The conveying air is bypassed from inlet to the outlet of the heat exchanger in an external pipe. At the product discharge (rotary valve) the bypassed air is taking-up the thermally treated product and the pneumatic conveying is continuing its way.

BULK-X-CHANGE® Inline
This concept was developed especially for fine powders. Main principle of this new patented design is the direct integration of the BULK-X-CHANGE® in a vertical pneumatic conveying line. The pneumatically conveyed powder is in this way is flowing from bottom to top.
2.2 General arrangement Bulk-X-Change Gravity

Fig. 4: Bulk-X-Change ® solids heat exchanger
2.3 Basic principle of the Bulk-X-Change®

On the following the basic principle of the Bulk-X-Change® heat exchanger is described:

**The following points characterizing the Bulk-X-Change®**

- product buffer at the inlet of the heat exchanger
- vertical gravity mass flow of bulk solids through tubes
- special shaped product distribution plate at the inlet of the tubes to avoid product residuals
- tube diameter depends on the product properties (pellet size, type)
- number and length of the tubes will be determined by the process calculation
- heat transfer by thermal conductivity between product and the cooling/heating medium
- the required cone angle to assure mass flow is determined in the laboratory shear tester
- cooling or heating medium flows on the shell side
- level control for product above the tubes to achieve max. heat transfer in all tubes
2.4 Product distribution inlet plate

A major feature of the Bulk-X-Change® bulk materials heat exchanger is the patented special shaped product inlet plate (fig. 7). The special machined plate ensures a uniform product flow from the buffer to each single tube by without death zones and product residues between the tubes. Figure 8 shows a top view of the heat exchanger with the product distribution inlet plate.

Fig. 7: Product distribution plate           Fig. 8: Top view on a Bulk-X-Change®

2.5 Evidence of mass flow by the special shaped distribution inlet plate

In a lab test it could be verified, that homogeneous mass flow of bulk product could be achieved based on the special design used for the Bulk-X-Change®.

The following pictures show the different stages of product flow in the buffer into the tubes.

covered tubes           discharge           Empty tubes

Fig. 9: Verification of homogeneous product flow into the distribution plate
2.6 Applications with the Bulk-X-Change ®

**Plastics:**
Heating of PET Chips  
Cooling of PTA, PA, TPU, PET  
Cooling of Polyolefin pellets, PP, PC, ABS,  
Cooling of PC, POM, PPS

**Fertilizer:**
Cooling of AS (Ammonium Sulphate)  
Cooling of CAN (Calcium Ammonium Nitrate)  
Cooling of NPK (Compound Fertilizer)

**Others:**
Cooling of slug pellets (Insecticides),  
Cooling of coating powder

**Chemicals:**
Cooling of CaCl2,  
Cooling of Sodium Meta Silicate

Fig. 10: Assembled Bulk-X-Change  
Fig. 11: Installed Bulk-X-Change
3. Bulk cooling in the Fertilizer industry

The Bulk-X-Change ® was primarily developed for the thermal treatment of plastics. It has been proven to be a successful solution in numerous installations and in a variety of applications worldwide.

The special designed Bulk-X-Change ® can be used also as a cooler for free-flowing, granulated or prilled Fertilizers, such as AS, AN, CAN, NPK or UREA. Coperion has references with AS, CAN and NP. Successful large-scale tests with UREA and other fertilizers have been proven to give an excellent applicability of the Bulk-X-Change ® for cooling such products.

Fig. 12: Fertilizer piles in a warehouse

3.1 Fertilizer cooling prevents caking

Most fertilizer have some tendency to form lumps or agglomerates (caking) during storage.

The caking mechanism and the factors influencing caking have been widely discussed over years and the fertilizer industry has adopted various measures to overcome as:

1. The use of various drying processes to obtain a product with a low moisture content.
2. **The use of various cooling processes to obtain a product with a low temperature.**
3. The use of various granulation, prilling, and pelletizing processes to produce larger particles which reduces surface area and number of contact points between particles.
4. The use of screening equipment to obtain a more uniform particle size thereby decreasing the surface area and number of contact points between each particle.
5. The control of storage conditions such as RH, temperature, pile height, and storage time.
6. Packaging fertilizer products in moisture-resistant bags.
7. The addition of anti-caking agents (conditioners).
3.2 Bulk-Cooling Systems used in the Fertilizer industry

There are mainly 2 conventionally systems used for cooling of fertilizer granulate. This is the rotary drum and fluid bed coolers.

![Diagram](UFTGranulationSystem_with_two_stage_Fluid-Bed_cooling_system.png)

Fig. 13 UFT Granulation System with two stage Fluid-Bed cooling system

3.3 Bulk-X-Change ® cooler applied in the fertilizer industry

Compared to the conventionally used cooler systems the Bulk Cooler concepts as the Coperion Bulk-X-Change ® offers a lot of advantages/benefits:

Fertilizer Process Licensors and engineering contractors are more and more using the Bulk Cooler Technology because of their benefits with low energy demand and low emissions.

Depending on the product, the used process and the local situation it is possible to use a Bulk cooler for the final cooler stage or even use only one Bulk Cooler in the process.

<table>
<thead>
<tr>
<th>Remark:</th>
<th>Depending on Processes (UFT, TEC, Stamicarbon), and Product (UREA, NPK, CAN, etc.) different Cooling processes are possible:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling process:</td>
<td>Fluid Bed</td>
</tr>
<tr>
<td>Two Stage: Stage 1</td>
<td>Main Cooler after Granulator</td>
</tr>
<tr>
<td>Stage 2</td>
<td>Final cooler after screening</td>
</tr>
<tr>
<td>One Stage:</td>
<td>Main Cooler after Screening</td>
</tr>
</tbody>
</table>

Bulk-X-CHANGE® is the registered trade name of the Bulk Solids Heat Exchanger from Coperion

Fig 14: Bulk Cooler Application
4. Benefits of using bulk cooler technology

4.4 Bulk-X-Change® comparison to conventional cooling Systems

On the following the advantages of Bulk-X-Change® in comparison with conventional solutions like rotary drums or fluid beds have been listed:

Lower investment and operating costs due to:

- Compact design → less required installation footprint
- Smaller apparatus → less insulation
- Easy installation → low erection costs
- No blower or other drive → reduced energy consumption
- Easy control → low operating effort
- No moving parts → nearly maintenance free
- No emissions → vent air treatment is not necessary

Improved product quality due to:

Slow product movement → gentle treatment avoids product degradation

4.5 Bulk-X-Change® comparison of different cooling Systems

**Specific electrical Power Demand**

![Electric power demand of different bulk cooling systems](image)

Fig. 15: Electric power demand of different bulk cooling systems
5. Investigations and Tests with fertilizer

5.1 Bulk-X-Change® Fertilizer product experience

<table>
<thead>
<tr>
<th>Product</th>
<th>Reference/Laboratory Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAN (Calcium Ammonium Nitrate granulated)</td>
<td>Reference plant</td>
</tr>
<tr>
<td>CAN (Calcium Ammonium Nitrate Prills)</td>
<td>Laboratory tests</td>
</tr>
<tr>
<td>AN (Ammonium Nitrate Granulate)</td>
<td>Laboratory tests</td>
</tr>
<tr>
<td>AS (Ammonium Sulphate)</td>
<td>Reference plant</td>
</tr>
<tr>
<td>NP (22-20-0 Prills)</td>
<td>Commissioning scheduled</td>
</tr>
<tr>
<td>NPK (14-8-24)</td>
<td>Laboratory + on site tests</td>
</tr>
<tr>
<td>NPK (5-6-30+3)</td>
<td>Laboratory + on site tests</td>
</tr>
<tr>
<td>NPK (10-12-18)</td>
<td>Laboratory + on site tests</td>
</tr>
<tr>
<td>PK (0-13-28)</td>
<td>Laboratory tests</td>
</tr>
<tr>
<td>PK (0-8-31+5)</td>
<td>Laboratory tests</td>
</tr>
<tr>
<td>SSP (Single Super Phosphate)</td>
<td>Laboratory tests</td>
</tr>
<tr>
<td>UREA (Urea Granulated)</td>
<td>Witnessed Client Demo Testing</td>
</tr>
</tbody>
</table>

5.2 Lab testing for determination of Bulk Product data

In the Coperion laboratory there will be a number of tests performed for each product samples supplied from clients:

**Main Bulk Product Data:**

- Bulk density / packed density
- True density / particle density
- Particle size distribution
- Particle shape
- Moisture content
- Shear test
- Discharge flow test

<table>
<thead>
<tr>
<th>Substance</th>
<th>NP Danger</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk material</td>
<td>NP 22-20-9</td>
</tr>
<tr>
<td>Handelsname : Typ</td>
<td></td>
</tr>
<tr>
<td>Tradenames : grade</td>
<td></td>
</tr>
<tr>
<td>Probem Nr.</td>
<td>201400 GR 6013</td>
</tr>
<tr>
<td>Sample no.</td>
<td></td>
</tr>
<tr>
<td>Schütt : Rohdichte [kg/m³]</td>
<td>1050±1115</td>
</tr>
<tr>
<td>Bulk density : packed density</td>
<td></td>
</tr>
<tr>
<td>Stoffdichte : Partikeldichte [kg/m³]</td>
<td>1945</td>
</tr>
<tr>
<td>True density : particle density</td>
<td></td>
</tr>
<tr>
<td>Korngröße (median) [µm]</td>
<td>x10=1350±x10=2430; x50=3955</td>
</tr>
<tr>
<td>Particle size (distribution)</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 16: Bulk product data determined at the Coperion lab
5.3 Lab testing for determination of Bulk Heat Conductivity

A special test will be performed necessary for the sizing of the Bulk-X-Change®. By this the heat conductivity will be determined using a standardized cooling test.

Bulk product is filled in a tube with a heating or cooling chamber. The temperatures at different radial positions will be measured during cooling/heating from start to end temperature. The measured data will be compared with the model data and aligned.

Fig. 17: Bulk heat conductivity test apparatus  
Fig. 18: Temp. Measurement

Fig. 19: Determination of Bulk heat conductivity
6. Bulk-X-Change ® features for fertilizer cooling

6.1 Bulk-X-Change ® Fertilizer cooler dry air purge

The Bulk-X-Change® for fertilizer application is equipped with a product distribution device in the inlet buffer air and purge gas supply system, to remove moisture released from the hot product before it enters the heat exchanger. The purge gas leaves the cooler via aspiration at the buffer vent and at the cone. The dry air purge:

--> removes surface moisture from the entering product
--> removes vapour and fines coming with the air entering the cooler
--> reduces risk of condensation at the cold cooling water tube wall

![Fig. 20: PID of a Coperion Urea cooler system](image)
6.2 Bulk-X-Change® wet cleaning device

The cooler is equipped with an easy cleaning device that allows wet cleaning of the heat exchanger in the event of any blockage.

The washing adapter device (pan design) is mounted at the bottom of the Bulk-X-Change® equipment to enable water filling and drainage.

Due to the closed & round shell design of the Bulk-X-Change® and due to the good solubility of most Fertilizers, a simple water washing procedure (flooding) can be applied.

This simple and effective way of cleaning, minimizes the time and the efforts for the operators, compared to a manual cleaning method.

6.3 Bulk-X-Change® wet cleaning procedure

- Discharge of product and flooding of the complete BXC with warm water,
- Adding of pressurized air at the cone to improve the cleaning effect,
- After draining, final drying of the Bulk-X-Change® by using a dry air-purge,
- The whole washing sequence with water can be executed automatically,
- The round design and the straight tubes avoid “dead” zones with product deposits
  ➔ good washing results

Fig. 21: washing device (pan)

Fig. 22: washing in the buffer

Fig. 23: air bubbling
7. **Bulk-X-Change® application for fertilizer**

7.1 **Specification and performance data for a AS granulation plant**

A customer in Europe has scheduled to expand his Ammonium Sulphate production. The existing cooler was too small and there have been two Options considered:

**Option 1:** Expansion of existing Bulk Cooler

**Option 2:** New Bulk Cooler with larger design

Coperion Bulk-X-Change® Cooler was selected after performance trials.

The tests have shown extended operating time and simplified washing / cleaning process.

**Performance data:**

**Product AS:**

- Average part. ø: 2.2 mm
- Moist content: 0.5%
- Throughput rate: 60 t/h (Design)
- Inlet Temp: 75-80°C
- Outlet Temp.: 40-45°C

**Cooling water:**

- Flow rate: ca. 90 m³/h
- Inlet Temp.: 20-25°C

**Purge gas:**

- Vol. flow: 1500 Nm³/h dry air

---

**Fig. 24: Process flow diagram**

**Fig. 25: Typical cooling curve example (AS-plant)**

**Installed Coperion equipment:**

- Bulk Cooler incl. Instrumentation
- purge air-conditioning unit

**Material of construction: 316**
7. Bulk-X-Change ® application for fertilizer

7.2 Specification and performance data for a new NP prilling plant

Performance data:

Product NP prills 22-20-0:
- Average part. ø: 2,2 mm
- Moist content: 0,5%
- Throughput rate: 57,5 t/h
- Inlet Temp: 95°C
- Outlet Temp: 53°C

Cooling water:
- Flow rate: ca. 104 m³/h
- Inlet Temp.: 34°C
- Outlet Temp.: 43°C

Purge gas:
- Vol. flow: 1500 Nm³/h dry air

Fig. 26: Process flow diagram

Specified cooler equipment:

Coperion scope of supply:
- Bulk Cooler incl. Instrumentation,
- secondary cooling loop
- purge air-conditioning unit

Material of construction: 304 L

Fig. 27: Layout of the NP Cooler installation
7.3 Specification and performance data for a new CAN granulation plant

Performance data:

**Product CAN:**
- Average part. ø: 3,6 mm
- Moist content: 0,23%
- Throughput rate: 60 t/h
- Inlet Temp: 105°C,
- Outlet Temp: 35°C

**Cooling water:**
- Inlet Temp.: 25°

**Purge gas:**

Coperion scope of supply:
- Bulk Cooler incl. Instrumentation,
- purge air-conditioning unit

Material of construction: 304 L

Fig. 28: Process flow diagram

Product inlet during filling and outlet device is shown at a fertilizer production plant.

Fig. 29: product inlet during filling  
Fig. 30: product discharge (Rotary valve)
8. Bulk-X-Change® fertilizer cooler manufacturing

Fig. 31: Assembled Bulk-X-Change® with buffer

Fig. 32: View to bottom tube plate

Fig. 33: Bulk-X-Change® Assembly with product inlet buffer and outlet cone
25th AFA International Fertilizers Technology Conference
Sustainability Driving the Future
July 09 – 11, 2012

“GPIC Sustainability Reporting Approach in line with the Global Reporting Initiatives (GRI) Framework”

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Bahrain
GRI Sustainability Reporting
“GPIC Experience”

By:
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25.06.2012
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Gulf Petrochemical Industries Company – Bahrain

Company Profile
Headquarters based: Manama, Kingdom of Bahrain
Year of establishment: 1979
Number of staff: Medium (Less than 500 employees)
Industry: Oil & Gas
Website: http://www.gpic.com/

Introduction:

Established in December 1979 as a joint venture between the Government of Bahrain, (SABIC) Saudi Arabia & (PIC) Kuwait, GPIC Bahrain utilizes natural gas as raw material.

GPIC complex is consisting of three production plants. GPIC operates Ammonia, Methanol and Urea. Ammonia and Methanol plants were commissioned in May 1985 at Sitra Island on an area of 60 hectares with a capacity of production 1200tonnes/day for each plant. In 1998 a Urea Plant was commissioned with a capacity of 1700tonnes/day with full marine export facilities.

In 1995 GPIC attained ISO 9002 which was the most important achievement since it was formed. It was the Quality Assurance Standard Certification in its operation for both plants Ammonia and Methanol. In 1996 GPIC was selected as the best operating operation in the Arabian Gulf Region regarding its high levels of production, environmental standard and safety procedure.

In December 1999 GPIC received certification to the ISO 14001 standard for its environmental management system from Lloyds Register, London which gave the company a strong value in the market that it was the first industrial company in the Gulf Region hold both ISO 9002 and ISO 14001.
In just over more than two decades GPIC has grown to become a major Petrochemical Venture. It has earned a reputation for reliability, quality, safety, health and care for the environment on an international scale.

**Vision:**

To be global, dynamic, world-class organization of choice recognized for excellence.

**Mission:**

To add value to our customers and stakeholders by meeting their expectations:

- To produce high quality petrochemicals
- Managing our business in a safe, environmentally friendly and socially responsible manner.
- Optimizing resource utilization.
- Embracing knowledge, innovation, creativity and best practice.

**GPIC Corporate Values:**

- Excellence.
- Integrity & Fairness.
- Respect.
- Transparency.
- Safety
- Professionalism
- Social Responsibility
- Creativity Team Work.
GPIC Role towards Sustainability:

According to the top message by GPIC President, "At GPIC we dedicated ourselves and our business practices to suitability- the betterment of society, the environment and the economy", President, Abdulrahman Jawahery

GPIC has gone extra mile in setting its strategy and its day-to-day activities to ensure all of its operations are planned and performed in a sustainable manner, in terms of maintaining a competitive financial growth and robust corporate governance, an environmentally friendly operation while exerting its socially responsible commitments towards its host nation and stakeholders. This commitment is further expanded, when GPIC aligned its sustainability program and produced its first sustainability report in-line with the Global Reporting Initiative (GRI).

Over the years, the company has developed a lot of programs that focus on areas such as education, vocational training of students, environmental awareness, research and employee wellbeing. GPIC has also been able to support a number of local NGO’s and charity organizations as part of its contribution to social development in Bahrain. The company is the first of its type in the Gulf to be certified with RC 14001:2008 in July 2010. With a high level of emphasis on sustainability, GPIC measures success through Profitability, Enhancing HSE (Healthy, Safety and Environment) and Social Responsibility.
Sustainability Model at GPIC:

1) Socially Responsible Business/Investment

GPIC believes that in investing capital to make the process plants at GPIC safe and reliable is only one side of the coin; investing in the welfare of the society and needy sectors of the society in particular being the other side.

Since the year 2000 to 2010 alone, GPIC’s contribution to the community has amounted to almost US$ 6.78 Million. The graph below shows the distribution of these funds to various segments of society.

GPIC has also injected about US $ 2.6 Billion into the national economy of Bahrain since its inception. This contribution has been made in several areas such as employment, training, procurement, dividends to the Government and most importantly in the form of purchases from within Bahrain.
2) **Community Involvement**

Community involvement is embedded in the fabric of GPIC’s business. Most importantly, GPIC’s active participation in various institutions has been growing by the year. GPIC is represented on the Boards and committees of several organizations both inside and outside Bahrain: University of Bahrain, Bahrain Training Institute, Bahrain Polytechnic, Bahrain’s National Committee for safety, the Royal Society for the Prevention of Accidents (RoSPA, UK), National Safety Council (USA), Gulf Petrochemical and Chemical Association, International Fertilizers Association, Arab Fertilizers Association; to name but few.

Supporting the welfare of the community is also realized through generous contributions to organizations such as sport clubs and associations, libraries, professional bodies, the health sector and charities. In the past few years, GPIC has trained more than 900 school and university graduates and provided material support to organizations caring for the young.
The educational projects sponsored by GPIC carry significant prestige in the country as they support the Crown Prince’s International Sponsorship program for higher studies. Moreover, GPIC also supports and participates in the Bahrain Institute for Banking and Finance (BIBF) Executive Development program in association with Darden School of Business (USA).

To encourage good educational skills, GPIC also rewards best students from amongst the employees’ children as well as children from neighboring schools. The company generously contributes to the employees’ children’s education and financially supports employees for further studies inside and outside Bahrain.

The company also participates in inJaz Bahrain programme (Part of Junior Achievements) for secondary school students supporting it financially, chairing its Board of Directors and providing 30 volunteers annually to teach its subjects.

The company’s Toastmasters Club is also very active in providing support to the society spreading the art of public speaking and leadership to schools, societies, employees’ children and employees themselves.
3) Caring for the Environment

GPIC is certified to the Environmental Management system ISO 14001 and implements strict waste management control. However to make positive contribution towards protecting the environment, GPIC has launched several unique environmental projects and programs; both inside GPIC boundaries and outside.

Environmental Projects

In November 1996, the company established its Fish Farm. Since then, 330,000 Sea Breams have been released into territorial water replenishing dwindling fish reserves and benefiting local fishermen.

In June 2002, a Bird Sanctuary was inaugurated. Built on a coastal strip of 600,000m², the sanctuary provides a safe haven for migrating birds, waders and local species. Over 70 species have been recorded visiting the island. 2000 mangrove trees were also planted around the island to mimic natural habitats. Today, those same trees have mushroomed to more than 20,000.
To preserve local herbs that were once used for treatment by our ancestors, the *Herbal Garden* was officially opened on 9th May 2005. It was expanded later to include a rare arid plants garden with an overall area of more than 26,800m².
In 2009, Her Royal Highness Princess Sabika bint Ebrahim Al Khalifa, the wife of His Majesty the King of Bahrain inaugurated *Princess Sabika Aromatic Plants Garden* containing 75 rare Aromatic plants.

On her visit to Bahrain on 5th Feb 2011, the Queen of Denmark also inaugurated *Queen Margaret Olive Oasis*. The oasis contain more than 600 trees.
Complementing these projects is the Green Oasis that contains all types of trees mostly donated by employees and others planted by dignitaries; raising the total number of trees in the complex to about 5400.

**Awareness Program**

GPIC also believe that caring for the environment does not end at its door steps. In 2001, GPIC started its *Environmental Awareness lectures to schools*. Till the end of 2011 academic year, 286 schools have been visited benefiting 20,927 students.

![Image of a lecture to students]

The Environmental Awareness Program for schools is part of GPIC’s initiatives towards protecting the environment and the society. It aims at enhancing the awareness of students about the major local, regional and global environmental issues. GPIC experience in minimizing pollution and developing its surrounding environment are also highlighted in the lectures.
In 2004, GPIC also launched its *Environment Research Program – Environment Award for secondary school students*, where it funds 20 research projects annually and rewards top three projects. This interactive initiative allows students to suggest their own research topics as well. Some of the topics that GPIC has sponsored over the years cover a range of environmental issues such as Effects of using water saving devices on water consumption, Impact of the Kena-Capris tree implantation on the environment, Impact of materials used in coastal reclamation, 101 Practical ways for domestics waste management and many more.
4) 

**Plants Operation Projects**

On 3rd March 1998, GPIC inaugurated its Urea plant producing 1700 MTD of granular Urea. This plant not only effectively utilized the Ammonia produced in-house, but also reused the Carbon Dioxide, that would otherwise be vented into the atmosphere. The Urea plant also reduces dramatically the amount of Ammonia stored on site reducing hazard and thus increasing safety.

On 24th Dec 2009, GPIC inaugurated its latest initiative in carbon reduction “The Carbon Dioxide Recovery” project. The unit recovers 450 tonnes of CO 2 daily from the stack of the Methanol plant and utilizes it to increase the production of Methanol by 120 Metric ton per day and another 80 tonne per day of Urea. The project is the first of its kind in the Middle East.

In addition, a number of significant modifications were implemented resulting in considerable energy saving.

GPIC also has standardized waste management procedures that allow it to reduce the ecological footprint from its core operations. These procedures ensure that all waste is managed in compliance with the local regulations and that risks to human health and the environment are minimized.
The Company has also assigned a specific Waste Management Program representative whose responsibility is to conduct all administration and communication related work for Waste Management at the company. This demonstrates GPIC’s commitment to ensure that all recyclables are prevented to going to the landfill and all hazardous waste is disposed of properly.

5) Financial Contribution and Participation

Financial support to environmental care agencies amounted to US$238182 from 2000 to End-2010. And to make a lasting impact on national policies, GPIC is strongly represented in decision making institutions such as Bahrain’s Consultative Council, the National Oil and Gas Authority, Health and Safety Organizations and adhoc committees entrusted with drafting environmental legislations.

At the international level, in 2006, GPIC in coordination with RoSPA, UK, launched its International Dilmun Environmental Award for organizations worldwide to compete for. The company is also represented in the Royal Society for the Prevention of Accidents (RoSPA, UK) and The National Safety Council (USA).
6) **Treatment of Employees**

At GPIC, employees are the most valuable assets. This is translated first and foremost in the strong relationship between Management and Labor Union. The two parties are cohesively bonded in working committees such as: Management Labor Union High Council, Management Union Committee, SHE Committee, Safety Committee, Health Committee, Environment Committee, Saving Scheme, Omra Committee, Social Committee, Training, Development and Education Sponsorship Coordination Committee, Housing Loan Committee and Special Needs Cases Committee. This arrangement ensures that the Labour Union representatives are involved in all decision making processes.

To further enhance participation in the decision making process, employees voice their views through the well-established committees and through the suggestion scheme where well-worthy ideas are rewarded on monthly basis. The same occasion is also utilized to reward Employee of the Month.

Annually, outstanding employees are also rewarded for their achievements. Employees’ benefits include a saving scheme, health insurance covering all employees and their families, loans, indemnity, annual bonus, etc.
An incentivized scheme is to reward employees during the Annual Awards Ceremony. Some of the Awards include Employee of the Year for Sustained Performance, Employee of the Year for Outstanding Performance, Department of the Year, Quality Auditor of the Year, Early Bird Award and the like.

Employees are taken into account before making all major decisions at GPIC. Employees are offered housing loans, health insurance and end of service compensation schemes.

**The Global Reporting Initiative (GRI):**

The Global Reporting Initiative (GRI) is one of the world’s comprehensive sustainability reporting framework for organizations of any sizes and sector. The GRI mission is to make sustainability reporting standard practice by providing guidance and support to organizations.

Sustainability reports based on the GRI Framework can be used to demonstrate organizational commitment to sustainable development, to compare organizational performance over time, and to measure organizational performance with respect to laws, norms, standards and voluntary initiatives.

Currently, thousands of organizations worldwide are already benefiting from the sustainability reporting which have a number of rewards:

- Providing a clear picture of main economic, social and environmental impacts of the organization
- Identifying risks and opportunities for current activities and areas for improvements
- Increasing stakeholders engagement and attraction
- Enhancing reputation and increasing customer of client loyalty and community respect
- Achieving a competitive advantage
The process of preparing the GRI sustainability reporting is developed while progressing through five phases as summarized below:

1. **Prepare the GRI sustainability reporting plan**

   As this phase, the organization GRI sustainability reporting to be planned according to the organizational goals mission and vision. It should be aligned with the three core aspects of organizational success which are economic, social and environmental aspects in terms of approaches and performance indicators. Following that, a timeline plan should be created that identifies each step of the process starting from preparation, connect with stakeholders, Define the objectives, monitor the process, report and finally lunching the report. This process should be supported by a team consisting of process coordinator, decision maker and supporters.

2. **Stakeholder’s engagement.**

   Stakeholder input is key component for defining the content of the report and aspects to be focused on. Therefore at this stage, identifying and prioritizing stakeholders and initiation of discussion topics on economic, social and environmental should be materialized. The benefit of engagement is to strengthen the trust between the organization and its stakeholders. This covers both internal stakeholders such as employees and external stakeholders such as customers, shareholders, suppliers, etc.

   The common aspects that should be discussed should all falls into the three main categories which are economic, social and environmental. The social aspect has further four sub-categories: Labor Practices, Decent Work, Human Rights, Society and Product Responsibility.

   This process is considered to be the core subject of the sustainability reporting at which, it should have a humble time frame and resources to interact and create dialogue channel with the stakeholders based on those who are identified and prioritized. The organization chooses different method of interaction with their stakeholders depends on each stockholder such as surveys, meetings, letters, etc.
3. Define the actions and indicators

At this stage, the list of aspects should be defined based on the engagement process described above. The selection of aspects can be narrowed down by applying materiality test which is recommended by GRI protocol. Based on the aspects selected, the indicators should be developed in line with GRI 3.1 version guidelines which are related to the selected aspects.

It is recommended by GRI to report all performance indicators found to be material by either providing the information, or explaining the reason of its omission. This is a requirement of level A GRI report.

The ultimate decision makers within an organization should be involved to make the final decision on the aspects and indicators to report on.

4. Monitor and build the report.

The sustainability reporting is more than just producing a sustainability report, it is also about improvements and changes to the organizations that can be initiated as a result towards a sustainable activities.

It is important to collect data regularly and systematically to ensure balance, comparatively accurate, clarity and reliability of the report. The performance can be measured in two ways: quantitatively and qualitatively.

5. Check and Communicate

At this stage, all the information required for the report are gathered and should be ready for checking, writing, finalizing, and then lunching the report. Following that is the preparation phase for starting next reporting cycle.

Choosing the best communication tool or method to reach stakeholders internally and externally is important part of the sustainability reporting. The organization should provide access channel to the complete set of the report either in the form of
printed report or web-based report. Some of the organizations produce a summary printed report, and their full report is posted in their website.

There is no single standard report structure, organization can used different structures that suites their culture. However, the general report starts from contextual information, to high level strategic issues, to management approach, and closes with performance results. The following framework can be used as table of content in preparing the final report:

1) Strategy and analysis
2) Organizational profile
3) Report parameters
4) Governance, commitments and engagement
5) Management approach and performance indicators
6) Application level grid.

Upon finalizing the report, the organization should declare the GRI reporting level (C, B or A), and it may consider external assurance party which gives the report credibility represented by “+” sign.

Below is table of GRI level classification.
GPIC Sustainability Report in line with GRI: (2010-2011)

Our initial sustainability report “30 years of excellence,” published in 2009, was issued to commemorate our 30th anniversary since inception. As a way to further enhance our transparency and diligence in our approach to monitor measure and report on our economic, environmental and social performance, we have taken an initiative to align our sustainability reporting with the Global Reporting Initiative (GRI) G3.1 sustainability reporting guidelines.

This report also includes information on the various corporate social responsibility and sustainability initiatives we have invested in the financial years 2010 and 2011 (period ending December 31, 2011).

This report is aimed at our shareholders, employees, governmental and non-governmental organization and other parties or individuals with a working interest in GPIC.

In preparing the report we have gone through the following cycles:

- GRI Reporting team leader attended a workshop on Sustainability GRI reporting.
- A working team was formed to prepare the sustainability report for 2010-2011.
- All relevant section heads were briefed about GRI reporting requirements in a kick-off meeting.
- A brainstorming session was conducted by relevant sections heads to identify and agree on our key stakeholders.
- Information was collated from relevant sections related to the GRI 3.1 Performance indicators.
- KPMG Consultancy was engaged to assist us in preparing the report, including the review of draft write ups.
- In parallel with the report preparation, a professional designer and publisher was also engaged.
- Diverse materiality processes were observed to ensure we only reported on those indicators (GRI3.1) that are relevant to our business.
- The boundaries were well defined as all our business facilities are in Bahrain and our product marketing is done by SABIC and PIC. The report boundary covers our facilities and operations covering our manufacturing and export facilities. As
the marketing of products is done by our shareholders, therefore we do not have a direct link with our customers.

- Data collection for the relevant GRI3.1 indicators was provided by the concerned sections of our business. The information was verified by the concerned professionals during the review phase of the report. Most of the data was already available within the company as part of our regular data collection, monitoring and reporting process for our day to day business.

This is the first year that GPIC Sustainability Report 2010-2011 has been prepared, assessed and reporting against the GRI G3.1 guidelines. We will continue to refine our sustainability reporting and will work to further enhance our commitment, targeting full compliance with GRI report “A” level in future years.

**Materiality Process:**

We observed divers materiality processes to ensure our reported indicators are having significant impact on the economic, environmental and social aspects and are mostly relevant to our business.

This covers both: the importance of our organizations impacts and the priorities of stakeholders. We have tried to provide a balanced representation of material issues based on internal and external feedback and factors concerning GPICs sustainability performance. Therefore, GPIC business principles are based on the triple bottom line approach and hence forms the basis of our sustainability reporting.
Qatar Fertilizer Company
Commitment to Health & Safety and Environmental Stewardship

Iftikhar Hussain Turi
HOS A2/ AHOS Urea-2-, QAFCO
Qatar
25th AFA International Technical Conference and Exhibition HSC Summit

Topic:
Sustainability and Social Responsibility

Title:
Qatar Fertilizer Company Commitment to Health & Safety and Environmental Stewardship

Iftikhar Hussain Turi
Qatar Fertilizer Company, Mesaieed QATAR
Introduction

Located in state of Qatar, Qatar Fertilizer Company now a multi product facility is a world class producer of urea and ammonia since 1973. At present, QAFCO operates five ammonia and five urea plants and one ammonia and urea plant are in the final stages of commissioning and start up. Beside Urea and ammonia it also produces Melamine, Urea formaldehyde and Aqueous ammonia.

Being a responsible organization, QAFCO considers the safety, health and wellbeing of its employees a core value and the protection of the environment its prime responsibility. Keeping focus on safety and environmental protection, and maintaining the organization growth, QAFCO management is successfully fostering a strong safety vision at all levels of organization by showing its commitment towards continues improvement, risk mitigation, employee’s engagement and implementing, adopting industry best practices and available technologies to reduce its environmental footprint and improve process and personal safety. On a social level QAFCO is reaching out to the communities by sponsoring events and shows, sponsoring environmental and marine protection projects. QAFCO is actively involved in improvement of marine habitat by installing artificial coral reef near Sea line beach. QAFCO is also looking after the improvement of Al-Besheriya Island and is the main sponsor of Sahara environmental project to utilize green technology to produce fresh water utilizing solar energy.

Background

Founded in 1969 as a joint venture was the first step towards the industrial diversification in Qatar to utilize the available natural gas resources. With the startup of its first 900MT anhydrous ammonia and 1000MT of prill urea plant, QAFCO joined the list of the world nitrogenous fertilizer producers in 1973. Over the years, responding to the world fertilizer demand, QAFCO has gradually increased its production from 1000 MTPD urea and 900 MTPD ammonia to 11550 MTPD and 8550 MTPD respectively by adding more production trains and by revamping the existing plants to increase production capacity. All the plants in QAFCO are operating well above the rated capacity. Beside the two main products (prilled and granular) QAFCO is also producing UFC-85, Melamine and Aqueous ammonia. The aqueous ammonia is utilized in the DeNOx system to reduce NOx emission.

At present, QAFCO average annual production is about 2 million tons of ammonia and 3 million ton of urea. After completion of the two new projects its average annual production capacity will rise up to 3.8 million ton of ammonia and 4.8 million ton of urea making QAFCO world’s largest single site producer of ammonia and urea.

With the increase in plant throughput, its on site anhydrous ammonia storage capacity has also increased gradually from 20,000 MT to165000 MT by adding two world’s largest anhydrous ammonia storage tanks.
Improving safety and reducing environmental footprint while expanding

After putting its product in the world market to support the world grain production, QAFCO started to get voluntary certification for Safety, Quality and Environment management system to get aligned with the international producers and suppliers of the global market and also to improve its safety, quality, reliability and to reduce the environmental footprint to comply with state environmental laws and regulations. Being a responsible member of the Mesaieed industrial community, QAFCO is diligently working to comply with local environmental laws by adopting new technologies and conducting the required modification to bring down its emissions.

QAFCO holds the following certifications:
ISO 9001: 2008 (Quality Management System)
ISO 14001: 2004 (Environment Management System)
BS OHSAS 18001:2007 Occupational Health and Safety Management System
Responsible care RS-14001:2008 Technical Specification
Product stewardship

Challenges for QAFCO

QAFCO a multi cultural and multi product company is located in Mesaieed industrial city of QATAR surrounded by chemical and petrochemical plants, handling a very high volume of hazardous, toxic chemicals and highly explosive gases. QAFCO considers the safety and health of its employees and the contractors working in QAFCO a core value and the protection of the environment its prime responsibility.

While working on safety improvement, QAFCO has to take into consideration not only the internal risks and hazards into consideration but also the external risks to QAFCO employees and at the same time to ensure the safety of the people working in the neighboring plants in case of any accidental release from QAFCO plants. As per the nature of the business, QAFCO faces a unique set of challenges to implement its OH&S program and keep check on the releases from the plants. Due to ongoing expansion and modification activates and much needed yearly plant turnarounds a series of simultaneous activities takes place in an environment where other plants are live and fully functional. Plant personnel and contractors works to get the job done within a very tight time frame and some time in a very extreme weather conditions.

Hazard Identification and Mitigation

With the passage of time QAFCO has not only increased its production capacity but has also diligently worked on improving its safety performance by adopting continuous improvement strategies, implementing and adopting industry best practices, conducting risk assessment, mitigation, engaging and challenging employees at all levels, adopting best available technologies, learning from others and sharing information with the industry on a local as well as on a global level by attending seminars and workshops around the world.
Site wide safety improvement

As mentioned, QAFCO from the very beginning remained a dynamic organization by continuously expanding not only adding more production units also revamping its existing units to increase its production capacity. To support and maintain the existing and the newly added units its work force also increased from about 400 employees to 1550 till date excluding contactors working inside QAFCO. The focus has been shifted from traditional safety to behavior based safety program where every one including contractor’s behavior is watched and rewarded accordingly to ensure compliance and implement QAFCO safety policy. Frequent safety briefings and refresher trainings are conducted for employees and contractors about the potential hazards may be faced during plant turnaround activities.

History of improvement initiatives

Safety system

QAFCO has established Safety Management Systems in accordance with the requirements of the ISO Standards. QAFCO continuously works to improve the effectiveness of the Management Systems by monitoring personnel safety performance of its employees and contractors working at site, involved in routine and major turnaround activities. QAFCO has adopted a proactive approach by using leading indicators - routine hazards assessment and near misses etc to identify the potential weaknesses to get rectified on time.

Personnel Safety

Risk assessment for buildings

A risk assessment was done to evaluate the potential risk to the tenants of the admin buildings from the existing plants, new ammonia & urea plants and the chemical risk from the surrounding plants located in the close vicinity to QAFCO.
The study was conducted based on different scenarios, i.e. Full bore rupture of tank, vessel and large pipeline, major leakage and small leakage of different gases, ammonia, synthesis gas, chlorine and HCl.

As per the report recommendations a number of risk mitigation projects were initiated and implemented to eliminate or minimize the potential risks.

Toxic gas detection system

A detailed hazard assessment was conducted based on the feedback from the neighboring plants and their products toxicity, storage capacities and transfer pipes in their premises. Gases handled and produced by QAFCO were also included in the risk assessment.

In order to get early warning and source identification, gas detection system has been installed and connected to the SCADA system with trending capabilities to monitor NH₃, H₂S, SO₂, HCl, Cl₂ and VCM toxic gases in the environment surrounding QAFCO. Any accidental gas released from the QAFCO or neighboring plants can be detected and monitored depending on the wind direction and concentration of the gas in the environment.

Emergency trip system for air conditioning system

Integrated toxic gas detection system is also used to isolate the buildings, operator rest rooms and central control room from outside by shutting down the air intake from outside of the HVAC system. Dedicated toxic gas detection sensors are provided at all the fresh air intake, upstream of the dampers to avoid contaminated air ingress into the buildings.
Process Safety

Relief valves study
In order to increase the production capacity, old plants in QAFCO are subject to debottlenecking process. For the past may years QAFCO is able to operate the plants well above the name plate capacity by conducting plant revamps and modifications. During one of the internal evaluation process it was observed that the relief valves evaluation against the maximum demonstrated production (MDR) load is not done. A concern was raised that improper safety relief valve may leads to unsafe condition at site As recommended relief valves evaluation (maximum relieving capacity vs. plant load was conducted across the site and found satisfactory except few relief valves were found operating close to rated capacity. The case was referred to the vendor for further evaluation and recommendations.

Hazardous Area classification
In order to protect the personnel and equipment from unexpected fire QAFCO has adopted the international standard IEC 60079-10 as the basis for classification of hazardous areas within QAFCO site. This standard has been applied to all production facilities (all ammonia, urea, power generation and utilities areas) and plant areas have been suitably classified into different zones (Zone-0, Zone-1, Zone-2) and non-hazardous areas. The purpose of area classification was to identify the extent of the area made hazardous due to the presence of flammable atmosphere and to classify the identified hazardous area on the basis of frequency of flammable release or ignitable gas expected to be present, the flammable material release rate and the degree and availability of ventilation in the area.
When changes are proposed in plant facilities, concerned trades in the project team assess the impact of proposed changes on existing hazardous area classification drawings and suitable changes are made as per established guidelines and procedure.

Ammonia venting in the old plants
During one of the annual risk assessment review it was observed that the old ammonia plants do not have adequate system to handle ammonia release during plant upset and emergency shutdown. It was proposed that instead of venting ammonia vapors at the high elevation an adequate flaring system should be installed to avoid ammonia concentration in the surrounding and splashing out of liquid ammonia from the vent. The project is in the final stages of implementation. So for in QAFCO we do not have any recordable incident of massive ammonia release from vents but flaring system when installed will eliminate the potential hazard of spreading ammonia in the surroundings.

Modification of the Primary Reformer fuel supply system
Due to the recent incident of primary reformer explosion during plant startup in one of the European fertilizer plant, QAFCO conduct a risk assessment study to evaluate all the reformer firing procedure and the built in safe guards available to avoid explosion of the reformer during startup. Based on the study two out of four reformers were found not to have a adequate built in safe guard. A project was initiated and the required safe guards were provided as recommended by incorporating the header tightness test as condition to get permissive to open the main fuel supply valve to reformer.
Equipment Critically Ranking

In QAFCO equipment criticality ranking is done based on the consequence of failure of the particular equipment or machine on the safety of personnel, impact on the environment and its cost implication due to business interruption.

As per CRP all the new and existing tagged equipment at site are categorized in term of its consequence of failure, probability of occurrence and assigned the necessary preventive maintenance tasks in accordance with the requirements of the QAFCO maintenance process.

### Ammonia Storage systems

QAFCO anhydrous ammonia storage capacity increased with the increase in production capacity. It is normal practice in urea fertilizer production facilities, that surplus and unconsumed anhydrous ammonia produced by ammonia plants are stored in a suitable storage tanks. The stored ammonia is either consumed with in the process or shipped to external consumers for further use.

At present QAFCO is operating fully integrated four ammonia and four urea plants and will integrate two ammonia and two urea plants to the existing setup. Under the existing scenario surplus ammonia is stored in the refrigerated storage tanks for export and for internal use as needed. This gives QAFCO the flexibility to keep all the urea plants in service even when any of the frontend (ammonia) plants are down, depending the availability of carbon dioxide produced by the ammonia plants. All the surplus ammonia stored in four interconnected specially designed ammonia storage tanks.

### Change in Design

As the two old tanks were build in seventies according to the best available technology at that time. In 1970’s it was normal practice to store anhydrous ammonia in single wall (single containment) refrigerated atmospheric tanks.

During 1997 expansion project, QAFCO decided to increase the storage capacity as per plant requirement. A double integrity, double wall full containment design was chosen to improve the safety and reliability of ammonia storage facility.

The same philosophy was adopted during 2004 expansion, when the third ammonia storage tank was constructed.

To avoid spread of ammonia vapors in the surroundings in case of plant upset or breakdown of storage tanks refrigeration system, a flare system has been installed to be used for ammonia gas venting through flare.
**Provision of secondary containment (Bund Wall)**

To prevent anhydrous ammonia from spreading in case of any leak from ammonia tanks or loss of containment a secondary containment has been provided for both the tanks. The storage tanks are placed inside a Dyke of 4.3 m height. The Dyke is designed to collect 100% of storage volume of T6002 plus 10% storage volume of T6001. The dyke area is divided into two parts by a separation wall.............

The same philosophy has been adopted for the design of two new ammonia storage tanks with a better design then before. The tanks are “cup in tank” double containment design. These tanks are single wall surrounded by pre-stress concrete wall with the annular space sufficient enough to hold the full volume of the stored product. A dedicated flare system is provided to avoid any accidental release of ammonia vapor from the storage tanks refrigeration loop.

**Foam suppression system**

An improvement project has been initiated to further reduce the risk of spreading ammonia in case of accidental release from the storage tanks by applying foam to slow down the release of ammonia vapor into the atmosphere. It will provide enough time for evacuation if needed. The project is in the initial stages, as the foam stability with respect to the local weather conditions is being evaluated.

**Evaluation of ammonia storage tanks integrity**

In order to maintain the integrity of the ammonia storage tanks, to protect workers and environment a detailed study was conducted to evaluate the operation of the ammonia storage tanks in QAFCO by comparing the data with others and identifying, recommend the industry best practices.

No design or facility can be considered completely foolproof and safe. There is always a need to evaluate and reduce the potential risks and the hazards that are associated with the equipment or plant operation.

**Assessment for inspection frequency**

A detailed study has been made by using EFMA guide lines and the risk base inspection (RBI) approach by giving a due consideration to the industry standards and legislations adopted and enforced in different part of the world. A failure probability and consequences of failure is also considered during assessment process.

Based on the RBI assessment one of the oldest tank (1997) falls in the rank of very low risk
Stress corrosion cracking study
For many years stress corrosion cracking (SCC) in carbon steel anhydrous ammonia storage tanks has been a major concern for the fertilizer industry as in early 80’s SCC was found in fully refrigerated ammonia storage tanks and the research performed afterwards confirmed the potential of SCC in low temperature applications. Considering the potential risk of SCC, an internal study was conducted to evaluate QAFCO anhydrous ammonia storage tanks for SCC to ensure the safety and health of workers in QAFCO, to protect the environment and to maintain the integrity and operating capability of these assets.
In this study the operating parameters were taken into consideration as one of the main reason for SCC is moisture and oxygen content in stored ammonia. As mentioned earlier QAFCO has a multi layer of protection around the ammonia storage tanks, the chances of ammonia containment loss from the storage tanks is minimal.

Environmental Improvement
QAFCO has taken many initiatives to reduce its impact on the environment by reducing its emissions and discharge to the sea. All the emissions and releases are continuously monitored, documented and reported to the local authority regularly. The objective is to comply with local environmental emission limits by conducting studies and to utilize the available technologies to reduce plant emission as much as possible.

De NOx system in Ammonia-3
In order to achieve the Nox emission limits specified by local authority, QAFCO implemented the following projects:
SNCR DeNOx system was installed at the primary reformer flue gas duct. Both ammonia and urea solution is used to reduce the NOx in the flue gases of the primary reformer. It has been planned to implement the same in another ammonia plant to further reduce the Nox emission at QAFCO site.
In Heat Recovery Steam Generator system, SCR DeNOx technique has been applied to reduce the NOx emissions from the gas turbine exhaust. The system is a combination of catalytic and ammonia or urea solution injection system.
In order to reduce the Nox emission from the Auxiliary boilers in ammonis-3, Low NOx burners with FGR (flue gas recirculation) technique has been applied.
Low NOx burners are designed to provide fuel staging which generates fuel rich and fuel weak areas to reduce flame temperature. Introduction of FGR reduces NOx by reducing flame temperatures and local oxygen concentration in the flame zone. All these measure has significantly reduced plant NOx emissions.
Process waste water collection and neutralization

To attain the goal of zero process waste water discharge to the sea, QAFCO has initiated a project to collect all the discharges from the plants to be sent for proper treatment and disposal. The plan is to reuse the treated water after further processing for steam production or for other uses in the plant. By incorporating and modifying operating procedure QAFCO has already significantly reduced discharge to sea during plant startup and rundown activities.

Waste water treatment

To avoid any waste water discharge to the sea QAFCO installed (SBR) a biological waste water treatment plant to treat all the waste water produced in the facility. A portion of the treated water is used for the irrigation purpose. There is plan to fully utilize the treated water for irrigation by increasing green spaces in QAFCO.

QAFCO environmental protection and safety performance

Industrial accidents are a major concern to every industry due to the potential of heavy economic losses, loss of lives and damage to property and environment. Like any other industry, QAFCO is diligently focusing on its safety improvement by utilizing the currently available technologies, resources and skills to operate and maintain its production units and related installations with a high degree of safety and environmental protection standards.

Over the years considerable improvements have been made in risk mitigation and hazard elimination. QAFCO is also responding to the local environmental regulations by conducting feasibility studies and modifications to reduce emissions. There is significant
decrease in emissions to air from plants and efforts are underway to improve compliance by implementing environment related projects.

Public reach out and environmental protection projects
QAFCO is not only focusing on to comply with local regulations by reducing its environmental foot print but also reaching out the community by organizing and sponsoring events to educate community members and school children about their responsibilities towards environmental protection. For many years QAFCO is conducting flowers and vegetable shows and sponsoring environmental awareness related events in schools located in Mesaieed.

The Sahara Forest Project
Recently QAFCO has signed an agreement with Yara International to build a pilot plant to demonstrate the potential of green technology in arid region like Qatar. The objective of the Sahara Forest Project is to develop and deploy an integrated, large scale system for reforestation and creation of green jobs through profitable production of food, freshwater, bio fuels and electricity. It is designed to utilize deserts, saltwater and CO$_2$ to produce food, water and energy. The project is expected to provide a base for commercialization of green technology to produce fresh water required for irrigation.

The processes integrated into the Sahara Forest Project will work optimally in Qatar as it requires sunny and arid conditions. Seawater greenhouses which allows the production of freshwater from seawater by providing a cool and humid micro-climate well-suited for food and biomass production. Concentrated solar power which uses solar radiation to produce heat and power.
The aim of this project is to restore desert areas to biological activity and sequester large amounts of carbon in plants and soil. This project would also create employment opportunities in some of the poorest areas of the world. The solar power technologies have the potential to meet a huge part of future energy needs.

**Artificial Reef installation**

Due to increase in industrial activities close to the Mesaieed shorelines have adverse effects on the local marine environment due to the damage to natural reefs and decrease in fish population. These reefs provide a rich habitat for fish and other marine species which unfortunately cannot rebuild themselves fast enough to meet the environmental and human demands. QAFCO took the initiative to reduce the impact of industrialization on marine environment by deploying an artificial reef balls in selected sites close to Sealine beach in Mesaieed. There has been a significant build up and recovery of coral reef has been observed in the area.

**Al-Besheriya Island**

Al-Besheriya Island is a small island situated southeast of Qatar in the vicinity of Mesaieed Industrial City. This island is the resting place for the birds and also used as nesting place by migratory birds. QAFCO environment section conducts frequent cleanups and maintenance activities to improve the area. It has also conducted a mangrove tree plantation activities to make the area a favorable place for birds and other habitats.

**Fish Hatchery**

To support and improve fish diversity and population, QAFCO is planning to establish fish hatchery in Mesaieed. After completion, the project will improve the biodiversity of the local marine life by introducing various native species.

**QAFCO last twenty years**

QAFCO has achieved five million continuous working hours without lost time accident. The following trends show the significant and gradual reduction in first aid and lost time accidents. Compared to some of the fertilizers units operating in Europe and elsewhere, QAFCO falls in the rank of lowest lost time incidents (LTI) and first aid incidents reported. QAFCO always handled and maintained a high volume of anhydrous ammonia in storage but so far there is no recorded incident of significant amount of ammonia release in QAFCO’s history due to system malfunction or tanks failure.

**FIRST AID ACCIDENTS – (1985 TO 2010)**

![First Aid Accidents Chart]

**LOST TIME ACCIDENTS – (1985 TO 2010)**

![Lost Time Accidents Chart]
Summary

QAFCO believe that by placing a right safety enabling system, supported by the organization management can create a truly safe working environment, where safety is every one responsibility and where employees at all levels are actively engaged in identifying the hazards to be eliminated and controlled. By creating a safety culture and providing the required resources will keep the working interface safe for workers.

As a Responsible Care certified company, QAFCO is committed to environmental, health, safety and security excellence in all our business activities. QAFCO does this voluntarily, and we consider this commitment as a core value of our business. Our commitment to excellence in environmental, health, safety and security performance is a continual improvement process.

QAFCO is committed to support social and environmental related activities and projects and will continue to work towards sustainability by further reducing its environmental footprint and maintain its good safety record.
1. **How Automation Improves Operational Efficiency of Nitrogen-based Fertilizer Plants**  
Brendan Sheehan, Chemical Marketing Manager. Honeywell Process Solutions, Turkey

2. **Energy Conservation Study for Ammonia Urea Complex**  
Anthony Conning – Business Unit Manager, ABB, UK  
Magdy Mohamed Ali - Senior Process Engineer - Projects Division, FERTIL – UAE

3. **Catalysing profit margin with LK-853 FENCE™: A new generation of Topsøe low methanol LTS catalyst**  
Kristina Svennerberg, General Manager, Marketing Synthesis, Haldor Topsøe, Denmark

4. **Elimination of radioactive sources in Ruwais Fertilizer Industries Co.**  
Ahmed Al-Awadhi – Sr. Instrument Engineer, FERTIL, UAE
25th AFA International Fertilizers Technology Conference
Sustainability Driving the Future
July 09 – 11, 2012

How Automation Improves Operational Efficiency of Nitrogen-based Fertilizer Plants

Brendan Sheehan
Chemical Marketing Manager
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How Automation Improves Operational Efficiency of Nitrogen-based Fertilizer Plants

Brendan Sheehan

Honeywell Process Solutions
Chemicals Marketing Manager

May 2012
Abstract
This presentation describes how Automation Solutions can improve the operating performance of Ammonia, Urea and Nitric Acid plants. The price of natural gas varies widely around the globe – ranging from less than $2/mmbtu in the US to more than $10/mmbtu in Europe, where it is linked to the price of oil. Fertilizer prices have been rising as global demand for crops increases, while available arable land slowly decreases. To compete, it is imperative that fertilizer producers focus on getting the most from their existing assets and assure that improvements are sustained over the long term. This can be challenging when we consider the constantly changing competitive landscape, increasingly stringent environmental standards and the difficulty hiring and retaining experienced operators.

This presentation focuses on a number of automation solutions that can help:

a) capturing the experience of your best operators and training new operators using dynamic simulation models;

b) maximizing yields and reducing energy costs using advanced multivariable control applications;

c) improving information such as energy efficiency and knowledge transfer across units to help make better manufacturing decisions as business conditions change.

This presentation includes examples of where these automation solutions have been applied and the level of benefits that have been realized as a result.
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Introduction
As many people are aware, the fertilizer industry and in particular the price of nitrogen-based fertilizers have had a very good run in recent years—climbing rapidly before the global financial crisis, falling pretty hard right after before recovering strongly over the past few years.

Much of this is due to higher crop prices - particularly corn prices here in the US – which have encouraged farmers to use more fertilizer.

At the same time, the production cost of ammonia and urea is closely linked to the cost of natural gas. So in a scenario of increasing ammonia prices driven by higher crop prices, the regions with consistently low natural gas prices are positioned to make excellent margins. The Middle East, Russia and Trinidad are regions with abundant natural gas resources and have enjoyed solid profits producing and exporting nitrogen-based fertilizers to Europe and the Americas. More recently, the US has joined the low-cost natural gas regions due to the recent rise in production of shale and tight gas. This is particularly advantageous for the US which has been a major importer; as local production can now compete with imports from Eastern Europe, the ME and elsewhere.

However, it should be noted that not all regions are experiencing low natural gas prices. In the US, natural gas prices are decoupled from the price of oil and hence while oil prices have been between $90-100/bbl, natural gas prices have fallen as low as $2/mmbtu. In Europe, however, natural gas prices are tied to oil prices with prices closer to $10/mmbtu.

Regions with low natural gas prices are now enjoying very good margins on fertilizer production, but fertilizer prices recently have been so high that even with high natural gas prices in Europe, good margins are possible. For the ME, export markets remain strong as transportation costs are not so high that they damage overall margins.

Fertilizer demand tends to rise at a rate somewhat close to global GDP rates and is expected to increase at around 2.3%/year until 2019 which is a little below GDP rates. Of the total, about three-quarters of demand will come from China, ME, Africa, South America and India.

At the same time, capacity will increase faster than demand, growing almost 50 million tonnes/year by 2019 – with most of this increase in China, ME and Africa.

With capacity growth outpacing demand growth over the next few years, one could expect utilization rates to fall while some less efficient plants shut down. This means fertilizer producers need to maintain their competitive position in the face of continuing challenges from the market, the environment and changing demographics.

Industry Trends
The fertilizer industry shows similar trends to those found across a range of process manufacturing industries. These can be broadly divided into four categories - safety, reliability, efficiency and sustainability.
Safety
At the top of the list is the increased attention to safety and process security. Plant managers consider safety their highest priority because safety-related incidents can injure personnel, damage equipment, harm the environment and interrupt production.

To mitigate these risks, it is important to consider safety from all aspects of a plant’s operation. Plant safety today requires a comprehensive approach, including managing operator effectiveness, the constant monitoring of distress indicators, personnel tracking and mustering applications and ongoing asset monitoring and maintenance.

Ideally, a safety system should incorporate multiple layers of protection that can first help avoid the incident, then, if that fails help mitigate the impact and in the final event help protect people and assets.

Besides the inherent risk associated with operating fertilizer facilities, in today’s challenging times, many have been identified as potential targets for terrorist activity. Security has always been an issue for the fertilizer industry given that nitrates, for example, are commonly used in explosives. It is necessary to anticipate and respond to threats both against the physical plant and the process control network. In terms of physical security, this means being able to monitor the plant perimeter and all access points, including waterways – and be able to respond quickly to an intrusion. It means knowing where everyone is, including any visitors, at any time, and being able to quickly get them to a mustering point in the event of an emergency.

Reliability
In mature regions like the US and Western Europe, companies are facing the loss of experienced people, while in developing regions like China, India and the Former Soviet Union, experienced staff may be hard to find. In all regions this makes it more difficult to achieve consistent, reliable, safe production. As a result, it is critical to capture best practices that provide a foundation for future operations. Moreover, making sure operators are well trained and know how to react during upsets or abnormal situations is imperative in improving the reliability of the plant.

As plants become more integrated in terms of heat and material balances, an upset in one area can quickly spill over to others. Therefore, consistent execution of infrequent tasks such as a compressor start-up is vital to maintaining operational excellence.

To maximize profitability in a competitive environment, it is necessary to maximize and maintain process and equipment availability. However, it is impossible to implement a quickly changing production plan if the changes in production rate in the reformer result in an upset in the syngas quality to the converter. Plant personnel must know how hard they can push the unit without compromising the integrity of key pieces of equipment and be able to plan for equipment turnarounds as needed. This requires a tight connection between process data and equipment
health monitoring so that boundary limits are recognized even though operating modes and equipment demands are constantly changing.

**Efficiency**
As mentioned, fertilizer companies continue to drive towards a more efficient operation, aiming to meet production targets at the lowest possible operating costs. In fact, the industry has done a decent job as the average energy consumption for ammonia production today is more than 20% lower than it was 20 years ago.

Manufacturers continue to focus on making the most effective use of the capacity they have at their disposal while delivering the lowest manufacturing cost per kilogram of product. New plants have much larger capacities to gain economies of scale and are often located in regions where natural gas feed-stock is cheap and abundant. Existing plants add capacity incrementally and manufacturers focus on operational efficiency to minimize off-spec product, minimize energy consumption and maximize yields of the most valuable products.

As the industry focuses on driving down costs, many producers increasingly integrate their supply chain, both upstream and downstream, to assure they have a low-cost source of feed-stock and so they can realize greater margins through the sale of end-use products. The opportunity exists, but it requires a better understanding of the entire supply chain and the implementation of improved workflow practices to take advantage of changing market conditions.

**Sustainability**
Even as producers try to increase efficiency, they must also consider increasingly stringent environmental policies. Acid Rain regulations, and in some regions restrictions around GHG emissions, continue to pressure producers to manufacture fertilizers in a sustainable manner.

This has led to a further focus on energy efficiency as well as new methods of delivering fertilizer to crops that minimize run-off into the water system and maximize nutrient absorption by plants.

**Automation for Operational Efficiency**
In spite of all the good work the fertilizer industry has done to improve efficiency, there are still opportunities for improvement; better use of automation is one way to achieve these benefits.

The remainder of this paper will describe how modern distributed control systems with improved integration across the plant and better connections between the control room and board room can provide tools and applications to improve plant performance. The following areas will be considered:

1. Integration of Safety Systems and Main Automation
2. Abnormal Situation Management Consortium – Technology and Best Practices
3. Alarm Management - Use of Smarter Alarms and Trends
4. Operator Training Simulators
5. Advanced Control
6. MES Solutions – Monitoring; Energy and Emissions Dashboards

**Modern Automation Platforms – Integrated Control and Safety Systems**

Process information truly comes to life when it’s shared. Having the right knowledge at the right time is the key to making the right decisions. This sounds obvious but for plants that have been around for many years, their systems often grow separately and apart - creating valuable, but independent, information silos. As a result, operators and engineers of each unit only see part of the whole picture. Meanwhile, maintaining efficient operations while gathering facility-wide data, making sense of it, and performing analyses, can take weeks or months—by which time, situations have probably changed. It’s this ability to quickly turn data into information in support of knowledgeable decision-making that makes the difference in effective business performance. For producers considering an automation solution for a new fertilizer complex, it is clear how important the ability to easily share information is for keeping investment costs down and shortening the start-up time. The advent of Open Systems and common communication protocols for the process industries, such as Ethernet/IP, Foundation Fieldbus, HART, Profibus, OPC, etc., has opened up the possibility of better integration. A Modern control system today does not just connect valves and instrumentation to the distributed control system, but can also integrate wireless networks, Safety Instrumented Systems (SIS), Fire and Gas Systems and higher level advanced applications, such as Advanced Control and Production Management solutions. However, some cautionary tales should be noted. There are several competing standards in the market place and producers looking to mix-and-match best–in-class or lowest cost point solutions can find themselves having to handle all the interfacing between the individual point solutions.

The key to selecting a new automation system is to ensure individual point solutions are not separately interfaced together to create the communication connections but are naturally integrated.

For example, a modern fertilizer plant needs a modern Distributed Control System (DCS) and a reliable Safety Instrumented System that allow for integration of the process control platform with the necessary protection of critical equipment and process. Traditionally, the SIS is always built separately from the process control platform; indeed, it is important that the network and the database remain separate with triple or in some cases quadruple redundancy across key elements of the SIS platform. Today, new features maintain the critical separation of the systems but allow for a more balanced operational integration and lower the cost of installation, maintenance and long-term support. For example, some newer safety systems allow for remote universal I/O modules that enable holding a reduced set of common spares while removing the need for much of the costly wiring between field I/O, the junctions boxes, the
marshalling cabinets and the controller cabinets. Also, newer systems may have separate databases, but configuration in one is automatically detected and published to the other, while a common interface across the Emergency Shutdown System (ESD) and the control system helps the operator troubleshoot problems. A modern integrated automation system should also be able to quickly communicate between the SIS or ESD and the main control system. Ideally, this should be done via peer–to–peer connections so there is no need for a server to be in the communications loop. Also, many producers like to integrate their fire-and-gas system to both their safety system and the control system. Hence, in the event of a gas release or a fire, an outside operator can hit a fire alarm panel, which will trigger sounders and beacons to alert other personnel, but also automatically safely shut down the plant – with the whole sequence of events captured on the overall control system.

![Diagram of integrated safety and control systems](image)

**Figure 1 Integrated Safety and Control**

**Abnormal Situation Management Consortium**

The impact an automation system can have on operational efficiency is not all about the integration between the controls, safety system and other areas, such as fire and gas. It’s also about the way the operator interacts with the automation platform. The Abnormal Situation Management (ASM) Consortium, created in 1994, considers the way an operator views and controls the plant through the operating console and then what technology and best practices are required to support the operator. One example of best practices that emerged from the ASM was the use of ASM-compliant graphics. The ASM recognized that operators are very familiar with the process and do not need the equivalent of a process flow diagram on their screens. However, they do need to react quickly to changes in operating conditions and thus these changes need to attract the operator’s attention. So instead of having highly colored and
complex operating graphics, the consortium recommended building graphics comprised of largely muted colors like shades of grey, and that color is used mainly when an alarm is triggered or an action is required to attract the operator’s attention. Modern ASM graphics use icons and different colors to indicate when a point is in a state of alarm or a piece of equipment or a controller is not in normal mode. The impact of these new graphics was tested and it was found that operators using the ASM graphics showed a 35-48% improvement in speed and accuracy of response over traditional graphics and also a 38% improvement in recognizing an abnormal situation before the first alarm was triggered.

**Embedded Automated Procedures**

The ASM Consortium also looked at new technology to help operators work more consistently and efficiently. A study completed in the US in 1996 estimated that $20-billion per year is lost due to safety incidents in the US Petrochemical Industry alone. The study showed that a significant factor to plant process incidents was the improper execution of procedures. This led to the development of a solution that allows for procedures to be embedded into the automation system and, where appropriate, many of the steps automated.

In a fertilizer plant with a modern automation platform, it is now possible for the operator to directly interact with the procedure from his console rather than getting a procedure manual from a shelf. Procedural Operations technology allows the operator to execute a series of activities that happen infrequently to ensure more consistent execution over time and by different operators. It guides the operator interactively through the operation so steps aren’t missed or done incorrectly and can prompt the operator when it’s time to proceed to the next step, ensuring they’re done as quickly as possible. Procedural Operations combine manual steps (such as those completed by an outside operator checking a valve lineup) with semi-automated steps (such as setting controller modes and set-points) to fully automated steps, such as allowing a sequence program to automatically ramp up the reformer furnace ahead of plant startup. These procedures are developed by looking at the complete workflow of a few of the plant’s high-impact procedures (such as the startup of an ammonia plant, which can take a significant amount of time) and embedding that workflow into the automation platform.

A typical embedded procedure has the following characteristics:

- It can have any combination of manual and automatic control actions that direct the operator along the main path to accomplish the task (e.g., plant startup).
- It will include exception path handlers to anticipate and mitigate potential abnormal situations during the execution of a procedure (e.g., pause a ramp if the PV cannot keep up with the changing SP).
- It may have steps that do not have any instrumentation associated with it. (e.g., check valve positions)
- It can communicate with the operator – providing guidance regarding the action required at a given time.
Alarm Management Solutions
Before computers were widely available in alarm systems, control panels had limited space and each alarm required significant engineering (and associated cost) to implement. Computer-controlled alarm systems reduced the cost of implementation to near-zero, leading to ongoing and significant proliferation of alarms in the system. Compounding the issue, many alarms serve no purpose. As the number of alarms increase, and their quality erodes, operators lose the ability to respond effectively, leading to potential safety, environmental or business losses.

A consistent, auditable and cyclical process of managing the underlying practices of alarm performance, review, and maintenance allows plant operations to ensure good engineering practices within the alarm system.
ISA 18.2 Lifecycle Model
The lifecycle model is an excellent method of representing the overall process of alarm system management. It is an ongoing process suitable for new or existing systems.

![ISA 18.2 Lifecycle Model Diagram](image)

Figure 3 ISA 18.2 Alarm Management Lifecycle

Stages of the Lifecycle Model

**Philosophy**
An Alarm Philosophy documents the site approach to alarm management and is a mandatory requirement. It includes the definitions, principles and details of the practices and procedures for each of the remaining life-cycle stages and provides a lasting reference to sustain an effective alarm system.
Identification
Many methods are available to determine if an alarm is required. They include Process Hazard Analysis (PHA), incident investigations, HAZOPS/CHAZOPS and alarm design/rationalization workshops. The outcome of a HAZOP might be requiring an alarm to warn the operator of an abnormal situation (e.g., high pressure). Typically, a HAZOP exercise does not consider the following: which tag is the most suitable to alarm, the ideal setting and configuration details, the potential operator workload, etc.

Rationalization
Alarm rationalization is about reconciling each individual alarm with the principles and requirements of the alarm philosophy. It is important that relevant data for each alarm is documented to support the other stages of the life cycle. This includes the alarm description, settings, causes of an alarm, the consequence of no action, the required operator action, response time, consequence rating, etc. Alarm priority is determined from a matrix of the consequence severity and response time. This matrix is defined by the alarm philosophy.

Design
The design phase includes the alarm’s basic DCS/PLC configuration, Human Machine Interface (HMI) and any advanced methods of alarm management.

Implementation & Training
This stage involves other activities required to put the alarm into service. It includes testing alarm system functions and relevant training for the operator and other personnel.

Operation
In this stage the alarm is in service and reporting abnormal conditions to the operator.

Maintenance
Process measurement instruments, final control elements and control systems all require periodic/predictive maintenance to ensure their reliable operation. This is critical to ensure the alarm system’s ongoing performance.

Monitoring & Assessment
This stage includes the periodic collection and analysis of data from alarms. Without monitoring it is virtually impossible to maintain an effective alarm system. Assessments should be done frequently (daily or weekly) and is the primary method for determining problems such as nuisance alarms, stale alarms and alarm floods.

Management of Change
Management of change is a critical stage that helps ensure the alarm system’s ongoing integrity. It needs to be a structured process of approval and authorization for any additions, modification and deletions of system alarms.
Audit
A periodic audit of the alarm system and the processes detailed in the alarm philosophy may determine the need to modify processes, the philosophy, the design, etc.

Integration with the Control System
For most companies with a plant (and control system) already running, an audit is a good way to determine how they compare to industry benchmarks. Typically, a plant’s current performance is measured against guidelines such as those found in the EEMUA 191, which makes recommendations around key performance indicators, such as:

- Average Alarm Rate – less than 1 per 10 minutes
- Maximum Alarm rate - less than 10 in a 10-minute period following a major incident.
- Percentage of time alarm rates are outside acceptable targets – less than 1%

During the rationalization, design and implementation stages of the alarm management lifecycle, the control system plays a major role determining how easily and effectively the alarm management program can be implemented.

Rationalization, in addition to determining whether an alarm should or should not exist, usually means populating a large database with all the information associated with each alarm.

Most of this information is gathered from the control system and manipulated in spreadsheet or database tools, but ideally can then be reloaded to the control system so it can be accessed by the operator. Tools like Honeywell’s Alarm Configuration Manager support the rationalization process, but also provide information directly to the operator so all details associated with an alarm can be seen via the Experion operator console.

Some modern alarm systems include clustering alarms by equipment and time. So now it is possible to match alarm patterns generated simultaneously or at a consistent time delay after the initial alarms.

Some other features of a modern control system are:

- Alarm Shelving
- Alarm Reports, Filtering, Comments, etc.
- Alarm + Continuous Trending
- Alarm Metrics Trend
The control system is also critical in the use of alarms during operation. Even after rationalizing the alarm database, it is still possible to get excessive alarms during a major plant incident. To control alarm floods, some control systems include dynamic alarm suppression, used to capture the critical alarm event, the root cause alarm and then suppress all subsequent alarms that are triggered. This ensures the operator can determine the event’s real cause and what they need to focus on. This is done by configuring alarms that can get suppressed in the event other alarms are triggered. At the same time, all alarms are still accessible if the operator wants to see them. Displays should be available so the operator will know which alarms belong to which groups and which are set to be suppressed by other alarms.

Concerning alarms and alarm management, fertilizer plants are the same as other process industrial plants in the need to address the way alarms are handled. One North American fertilizer company has been implementing Honeywell’s Advanced Alarm Management Solution Suite including the Alarm Configuration Management (ACM) application. In an exhaustive process, the company’s staff reviewed 44000 actual and potential alarm points across their Ammonia, Urea and Nitric Acid plants. Their goal was to reduce the total number of alarms that an operator had to deal with and in particular to reduce alarm floods during a process upset. As an example of the rationalization process, they determined that if there was no additional action for an operator to take when a HH alarm was triggered (after the H alarm had been triggered), there was no point in keeping the HH alarm. As a result of the rationalization, the company found 7000 alarm points that need to be modified which they are currently handling through their Management of Change procedures. One aspect they believe will really assist the operator is the ability to display all the ACM information on the operator console.
Operator Training Simulators
As mentioned, a 1996 study estimated that over $20-billion per year is lost in the process industry due to abnormal situations, and of these losses, about 40% are attributable to human error. Most commonly, the human errors were due to inadequate procedures, a procedure(s) not being followed or an incorrect action taken. Given this, it is critical that in the event of an incident, the operator can quickly identify the problem, knows what the correct response is and can execute it in a timely manner.

Operator training simulators have been around for almost 30 years and are most commonly used in association with a Greenfield commissioning project. Justifying the purchase of an operator training simulator is a risk management decision based on the idea that avoiding a few days’ delay in the startup of a new plant will easily pay for the simulator.

However, for existing plants, training simulators have not been so widely adopted on the basis that these plants have experienced operators who don’t need a simulator. Recently, due a number of factors, companies are rethinking that approach. In mature regions, older, more experienced operators are retiring and new personnel are not getting adequate training, while in regions with high growth, companies are seeing high turnover with staff moving on to new plants that may be offering higher pay.

There are a number of different types of training simulators available, but the one that best supports improved operator efficiency is the high-fidelity custom dynamic training simulator. A high-fidelity custom simulator is built to most closely match the plant that it represents and can be connected to the actual DCS that is being used (or will be used) with identical graphics and control strategies. Key features of a best-in-class training simulator include:

- A model-based simulation of the plant that incorporates all major equipment in the plant and has first-principle reaction models that accurately respond dynamically to input changes.
- Correctly models the plant behavior during startup and shutdown.
- Incorporation of all regulatory control schemes, sequence logic, graphics and alarms to be found on the live system.
- Incorporation of specific training scenarios that allow the instructor to test the response of operators to critical, abnormal situations that have been seen or are anticipated as potential upsets.
- Allowing for the instructor to trigger equipment malfunctions to occur both during normal operation and startup and shutdown.
- Include testing and scoring so operators and instructors can track performance and satisfy requirements for operator certification.

In fact, a good training simulator can be used for more than just training operators. Coupled with the automation platform, it can be used to test new control strategies, try out new procedures on the plant or even examine the impact of process modifications.
In the case of fertilizer plants, it might be said that there are many ammonia and urea plants around the world, and the production process is pretty well understood – so maybe a training simulator is not necessary. However, not only are there always new operators to train, some features of nitrogen-based fertilizer plants make them ideal for training simulators. For example, ammonia and urea plants typically run for 2-to-4 years between planned shutdowns, so operators may be unfamiliar with some startup and shutdown activities. In the case of ammonia plants, the integrated heat recovery and process recirculation makes startup long and complicated. A typical startup can take between 36 and 48 hours and requires multiple process sections to start in parallel. The operator must monitor the status of many variables, and downstream process conditions affect upstream operations. Furthermore, an integrated ammonia/urea/utility plant is even more complicated since there is dynamic interaction between the units and the utilities (e.g., CO₂ and ammonia from the ammonia plant to the urea plant). In these cases, multiple integrated training simulators allow operators of different units to simultaneously train during a combined startup, sharing utilities and intermediates.

The ammonia training simulator incorporates reaction kinetics for the reformer and secondary reformer as well as the ammonia converter. It also includes typical scenarios to test operators, such as:

- Shutdown
- Startup
- Loss of Feed

Agrium in Canada looked at purchasing an operator training simulator for one of their existing Ammonia plants in the early 2000’s and began considering how to justify such an investment. The company recognized that incident avoidance is sometimes considered a soft benefit which makes it hard to attract real investment funding. So they looked at 10 years of data and, in particular, all of the incidents and outage information during that period. They found that the plant performance generally improved following a turnaround and then gradually declined year-over-year until the next turnaround. Further analysis showed that one reason for this was that operators were experiencing multiple difficulties and incidents restarting the unit following a turnaround and became more familiar with how to respond during startups/shutdowns and incidents immediately after a turnaround. However, as time progressed, operators became less familiar and began making more mistakes until the next turnaround began. Conclusion: The cause in both cases was the lack of practice around startups/shutdowns and incidents.

Agrium justified the training simulator project by anticipating that it would cut in half incidents directly caused by operators and that typical startup time would fall by 10%.

Agrium embarked on a complete structured training program and assigned a dedicated Training Simulator owner to roll-out and train the operators. They tailored the program to accommodate not only existing operators but also to train new operators.
Following completion of the training program, which included the purchase and development of a high-fidelity customer training simulator from Honeywell, two new operators completed the program and were certified in nine months instead of the typical 24 months. In addition, six experienced operators completed a refresher course that focused on startups and shutdowns ahead of an upcoming turnaround. As a result, there were no incidents during shutdown or re-start and shift supervisors said it was the smoothest startup in memory.

Agrium has since moved on to purchasing and developing a training simulator for its Urea plant.

![Figure 5 Example of OTS instructor Panel](image)

**Advanced Control Solutions**

Well-trained operators know how to respond during plant upsets and can keep the plant running smoothly during normal operations. However, to maximize the efficiency of the process, plants must be pushed to their current limits in a safe and repeatable manner. This usually requires applications such as advanced control to support the operator.

To improve a plant’s operational efficiency, consistent product quality must first be achieved and then drive for improvement. If economics demand increased production, advanced process control and optimization applications can work to remove bottlenecks in reactors, reformers, absorption towers, etc. At other times, those same advanced control applications can improve the production yields or reduce energy consumption - for example, tighter reformer control to minimize methane slip.
Advanced Process Control (APC) and Optimization solutions are typically implemented over the top of the base DCS and rely on the underlying regulatory controls to be stable, robust and repeatable. Hence, a layered approach that provides a solid regulatory control platform where base controls are well tuned, valves respond without stickiness or hysteresis is the best way to implement a scalable optimization solution matching plant needs.

Multivariable model predictive control strategies, such as Honeywell’s Profit Controller, are well-suited for unit-based solutions such as steam reforming control or quality control around the ammonia converter. Above this, optimization solutions can link several multivariable controllers to cover a broader process area stretching across multiple units, like the ammonia and urea plants. Combined with a first principles process model, this optimization level can provide non-linear dynamic optimization for large fertilizer plants.

These types of advanced control and optimization solutions have been widely used in fertilizer plants as they can be adjusted using economic factors to switch from maximizing production to minimizing energy while meeting a fixed production target.

In ammonia plants, advanced control strategies are divided into a couple of integrated controllers: one around the feed and reformer, the other around the synthesis loop and recovery section.

The objective of the reformer controller is to:

- Stabilize reformer firing
- Maintain the steam-to-carbon ratio
- Control methane slip from the reformer
- Minimize excess O₂ in the reformer outlet
- Control CO shift converter reaction
- Respect limits such as furnace firing limits, air compressor limits, and feed limits

The objective of the synthesis loop controller is to:

- Stabilize H₂ to N₂ ratio to the synthesis loop
- Maintain the inerts’ concentration level in the synthesis loop
- Control the converter temperature and pressure
- Maintain quality at ammonia recovery column
- Respect limits of refrigeration circuit, steam turbines, etc.

BASF in Germany was looking to increase process efficiency and increase production rates at its Braun designed ammonia plant and chose to implement a multivariable control strategy using Honeywell’s Profit Controller technology. They used the advanced controls to increase
production by 2.5%, maximizing against ambient conditions that created constraints in the gas turbine, the aMDEA coolers on the CO₂ wash column and the exhaust fan on the primary reformer. The project payback was just under six months.

Tata Brabala implemented advanced control on their Urea plant to stabilize the operation and reduce energy consumption. The plant has two parallel trains with a high degree of interaction and they noticed that there was a large difference in dynamic response between the front and the back end of the process. CO₂ and ammonia come directly from the upstream ammonia plant so Tata wanted to control CO₂ flow fluctuations, stabilize the compressors’ operations and reduce the consumption of high pressure steam.

The project covered the CO₂ compressors, the two high and medium pressure plant sections, the low pressure and vacuum sections and the process condensate treatment sections.

The objective of the CO₂ Compressor controller was to:

- Maximize CO₂ suction pressure to minimize turbine HP steam consumption
- Maintain safe operation of the feed compressor and stabilize CO₂ feed to the reactors
- Honor all compressor constraints, including anti-surge, minimum CO₂ flow, minimum turbine speed, etc.

The objective of the Reaction section controller was to:

- Control carbamate reaction by controlling the NH₃:CO₂ ratio
- Maximize urea synthesis reaction by controlling reaction conditions
- Maximize product recovery in the HP and MP sections
- Reduce energy by minimizing recycle steam to reactor
- Control system pressure to reduce losses through venting

The objective of the LP, VP and Condensate treatment section controller was to:

- Maintain condensate quality (conductivity) in condensate stripper
- Maintain urea quality (biuret content) at vacuum section outlet.
- Minimize vent openings

The controllers across the two trains were then coordinated with a master optimizer aimed at stabilizing the operation, minimizing the carbamate in urea solution, minimizing energy consumption across the complex and balancing the system’s water content.
As a result, the project reduced energy consumption by 1.3%, controlled the residual urea content in the environment and also stabilized the plant’s operation and decoupled the interaction between the two urea trains.

**MES Solutions – Monitoring and Reporting**

Another aspect of improving operational efficiency is assuring that the plant operation is meeting the requirements of the business as a whole. A full fertilizer complex can make a number of end products, such as Ammonia; Urea; Ammonium Nitrate; Ammonium Sulphate; Urea-Ammonium Nitrate (UAN) solution – all packaged and delivered in different ways. So inventory levels have to be balanced with the ability to meet customer requirements and information has to flow quickly and freely between the business and plant operation. It is important to decide quickly whether the plant can profitably produce a newly submitted order and how that will impact the rest of the production schedule.

To do that means the price of feedstock, plant availability and the cost of operations must be understood and quickly updated if plant conditions change. A unit shutdown or drop-off in yield caused by a process upset must be readily incorporated into a new production schedule.

To achieve this tight connection, management must have a good understanding of their plants’ operational capability. Manufacturing Execution Systems (MES) collect data from the DCS via a plant-wide historian and enable the creation of a broad range of key performance indicators that can help assess operational performance and where improvements are possible.

These days, many MES solutions platforms use a common architecture or framework comprised of a set of components used to create different applications that can readily connect and communicate with each other. These common framework components include:

- Data Acquisition Components – e.g., APIs, RDIs, OPC UA
- Security Components
- Semantic Model and Context Engine Definition
- Data Model and Service Creation
- Calculation Engines
- Reporting Functions
- UI or Visualization Tools for the Desktop
- Industry Web Parts and Portal Software
- Connections to ERP Systems
A development team can then create individual solution components or applications based upon the common framework. Typical applications include:

- Electronic Logbooks for Operators
- High Volume Simple Monitoring
- Electronic Operator instructions
- Production Quality Reporting
- Production Material Balancing
- Production Performance Analytical tools
- Production Planning and Scheduling

The individual solution components can then be configured and assembled to produce a specific solution for a specific customer. There is a broad set of solutions commonly used in fertilizer plants, including:

- Fertilizer Operations and Production Reporting Solutions
- Energy Dashboards for Monitoring and Reporting
- Environmental Compliance Monitoring and Reporting

More importantly, by using common components and tools such as semantic modelling, it is possible to connect data from different applications from different databases that may already exist on the plant. For customers that already have some point solutions, they can now create a solution like an Operations Dashboard from a combination of new applications and existing ones that are already running on different platforms.

An example of how this has been done at Honeywell is shown below.

![Figure 7 MES Example – Intuition Example](image-url)
Honeywell’s Intuition Executive platform which was released in May 2012 is designed for enterprise-wide information integration and real-time visualization. It moves beyond simple data access and display to providing context. It is capable of harnessing data from everywhere and delivering it to everyone to enable collaboration across business units and operational efficiency.

Intuition Executive can connect many data sources (including DCS, historians, applications, MES and ERP systems), while establishing context using tools to describe how the data from the different sources relates to each other. Using various calculation and event solution components, it analyzes & monitors the process, and triggers the right actions in the right circumstances.

The Intuition Executive user interface uses common web parts in a Microsoft® SharePoint® portal to display graphics, trends, tree maps, lists and discussion boards.

Qatar Fertilizer Company (QAFCO) needed to keep up with its rapid growth and update its business manufacturing systems to stay ahead of the times in a challenging and competitive environment. The existing systems developed in-house were no longer viable and the volume of manual data input was enormous, compromising both time and quality of data collected. QAFCO turned to Honeywell and its integrated Manufacturing Execution Solution (MES) to help eliminate manual procedures, thus ensuring accuracy and enabling better decision making.

The solution was built to span five of QAFCO’s Ammonia and Urea plants and was integrated with both the Experion automation platform and other third-party software. The infrastructure components used for the solution were:

- Historian – Uniformanace PHD
- Plant Reference Model and Data Processing Platform
- Visualization – Workcenter

The solution components implemented were:

- Electrical Energy Balance
- Natural Gas Balance
- Plant Production Balance
- Emissions Monitoring and Reporting
- Production Loss Reporting
- Plant Performance Analysis
- Production Costing

As a result, QAFCO realized the following benefits:
• Easy access to unified data, enabling quicker operational and business decisions
• Automated work process and collated and integrated quality data, eliminating the need for manual effort
• Readily available reports loaded with quality data, such as Key Performance Indicators, cost or inventory information
• Common plant model that ensured data consistency and accuracy
• PIMS/LIMS solution, providing a strong foundation to build and sustain its manufacturing competitiveness

Conclusion
Modern automation systems are now capable of much more than just basic regulatory control of the process plant. They act as the operator’s window into the plant and have more of a dashboard capability that not only enable control of the unit, but also how the plant connects with other systems, such as the ESD and the Fire-and-Gas or Security systems. The automation platform can capture the experience of your best operators and offload some traditional operator tasks by automating previously manual procedures. At the same time, it can push the plant to operational limits, maximizing yields and minimizing cost of production. Modern automation platforms also provide a two-way communication channel between the control room and the boardroom, improving the flow of information, such as plant availability and capacity, to allow for better manufacturing decisions as business conditions change.

More Information
For more information on Honeywell’s Fertilizer solutions, visit our website at www.honeywellprocess.com or contact your Honeywell account manager.

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Energy Conservation Study for Ammonia Urea Complex

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Abstract:

An energy conservation study was undertaken on the FERTIL ammonia and urea plants and related facilities at Ruwais, U.A.E. The plants on site are approaching 30 years of age and are relatively energy inefficient when compared with the best modern designs.

The current configuration of plant and equipment plus a set of plant operating data over a significant period of operation was used to construct outline energy maps on each main process area. Using these energy maps ABB employed a structured process to identify and pre-evaluate potential energy saving opportunities on the site.

Around 15 energy savings opportunities were identified, ranging from operational changes to minor modifications requiring local project management and ultimately to several significant modifications which would require plant revamp projects. In addition around 10 other improvement areas (including some “quick wins”) were identified.

Potential energy savings opportunities were ranked according to financial attractiveness, based on very provisional “order of cost” estimates. This provided FERTIL with a preliminary route map to consider energy improvement in a phased manner. The business is now further evaluating a number of opportunities as early projects for implementation.

In addition to the technical energy opportunity identification study, an assessment was conducted of energy practices and behaviours within the FERTIL organization. The business is now using some of the findings of this assessment to put in place an improved framework for energy management in FERTIL.
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1. **Background on FERTIL plants at Ruwais**

Ruwais Fertilizer Industries (FERTIL) was established in 1980, as a joint venture between Abu Dhabi National Oil Company (ADNOC) and Total Fina Elf. The Complex comprises Ammonia and Urea plants, plus related Utilities & Product Handling / Shipping & Storage facilities. Construction of the plant began in November 1980 and first production was in early 1984. The location of the complex is shown in Fig 1.

The main raw material is associated dry gas, piped from onshore oil fields 150 Km from the plant. Desalinated water, electricity and seawater are supplied by the adjacent Ruwais Utility Plant, supplemented by FERTIL's own emergency power generators and water tanks.

The Ammonia plant process technology is that of Haldor Topsoe. The original name plate capacity of 1,000 MTPD has been progressively increased to 1,300 MTPD. The Urea plant is a Stamicarbon unit of original capacity 1,500 MTPD which was progressively debottlenecked to 1800 MTPD and more recently has been revamped by conversion from prilled to granulated product and further uprated via the Urea Casale process to 2500 MTPD. A CO2 recovery Unit of 400 MTPD unit, using ammonia plant flue gas as feedstock was installed to supply the additional CO2 required for extra capacity of Urea.

No formal debottlenecking of the Ammonia plant has been carried out - the improvements in output are the result of a progressive series of in-house studies/projects implemented from time to time through the years.

FERTIL has a commitment to develop and use energy resources more efficiently in providing products and services and has identified energy management as cornerstone in maximizing operation efficiency, optimizing cost and minimizing harmful impact on the environment. The business therefore commissioned ABB to conduct a comprehensive Energy Conservation study, with the objective of identifying ways to improve the use of energy resources. The facilities covered by the study are shown in Fig 2.

2. **Objective of the energy conservation study**

The prime objective of the Energy Management Strategic Study was to identify practical ways to improve energy efficiency. The remit and methodology for the study included initial assessment to identify the magnitude of energy flows and transformations within the on-site process systems. This would be done by

i) Conducting a review of documents and existing data on energy usage & producing an interim report,

ii) Completing a site survey at Ruwais to confirm / develop interim findings, and

iii) Developing an Energy Balance and establishing an Energy Baseline for the site and main plants.

The above phases were then to be used to explore potential energy savings and these would then be presented to the business. Additionally FERTIL required a high-level assessment of the organization’s capability for energy management and reduction. This part of the study would comprise

iv) Making recommendations relating to long term corporate energy objectives, strategy and energy KPIs.

v) Establishing a unified methodology and related criteria for monitoring and reporting energy performance.

3. **ABB Model for Assessment of Industrial Energy Efficiency**

The ABB Global Consulting Industrial Energy Efficiency methodology normally comprises three stages, Opportunity Identification, Energy Management Master Plan and Implementation. This is illustrated in Fig 3. The aim of the assessment process as a whole is to identify, develop and implement a programme of energy efficiency improvements which deliver real savings, with the first two steps of the methodology delivering precisely the information needed to enable a successful implementation of the final step.
3.1. Industrial Energy Efficiency Model as applied to the FERTIL study

The first phase (Opportunity Identification) aims to identify specific opportunities to deliver improvements, by confirming how and where energy is used, by identifying areas of inefficiency and by comparing current performance with established best practice.

In the case of the FERTIL study, a distinctive feature was the fact that quite a lot of “up front” assessment was done in terms of reviewing and analysing key data provided in advance by FERTIL - this assessment was conducted ahead of the site visit enabling

- Provisional energy maps to be developed for each main plant area (ammonia and urea)
- Early consideration of likely areas for energy conservation well in advance of the visit to site
- An interim report to be produced

This enabled the study team more time to focus on key technical areas in sufficient depth during the site phase. This was a much more appropriate approach for an Opportunity Identification study on a complex chemical process like production of ammonia and urea, than the normal reliance on most opportunity identification being largely conducted during the site visit phase.

Although this study was essentially an Opportunity Identification study, some elements of the next stage (Master Plan) were also required by FERTIL and these were accordingly addressed. Outline schemes for energy improvements were defined and very rough order of cost estimates produced to facilitate some prioritisation by the business in addressing follow-up actions to achieve the Energy Roadmap.

3.2. Energy Maps

A key tool employed with the OI phase of an energy study is the Energy Map. A simplified example of such a map is shown in Fig 4. This technique provides a simpler and clearer device to enable major energy flows and conversions to be depicted than some other conventionally accepted techniques – such as Sankey diagrams. The latter are really more of a pictorial device to indicate relative magnitudes of energy flows into, through and out of a process. Pie charts can also be used to achieve this and indeed were also employed in this study.

The energy map depicts main energy flows numerically, thereby allowing preliminary analysis to take place around efficiencies, losses etc. Energy flows are normally shown in energy units (so in the example they are shown in MWh, but this could alternatively be in other energy units, such as Therms or GJ. Sometimes “equivalent” units may also be shown (such as tonnes/hr of steam).

The boxes depict key energy transformations within the process – such as boilers, furnaces, condensers, steam turbines, compressors and heat recovery systems.

4. Energy maps developed for FERTIL complex at Ruwais

4.1. Energy Balance for Overall Ruwais Site Operations

Based on analysis of the plant data collected prior to and during the site visit and taking account of further detailed discussions with FERTIL technical and operational staff, ABB developed high-level energy maps for the major energy consuming operations at Ruwais.

These high level energy maps were prepared in order to assist in a visual understanding of the major energy flows on site, such as the steam system and to help to understand operation and energy consumption within the major processes/systems.

The energy maps were built on the basis of live, simplified energy balance models for energy transformation stages within the process. These energy balances (constructed in Excel format) took account of relevant process thermodynamics – such as thermal efficiencies of key energy conversion stages (like boilers and condensers) and isentropic efficiencies of prime movers (such as compressors and turbines).

The energy maps were therefore a key tool to facilitate identification of potential energy reduction opportunities during the study. However in the future these maps can be maintained, developed and used as a basis for consolidating and measuring improved energy efficiency of site operation.
4.2. Energy maps for Ammonia Plant and Urea Plant

The energy maps developed for the FERTIL1 Ammonia and Urea plants are illustrated in Figs 5 and 6. It should be noted that considerable adjustment and reconciliation was required to “balance” these maps, due to the relative absence of energy metering on site.

4.3. Energy comparison for old and new NH3 technologies

The diagram in Fig 7 illustrates the relative energy usages of the original ammonia plant at Ruwais (FERTIL1, described as “Old Technology”) and the order of energy consumption to be expected from a modern state-of-the-art ammonia plant with a high degree of process integration (shown as “New Technology”, likely to be representative of the new plant currently under construction at Ruwais (FERTIL2).

As can be seen by inspection of these diagrams, the main areas of energy inefficiency on FERTIL 1 plant can be attributed to the fact that the plant contains numerous relatively inefficient drives (including many pass-out steam turbines) and also has generally lower combustion efficiencies in fired equipment. The basic structure of the site steam system also contributes to the lower thermodynamic efficiency (see below).

Hence the “fuel” element of gas consumption is very much higher in the older FERTIL ammonia plant at Ruwais. The “feed” element of gas consumption is very similar to modern day plants (BAT basis).

4.4. Overview of steam system on FERTIL 1

A simplified representation of the site steam system is illustrated in Fig 8. A number of inherent thermodynamic inefficiencies exist as a result of the basic structure of the steam system as originally designed and there are also additional adverse energy impacts which have resulted from progressive plant de-bottlenecking phases.

The basic structure of the installed steam system places limitations on the ultimate thermodynamic efficiency which can be achieved, for example:

- Fundamentally the 100 barg cycle (HP steam level) is more thermodynamically efficient than the 40 barg cycle (MP steam level). However many of the steam turbine drives are based on the latter.
- Many of the installed steam turbines on small or medium-sized drives are of pass-out design and oversized for the duty, hence inherently inefficient. This was less of an issue at the time of original plant design.
- The overall system lacks sufficient flexibility (to enable optimization at site level) via a suitable balancing mechanism.

The overall ammonia and urea processes are currently being run very successfully for output and reliability. However this has resulted in inevitable inefficiencies in terms of energy. So, for example, as the plant has been progressively de-bottlenecked process changes have been made which have given rise to inefficiencies, such as:

- MP steam is now being imported by a number of pass-out steam turbines on the Ammonia plant most probably due to turbines moving away from the original optimum duty point and operating now at lower machine efficiencies.
- Surplus LP steam is generated from pass-out turbines (ammonia & STG).
- On fairly frequent occasions surplus LP steam is being vented.
- Recent installation of a refrigeration turbine (serving the urea granulation chiller) results in significant new intermittent quantities of LP steam pass-out when this unit is operating.

As previously mentioned, there is at present insufficient steam metering to fully validate the site steam balance, far less optimise it. In addition the existing operational management structure means that in general production decisions and inputs are made locally within three separate plant areas (ammonia, urea and utilities). This naturally makes overall site optimisation difficult since there is no overview (which would be most appropriate for optimisation of overall site energy performance).
5. **Range of potential energy improvements identified**

The cascade diagram shown in Fig 9 illustrates the cumulative energy impact of the range of energy reduction opportunities identified during the study. In broad terms an ultimate energy reduction of around 5 GJ/tonne appears to be feasible if most of these ideas were implemented. It was concluded that at least another 0.5 GJ per tonne should be available from other subsequent energy savings initiatives, not yet fully defined.

Not all ideas are likely to be eventually supported by the business, given the associated payback for each opportunity (which will require more detailed analysis). The energy reduction opportunities could be grouped into separate types:

- Energy improvements achievable via relatively minor alterations in local process operation (such as optimization of boilers)
- Improvements which will require modifications which can be achieved via relatively small, locally managed works projects
- Improvements requiring major capital expenditure and large-scale plant revamps

The cumulative potential energy savings identified are shown in another way in Fig 10. This shows the range of opportunities as a road map based on representation of relative financial attractiveness of the various schemes.

Only the major and medium scale opportunities which were identified are shown in this diagram. Based on a preliminary view of energy savings and rough ‘order of costs’ around 10 of the opportunities yielded paybacks of potential interest (using criteria agreed with FERTIL for evaluating natural gas savings). Due to the preliminary nature of this assessment there is of course an error band around the savings (depicted in this diagram). As can be seen there are several relatively low cost projects which could enable “early wins” at relatively modest cost (items 1 to 6). No major or extended plant turnarounds would be required to implement these changes.

Examples of opportunities identified, with comments on ease of implementation, are summarised in the table below:

<table>
<thead>
<tr>
<th>Opportunity</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce Steam:Carbon ratio in Primary Reformer</td>
<td>Operational change with little capital cost. Would require further detailed modeling and accurate monitoring of reformer maximum tube temperature before being pursued.</td>
</tr>
<tr>
<td>Improve efficiencies of MP Boilers B-5501A/B</td>
<td>Operational change with little capital cost.</td>
</tr>
<tr>
<td>Preheat Fuel gas using surplus LP steam</td>
<td>Works project – see below.</td>
</tr>
<tr>
<td>Recycle urea process condensate as BFW make-up in MP boilers</td>
<td>Works project – see below.</td>
</tr>
<tr>
<td>Fire HRU off-gas as a fuel in the MP Boilers</td>
<td>Works project requiring further engineering definition particularly around detailed burner design and location of combustion.</td>
</tr>
<tr>
<td>Modify selected machine internals to improve efficiency</td>
<td>Works project requiring further engineering definition. Selective replacement of machine internals to restore operation to optimum duty point.</td>
</tr>
<tr>
<td>Stop using the front-end DEA desulphurisation system</td>
<td>Major revamp which could be accommodated within normal timescale for major planned TA. Further technical investigation would be required prior to implementation.</td>
</tr>
<tr>
<td>Purify Make up Gas using molecular sieves or ammonia washing</td>
<td>Major revamp. Established modification to synthesis gas loop proven elsewhere. See Ref 1. Would require extended major plant TA.</td>
</tr>
<tr>
<td>Preheat reformer combustion air via heat recovery from the reformer flue gas duct</td>
<td>Major revamp. Not trivial for side-fired reformer, but has been successfully implemented elsewhere. See Ref. 2. Would required extended major plant TA.</td>
</tr>
<tr>
<td>Convert CO₂ removal to aMDEA based system</td>
<td>Major revamp. Benfield process would be converted to amine based process employing aMDEA solvent together with vacuum flash. Already considered in a previous study conducted by plant licensors.</td>
</tr>
</tbody>
</table>
As described above several opportunities identified have significant potential. However these would require major plant turnarounds to install the modifications and these turnarounds would be extended significantly beyond the normal period of roughly 4 weeks.

For example the installation of combustion air pre-heating and modifications to convert the CO₂ removal section to an amine-based process are likely to require turnarounds lasting several months. (By comparison a similar combustion air retrofit on a plant in India is understood to have taken around 12 weeks). In view of the significant loss of production during such a revamp period, it could make sense to install more than one of these opportunities together in one large plant revamp (assuming financial acceptability).

5.1. Early opportunities being progressed

5.1.1. Fuel gas preheating

On the FERTIL1 plant natural gas is let down from the header at 23 kg/cm² to about 4.0 kg/cm² for supply to the auxiliary boiler & primary reformer furnace as fuel. The quantity of fuel NG is about 25000 NM³/Hr and the supply temperature varies from about 20°C in winter to about 45°C in summer.

At the pressure let-down stage the gas temperature drops significantly and hence external moisture condensation occurs which is a root cause of corrosion in the fuel supply lines.

In the energy study fuel NG preheating was identified as an energy-saving opportunity with the associated benefit of reducing/eliminating external corrosion of fuel lines.

FERTIL has conducted provisional assessment on the use of various low grade heat recovery options (process condensate, LP steam or by hot NG) and identified the use of surplus LP steam (3.5 kg/cm²) as the best source for preheating the fuel NG.

This scheme will utilise excess LP steam in the plant to preheat the fuel gas prior introducing to both primary reformer and auxiliary boiler. The existing system does not have preheating feature on the fuel skid. There is excess LP steam generated on site currently which is either vented or ended up in the condensate stripper.

The benefit of this scheme is the reduction of fuel gas consumption as a result of raising the flame temperature by preheating the fuel gas. The major modification needed for this scope is a new heat exchanger, retrofitting the burner to cope with higher temperature fuel gas, retrofit the fuel gas letdown station and new pipework installation.

5.1.2. Recycle of urea process condensate to the ammonia plant

Currently process condensate leaving the urea process is rejected to drain. This condensate typically contains very low levels of ammonia (5 ppm) and urea (10 ppm). This water could be recycled for use as BFW in the MP boilers. This practice has already been successfully adopted in a number of other urea plants.

The energy savings associated with this scheme are upstream (within the associated GUP), and represent reduced upstream energy cost in the production of desalinated water (which directly contributes to a reduction in the “rolled-up” energy cost of producing ammonia.

To enable this opportunity to be progressed, it was recommended that some initial tests should be conducted to validate the “spot” impurity analysis quoted during discussions on site. The apparent levels of impurity are very low, but if there are any remaining concerns about water quality or even just a desire to be “doubly protected”, the recovered condensate could be passed through a carbon filter (the correct grade of carbon would need to be used) or other means used to mitigate any risk.


In parallel with the technical assessment on potential energy reduction, ABB conducted an assessment of energy practices and capability at FERTIL.

The assessment involved a comprehensive gap analysis of current practices, procedures, policies etc. in use on the Ruwais Site and across the wider FERTIL Organisation against a benchmark standard for excellence in Energy Management.

The assessment process used the draft ISO50001 Standard for Energy Management Systems as the benchmark for excellence in Energy Management. See Figs 11 and 12.
An assessment tool was employed in which 17 elements were examined in detail for the FERTIL organisation – assessment was conducted via a combination of one-to-one interviews and review of existing internal policy documents and guidance. This is shown in Fig 13. This methodology was based on a modified version of a standard ABB assessment tool.

Main findings from the behaviours and practices assessment were:

1. FERTIL should establish a management framework (with high level support) to drive forward the policy issues
2. An active Energy Management Plan should be instituted
3. An on-going communication and awareness program on energy efficiency should be promoted with FERTIL.

7. Potential Future benchmarked energy position for FERTIL1 plant

During the past 10 years IFA has conducted several benchmarking surveys on a large number of ammonia plants in conjunction with Plant Surveys International (PSI).

One of the most recent of these surveys was conducted in 2006-2007 and covered a total of 93 ammonia plants across 33 countries. See Ref 3. The plot in Fig 16 shows Net Energy Efficiency in terms of GJ/MT for these plants.

As can be seen from Fig 14, the FERTIL1 plant was assessed to be around the middle of the 4th quartile of plants included in the survey. Total feed and fuel reported to PSI at the time of the survey accounted for an overall energy consumption of 40.1 GJ/MT, adjusted to 42.6 GJ/MT to account for other energy imports.

The potential impact of this programme on FERTIL1 benchmarked position is illustrated in the diagram above. It should be noted that the above profile represents the global position about 5 years ago and has probably changed to a lower energy position since then.

8. Main Findings from Study

1. FERTIL 1 is currently in the 4th quartile in terms of energy for ammonia plants (based on the 2006-7 IFA survey).
2. Based on the current energy conservation study and knowledge of successful energy savings projects implemented elsewhere, savings of 4-6 GJ/MT ought to be achievable, which would put the plant into the 2nd quartile.
3. Some key enabling changes will be required, in particular the installation of a significant range of energy metering devices covering both thermal energy and electricity metering.
4. The largest energy savings schemes will require significant capital.
   4.1. Modifications with greatest impact on energy reduction would require extended plant revamps.
   4.2. However the technical feasibility of the suggested modifications is high, since most are generic and have been successfully implemented on other ammonia plants around the world.
   4.3. Other suggested areas of energy improvement (including smaller opportunities and best practice recommendations) can be handled by the plant team at Ruwais.
5. At strategic level the FERTIL business has scope to address and improve the organisational aspects of energy management for the business, linked to a clear energy policy. Such strategic focus will require a programme of awareness at all levels and some adjustment in operational culture.
9. **Conclusions and Way Forward**

1. As a result of this study FERTIL identified two credible energy conservation opportunities to be studied for implementation in 2012. These are currently being progressed.
2. The other opportunities will be planned for implementation after consulting relevant process licensors for more detailed technical assessments.
3. The business support department will take the necessary steps for energy management standard ISO-50001 compatibility.
4. The FERTIL Production Flexibility program committee (PROFLEX) has addressed energy savings as one of the main committee tasks.
5. The PROFLEX committee has issued the following documents related to energy management:

   FERTIL has declared the following Energy policy with associated detailed guidelines for implementation of the policy:

   “FERTIL, a member of ADNOC group of Companies is committed to conserve scarce and non-renewable energy resources throughout the plant/equipments in order to make the company one of the most modern, energy efficient and cost effective manufacturing facilities by setting and reviewing the objectives and targets through Energy Conservation Management Plan”.

   FERTIL is committed to the following objectives:

   - Optimize the consumption of resources, viz., raw material, utilities, fuel and electrical energy and using possible alternate and renewable energy sources.
   - Adopt proven, Energy Efficient and Eco-Friendly Technologies during technology selection by providing a structured framework for energy optimization for new Developments and Projects.
   - Review and validation of final design of new Developments and Projects to confirm objectives of minimization of use of energy are met.
   - Establish monitoring parameters for operating phase of new Projects to ensure design objectives are achieved.
   - Monitor Specific Energy Consumption and conduct periodic review/audit and benchmarking of existing facilities in operation.
   - Identify the areas for improvement by carrying out Energy study and planning accordingly for the gray areas starting from High to Low level sources of energy conservation.
   - Prepare Energy Key Performance Indices (KPI’s) as well as cost of input per MT of Product and its awareness among employees.
   - Develop awareness for energy conservation amongst Employees, Contractor’s Staff and Related Agencies and motivate them to draw up energy conservation proposals.
   - Recover Waste heat, Effluent and minimize waste by way of recycling and reuse.
   - Improve capacity utilization and on stream hours through reliability centered maintenance practices.

   An Energy Management Plan is currently being developed by the business to deliver the above policy.
10. References

1. Success Story of Implementation of Energy Saving Project at IFFCO Phulpur Unit, M. Rajashekharaiah, Y. Narula, I.C. Jha, R. Maiti


Figures

Fig 1 – FERTIL Ruwais site location
Fig 2 – FERTIL Assets within scope of energy study
Fig 3 – ABB Industrial Energy Efficiency Model as applied to FERTIL
Fig 4 – Example of Simplified Energy Map
Fig 5 – Energy map for Ammonia Plant
Fig 6 – Energy map for Urea Plant
Fig 7 – Energy comparison for old and new NH₃ technologies
Fig 8 – Overview of steam system on FERTIL 1
Fig 9 – Range of potential energy improvements identified
Fig 10 – Cumulative energy savings identified
Fig 11 – Framework for Continuous Improvement in Energy Management (ISO 50,001)
Fig 12 – Assessed Position for FERTIL
Fig 13 – Energy Behaviours and Practices Assessment
Fig 14 – Energy Benchmarked Position for FERTIL 1 Plant
Fig 1 – FERTIL Ruwais site location

Fig 2 – FERTIL Assets within scope of energy study
Fig 3 – ABB Industrial Energy Efficiency Model as applied to FERTIL

Phase 1

- Initial Status
  - Data Collection & Historical Review
  - Review & assess existing plant facilities & energy use
  - Review existing energy consumption & forecast for future
  - Early view of potential opportunities and review of past studies
  - Preparation of energy metrics and plans for site visit in Phase 2

Phase 2

- Opportunity Identification
  - “Find the Savings”
    - On-site Assessment
    - Recommendations
    - Technology & Control
    - Monitoring & Targeting
    - Behaviours & Practices

- Master Plan
  - “Develop the Solution”
    - Solution Options
    - Rough Cost Estimates
    - Payback & ROI
    - Project Specification
    - Revamp projects recommendations

- Implementation
  - “Gain the Benefits”
    - ABB Technology
    - ABB Services
    - Solution Implementation
    - Measure Success
    - Quantify Benefits

Phase 3

Energy Roadmap

Fig 4 – Example of Simplified Energy Map

Energy flows: MWh unless otherwise stated

- Gas: 349.7
  - Furnace 1: 125.7 MWh
  - Furnace 2: 60.5 MWh
  - Furnace 3: 14.6 MWh
  - Flue gas: 44.8 MWh

- Electricity: 48.3 MWh
  - Boiler: 224.0 MWh
  - Steam Turbine: 15.0 MWh
  - Steam user 1: 46.8 MWh
  - Steam user 2: 18.4 MWh
  - Steam user 3: 12.8 MWh
  - Steam user 4: 5.2 MWh
  - To condenser: 96.0 MWh

- Site boundary

ABB Global Consulting & Ruwais Fertilisers (FERTIL)
Fig 5 – Energy map for Ammonia Plant

Fig 6 – Energy map for Urea Plant
Fig 7 – Energy comparison for old and new NH3 technologies

Most of the difference is attributable to low efficiency use of steam in the original installed technology

Total Energy = 39.23 GJ/MT
Old Technology
Flue Gas, 2.02 GJ/MT
Back Pressure Turbine, 4.63 GJ/MT
Condensing Turbine, 5.50 GJ/MT
Steam Consumption for Process, 5.44 GJ/MT
Gas Consumption for Process, 21.64 GJ/MT

New Technology
Gas Consumption for Machines and Other Losses, 7.00 GJ/MT
Gas Consumption for Process, 21.50 GJ/MT
Total Energy = 28.5 GJ/MT

Fig 8 - Overview of steam system on FERTIL 1

High Pressure Steam From Ammonia Plant

Condensing Turbines

Ammonia Plant Process Steam Condensers

Urea Plant Process Steam Condensers

CDR Unit Granulation Unit

Dehazer V-1801 V-6501

C-5401 Process Condens Super

Ammonia Condensers

Urea Condensers

Urea C-3706

Utility Boiler B-5501A/B
Fig 9 – Range of potential energy improvements identified

![FERTIL Potential Energy Improvements](image)

Fig 10 – Cumulative energy savings identified

![Cumulative energy savings identified](image)
Fig 11 – Framework for Continuous Improvement in Energy Management (ISO 50,001)

Many elements of the continuous improvement framework already exist…..

Fig 12 – Assessed Position for FERTIL

Some work is needed to develop an aligned Energy Policy, put in place the necessary business planning activities and robust monitoring of performance metrics.
Fig 13 – Energy Behaviours and Practices Assessment

Fig 14 – Energy Benchmarked Position for FERTIL 1 Plant

IFA Benchmarked Ammonia Plants (2006-2007 survey)

Potential impact of implementation of identified schemes on benchmarked position of FERTIL1
Catalysing profit margin with LK-853 FENCE™: A new generation of Topsøe low methanol LTS catalyst

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Catalysing profit margin with LK-853 FENCE™

A new generation of Topsøe low methanol LTS catalyst

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Abstract

In an increasingly competitive market, catalyst selection is of significant importance when it comes to optimising performance in ammonia and hydrogen plants. By installing high performance catalysts, it is possible to improve the overall plant efficiency and ensure optimal feedstock utilisation, thereby increasing profit margin. Ground-breaking research within the area of catalysts for ammonia and hydrogen production has resulted in a new low methanol LTS catalyst, LK-853 FENCE™, which has now been commercialised. This paper will highlight the developmental work, the unique catalyst features and discuss how ammonia and hydrogen producers can benefit from Topsøe’s new developments.

Introduction

Industrial plants using catalytic processes depend on outside sources to provide fundamental and applied research, technical know-how and to produce and supply catalysts. Internationally, many companies have competencies in one or two of these areas, but Topsøe is active in all the above mentioned fields.

For almost half a century, Topsøe has been one of the main suppliers of catalysts and technology for the ammonia and hydrogen industry. Through introduction of new catalysts, new equipment design and extensive process optimisation studies, Topsøe has contributed significantly to the development of efficient ammonia production technology. The unique combination of catalyst know-how and extensive experience within licensing of technology makes Topsøe a valuable business partner. In the last decades, 50% of all new ammonia plants have been constructed using Topsøe technology and catalysts.
In traditional ammonia plants, the final conversion of carbon monoxide to the hydrogen required for ammonia synthesis takes place across the low temperature shift (LTS) catalyst. This makes the LTS catalyst one of the most important catalysts in the plant and even small changes in its performance will have a significant impact on operational costs. By choosing a high performance LTS catalyst, the overall plant efficiency can be greatly boosted, leading to significant production gains.

Topsøe’s well-known LK series, LK-821-2 and the low methanol LK-823, is the result of a close cooperation between the industry, Topsøe’s Research and Development department and Topsøe’s catalyst manufacturing facilities. These catalysts meet all the requirements of ammonia and hydrogen manufacturing plants and are well-known in the industry for their outstanding performance.

Currently, more than 180 Topsøe LTS charges are in operation globally, making Topsøe the world-leading supplier of LTS catalysts. The unique qualities of Topsøe’s low methanol LTS catalyst are widely recognised within the industry, and approximately 40% of Topsøe’s LTS references are LK-823 charges, making Topsøe the preferred supplier of low methanol LTS catalyst.

Topsøe’s efforts to continuously optimise the product portfolio in order to meet the industry’s needs have resulted in a new generation of low methanol LTS catalyst, the LK-853 FENCE™.

LK-853 FENCE™ is the latest state-of-the-art catalyst from Topsøe for ammonia and hydrogen production, offering extraordinary advantages for our clients. Since the late 1990s, the predecessor, LK-823, has been recognised as the most active, commercially available low methanol LTS catalyst. During the development of LK-853 FENCE™, LK-823 has been used as the benchmark catalyst. The benefits of LK-853 FENCE™ include consistently higher conversion rates, increased poison resistance, low methanol formation and prolonged catalyst lifetimes.
Background

A fundamental understanding is the key to all new developments, and therefore also the key to providing the best products and service to our clients. Consequently, a significant part of Topsøe’s research activities are focused on long-term and fundamental research.

The objective for Topsøe’s research efforts within the area of LTS conversion is at all times to provide our clients with state-of-the-art products that meet the requirements for cost-effective ammonia and hydrogen production. When it comes to obtaining optimal performance, a high performance LTS catalyst must be optimised with regard to key parameters such as activity, stability, selectivity and poison resistance. The focus for the extensive research activities behind LK-853 FENCE™ has been to develop a catalyst superior in all aspects for efficient low temperature shift conversion. In the following, results obtained by Topsøe’s research team and the FENCE™ technology will be presented.

FENCE™ technology

The significant research efforts focused on continuously optimising Topsøe’s catalysts for low temperature shift conversion have resulted in a unique fundamental knowledge concerning the three-dimensional structural arrangements and deactivation mechanisms of the LTS catalyst.

The knowledge gathered throughout the years has been combined and constitutes the foundation of the FENCE™ technology, which is the basis for Topsøe’s new generation of low methanol LTS catalyst, the LK-853 FENCE™. The scientific background for the FENCE™ technology will be outlined below.

As all heterogeneous catalysts, the LTS catalyst is known to deactivate with time. The main deactivation mechanism is sintering of the active crystals constituting the catalyst. In the case of LTS catalysts, crystals of copper, zinc oxide and alumina are present and the size of the crystals will all increase with time.
From Figure 1 below, it can be seen that sintering of copper particles is considerably faster than sintering of zinc oxide.

![Graph of copper and zinc oxide crystal sintering](image)

**Figure 1.** Sintering of copper and zinc oxide crystals in a methanol catalyst

The reason for the deactivation process seen above is that large crystals are more stable than small crystals. Nano-sized crystals are particularly unstable. It is, however, possible to slow down the sintering process and this is the background for the development of the FENCE™ technology.

In general, sintering processes are so-called activated processes. This means that although there is energy to gain in going from for instance two small particles to one large particle, there is an energy barrier – or activation energy – to overcome for that process. This is illustrated in Figure 2 below.
The Topsøe FENCE™ technology is based on the philosophy of stabilising the finely dispersed copper particles that constitute the active phase of the LTS catalyst. The purpose is to inhibit sintering of the nano-sized copper crystals, thereby preserving the initial high catalyst activity. This is achieved by optimising the sintering barriers by increasing their size and number. Increasing the activation energy for copper sintering can be done by utilising the different interface energies between copper and the various metal oxides. Moreover, a contact point between two metal oxide particles also represents a sintering barrier simply by acting as a geometric restriction. This is illustrated by Figure 3 below.

The FENCE™ technology also includes careful selection of raw materials, modification of the composition and detailed insight in the preparation method. The result of introducing the FENCE™ technology is increased activity and stability, leading to prolonged catalyst lifetimes.
Catalysing profit margin with LK-853 FENCE™

Figure 3. Illustration of the FENCE™ technology. Separation of the copper particles by multiple metal oxide particles of different origin introduces multiple sintering barriers, thereby stabilising the nano-sized copper particles.

Besides deactivation caused by sintering of the active copper phase, the lifetime of the LTS catalyst is also determined by the capacity for absorbing traces of poisons, e.g. sulphur, that are inevitably present in the process gas in ammonia and hydrogen plants. The poison capacity is directly related to the available copper surface in the catalyst; a large copper surface area results in a large capacity for absorbing sulphur. The FENCE™ technology enables stabilisation and separation of the copper particles, resulting in a larger available copper surface area for poison uptake and prolonged catalyst lifetimes.

Topsøe’s scientists have used Transmission Electron Microscopy (TEM) to map the finer details of the structural arrangements in LK-853 FENCE™. High-resolution images have been recorded and the TEM image below illustrates the key-features of the FENCE™ technology. In Figure 4 below, it can be seen how the active copper crystals are separated from each other by a picket fence of metal oxide crystals, enabling stabilisation of the catalytic active sites and available copper surface area in LK-853 FENCE™.
Promoting selectivity

A small amount of methanol is formed as a by-product across any LTS catalyst. The methanol formed over the LTS reactor exits the reactor in the gas phase. After cooling, part of the methanol will end up in the process condensate while the remainder of the methanol will continue with the process gas to the CO₂ removal system. The methanol going to the CO₂ removal system will leave the plant with the exit gas from the CO₂ stripper.

In some parts of the world, regulations concerning methanol emissions from industrial plants have been implemented, thereby restricting the allowable levels of methanol in emissions to the atmosphere. In order to comply with the regulations, ammonia and hydrogen producers need to take necessary precautions to reduce methanol emissions.

As an alternative to removing methanol from e.g. the exit gas from the CO₂ stripper, which would require costly investments in additional equipment, a highly selective LTS catalyst can be installed. This will effectively reduce methanol emissions and improve the quality of the process condensate. Since methanol formation consumes valuable
hydrogen, a low methanol LTS catalyst also offers additional benefits such as increased daily ammonia and hydrogen production. The research within the area of low methanol LTS catalysts has thus gained increased importance and focus.

During the development of LK-823, which was the first generation of low methanol LTS catalyst from Topsøe, extensive research efforts were carried out to uncover the critical parameters for methanol formation in low temperature shift. The development work included a fundamental study elucidating the effect of alkali metals on methanol formation. The study demonstrated that the promoting of LK-823 with a carefully optimised level of alkali metals resulted in decreased methanol formation while still maintaining a high shift activity and poison resistance.

Since the introduction in 1997, the LK-823 has been the world-leading low methanol LTS catalyst. It has therefore been the benchmark catalyst with regard to both activity and selectivity. It is a significant challenge to increase low temperature shift activity and at the same time suppress activity for methanol by-product formation. However, based on the knowledge gathered from more than a decade of industrial experience with LK-823 and continuous research efforts within the area of low methanol LTS catalysts, Topsøe has succeeded in developing a state-of-the-art catalyst where low temperature shift activity has been significantly increased. At the same time, by optimising the type and amount of promoters in the LK-853 FENCE™, the methanol formation is maintained at the same level as for the predecessor, resulting in significant benefits.

**LK-853 FENCE™ – taking Topsøe’s world-leading position one step further**

Almost 50 years of industrial experience as a world-leading supplier of LTS catalysts provides an invaluable basis for new catalyst developments. The predecessor and benchmark catalyst, LK-823, is currently the world-leading low methanol LTS catalyst recognised globally for its unique characteristics and outstanding performance.

During testing and development of a new catalyst, numerous measurements are carried out to determine the activity and stability of the catalyst. In order to simulate real industrial operating conditions, the catalyst is subjected to long-term testing at typical low temperature shift operating conditions.

The key features of LK-853 FENCE™, which are outlined below, have been confirmed by both extensive laboratory testing and industrial experience.
Superior high and stable activity

From long-term testing and benchmarking against its predecessor, it is evident that LK-853 FENCE™ offers a considerably higher activity in comparison to LK-823. Moreover, the results demonstrate that the stability of this new catalyst is highly satisfactory. As described above, the FENCE™ technology enables separation of the nano-sized copper particles by multiple metal oxide barriers, thereby stabilising the catalytic active sites and preserving the initial superior high activity.

The outstanding stable activity of LK-853 FENCE™ results in consistently higher CO conversion rates and significantly prolonged lifetimes compared to the benchmark catalyst.

Outstanding poison resistance

The poison capacity of a LTS catalyst is directly related to the copper surface area in the catalyst. The FENCE™ technology not only results in increased activity and stability of the LK-853 FENCE™ catalyst, but also a larger copper surface area available for poison uptake. Consequently, LK-853 FENCE™ has an outstanding poison resistance, resulting in prolonged catalysts lifetimes.

Excellent selectivity

As mentioned earlier on, it is a significant challenge to increase low temperature shift activity and at the same time maintain a high selectivity for the shift reaction. In order to obtain a superior selectivity, promoters are added to the LTS catalyst, thereby suppressing the activity for methanol formation. The remarkable selectivity of LK-853 FENCE™ has been achieved by carefully optimising the type and amounts of promoters that inhibit by-product formation. LK-853 FENCE™ minimises undesirable methanol formation across the LTS reactor, leading to increased daily production rates, reduced methanol emissions and better quality of the process condensate.

Catalysing profit margin with LK-853 FENCE™

With the use of Topsøe’s new high performance LTS catalyst, the LK-853 FENCE™, numerous benefits can be achieved. The characteristics described above makes it possible to reduce operating costs and increase process efficiency. In the below, it will be illustrated how LK-853 FENCE™ can be used to increase profit margin in ammonia plants.
The high and stable activity of LK-853 FENCE™ will allow operation at lower temperatures for an extended period of time, leading to more favourable equilibrium conditions and consistently low CO leakage from the LTS reactor. At first glance, it seems straightforward to quantify the impact of a higher CO conversion on the production rate, but several factors should be taken into consideration in order to see the full effect:

- Higher conversion results in less CO and more hydrogen at the outlet of the LTS reactor.
- In the methanator, less hydrogen will therefore be consumed and less methane will be formed.
- In the ammonia loop, a lower purge rate is required due to less methane in the make-up gas.
- In the secondary reformer, more air has to be added in order to maintain the same H/N ratio.

Looking only at the front-end, the above contributions add up to a net gain of 3.4 mole of hydrogen per mole of extra CO converted in the LTS reactor. Thus, even a small reduction in the CO leakage will lead to significant production gains.

In order to illustrate the benefits of LK-853 FENCE™, a 1,500 MTPD ammonia plant will be used as an example. The higher activity, stability and sulphur capacity of LK-853 FENCE™ will result in an increased ammonia production compared to the benchmark catalyst. For an operating period of 5 years, which would be a typical lifetime for LK-823, this would add up to a total production gain of up around 7,000 metric tonnes of ammonia. When calculating the actual gain, the plant design should be taken into consideration, e.g. if it is equipped with a purge gas recovery unit in the ammonia loop. The production gain of 7,000 metric tonnes corresponds to a value of around 2,800,000 USD.

In addition, it is an often overlooked fact that the formation of methanol consumes valuable hydrogen and therefore inevitably leads to a lower ammonia production. Hence, significant benefits can be obtained by installing a low methanol LTS catalyst compared to a standard LTS catalyst. Below, the synthesis reaction from carbon dioxide to methanol is given:

\[
\text{CO}_2 + 3\text{H}_2 \rightarrow \text{CH}_3\text{OH} + \text{H}_2\text{O}
\]
Catalysing profit margin with LK-853 FENCE™

2012

As seen in the above reaction, it takes 3 mole of hydrogen to form 1 mole of methanol, so even a small reduction of the methanol formation will have a large impact on the amount of hydrogen available for ammonia production.

When considering the overall impact of the reduced methanol formation on the ammonia production, it should be taken into account that most plants will normally recycle some of the methanol back to the reforming section as a part of the process condensate. The actual amount of methanol recycled will depend on the temperature in the separator downstream the LTS. In the following, it is assumed that 25–50% of the methanol stays in the gas phase.

For a 1,500 MTPD ammonia plant, the reduced amount of methanol formed by using LK-853 FENCE™ would correspond to a daily production gain of 1.0–1.9 metric tonnes of ammonia. Over a 5-year period, this would add up to a total production gain of 1,500–3,150 metric tonnes of ammonia, corresponding to a value of 600,000–1,300,000 USD.

In addition to the above, the use of the LK-853 FENCE™ catalyst will lead to reduced methanol emissions and better quality of the process condensate.

Industrial experience with LK-853 FENCE™

LK-853 FENCE™ was commercialised recently and offered to a North American ammonia producer. Two charges have been installed in this plant and commissioned in October 2011. Another charge for installation in spring 2012 has already been ordered by the same client. Feedback from these first references confirms the expectations of superior activity and low methanol formation of LK-853 FENCE™.
Elimination of radioactive sources in Ruwais Fertilizer Industries Co.

Ahmed Al-Awadhi
Sr. Instrument Engineer FERTIL
UAE
TOPIC: ELIMINATION OF RADIOACTIVE SOURCES IN RUWAIS FERTILIZER INDUSTRIES

Scope Of Presentation

- Introduction of Ruwais Fertilizer Industries
- Introduction of the presentation
- An overview of radioactive level measurements
- An overview of radar level measurements
- FERTIL Effort-1: Replacement of radioactive device from radar technology in high pressure Urea reactor level measurements
- FERTIL Effort-2: Replacement of radioactive device from tuning fork device in ammonium carbamate service density measurements
- FERTIL Effort-3: Removal of radioactive device for dust level from main product conveyor
- Conclusion
A. Introduction Of the Company

Ruwais Fertilizer Industries (herein referred to as FERTIL) was established in October 1980 and the commercial production of prilled urea commenced in December 1983. The initial capacity was aimed at 1000MTPD of ammonia and 1500MTPD of Urea based on Haldor Topsoe and Stamicarbon technologies. Today after debottlenecking and other modifications the name plate capacities have increased to 1300 MTPD of ammonia and 2300 MTPD of granulated Urea.

In October 2009, FERTIL signed a contract with Samsung and UHDE to execute expansion project of the company which shall expand production capacity to 2 million MTPY of granulated urea by first quarter of 2013.

B. Introduction of the presentation

Despite being reliable, the radioactive source based instruments always pose potential radiation hazards during handling / maintenance / replacement / storage and transportation. Guided by the problem statement FERTIL has made sustainable efforts in near past to eliminate radioactive devices from the site. This technical paper shall discuss the ongoing efforts made by FERTIL to eliminate radioactive sources from its site.
C. An Overview of Radioactive technology for level measurements

- Two critical levels which require sensitive control in Urea synthesis are reactor level and stripper level
- A low level in reactor can cause strip gases bypassing the stripper. A high reactor level causes urea/carbamate solution to overflow to the scrubber. Hence the importance of correct reactor level measurements
- A high stripper level at bottom causes urea/carbamate solution to reach lower tube sheet. A low stripper level causes CO2 slippage. Hence the importance of correct stripper level measurements
- Contact type level measurements failed due to crystallization, corrosion and strong requirements of high pressure flushing water

Contd.

- From mid seventies the radioactive level measurement devices came into picture in the fertilizer industry and are still being widely employed even in new generation plants
- Radioactive radiations provide reliable non contact type level measurement devices
- The level measurement principle is based on absorption of gamma rays by the medium it passes through
- A typical radioactive type level measurement system comprises of a source(transmitter), detector and microcomputer
- The source emits gamma rays which pass thru the medium and are received at the detector. The percentage of gamma rays being received at the detector is inversely proportional to the level of fluid. As the level of fluid increases there is more absorption of gammy rays and the balance is received by the detector. This forms the basis of radioactive source level instrument calibration
The graph above shows percentage absorption (transmission) of gamma rays in different media.

Figure-2: The picture above shows a schematic of radioactive Cobalt rod source (old) for level measurement installed in FERTIL HP Urea reactor.
Advantages of radioactive level measurement devices

- Good reliability
- Robust
- Non contacting and wetting surfaces

Dis-advantages of radioactive level measurement devices

- Radiation hazards especially during handling / maintenance / replacement / storage and transportation
  This is the most important reason which has contributed to widespread research on using alternate technologies around the industry
- Malfunctioning of radioactive devices while x-ray radiography is carried out

D. An Overview of radar technology for level measurement

- Radar is an acronym for radio detection and ranging
- Offers reliable and sustainable technology as non contact type level measurement devices for critical services as reactor and stripper levels in a typical fertilizer complex
- Radar waves are characterized by very low heat intensity of the order of 0.01mW/cm²
- A typical radar level measuring device consists of a transmitter, an antenna, a receiver with signal processor and an operator interface
Level measurement with radar waves is based on the principle of reflection of waves by the media and detection of the reflected waves by the antenna.

**Figure-3**
A Radar level measurement set-up

- The signal is radiated by an antenna toward the surface of the process liquid. A portion is reflected back to the antenna, where it is collected and routed to the receiver. Here, a microprocessor calculates the time of flight and calculates the level. Time of flight is the period between the transmission of the radar pulse and the reception of the return echo. It is determined by the radar detector, which is simultaneously exposed to both the sent and the reflected signal.
- The depth of the vapor space (the distance between the datum point and the level in the tank, identified as "d" in Figure 3) is calculated from the time of flight (t) and the speed of light (c = 186,000 miles/sec): \( d = \frac{t}{2c} \)
- The level (L) is calculated by figuring the difference between the total tank height (E) and the vapor space depth (d). This becomes the basis of calibration: \( L = E - d \)
Knowing the signal velocity (c) and the dielectric constant (dc) of the vapor the velocity of the radar wave transmission (V) can be calculated: 

\[ V = \frac{c}{(dc)^{0.5}} \]

The above theory suggests the importance of dielectric constant utilized in making use of radar technology for level measurements.

- The antenna design is either parabolic or horn type.
- The level measurement device is of two types namely guided and non-guided.
- Non-contacting radar level devices either use pulsed radar waves or frequency modulated continuous waves (FMCW). Mostly used in fertilizer plants is the pulsed radar wave.
- Radar level measurement devices have been successfully installed and operating for both Urea reactor and HP Stripper level measurements across fertilizer sector.

A Typical schematic showing radar waves path in a level measurement device

![Figure-4](image)
Advantages of radar technology in level measurements

- Safe radiations
- Very low heat intensity

Dis-advantages of radar technology in level measurements

- Measurements affected by deposits on transmitter and antenna

E. FERTIL Effort-1: Replacement of radioactive level measurement device from radar level measurement device in high pressure Urea Reactor

- A Cobalt 60 radioactive source (A rod source of about 2.5m long) was utilized until the year 2011 for measuring the liquid Level in Urea Reactor
A Radar Level measurement system was attempted in the year 2009 as shown in Figure -6.

A picture of horn shaped antenna utilized is attached below.
This attempt failed since the level indications were highly erratic and not reliable mainly due to the turbulent and wavy surface of liquid level caused by the bubbling of the gas through the liquid stream inside the reactor.

FERTIL was forced to shut down the Urea Plant and reinstalled the Cobalt 60 radioactive source for resuming production.

During May 2011, an innovative in-house modification was carried out on the failed radar system by extending the internal pipe and installed a standpipe so that the guided radar waves always face a non-turbulent liquid surface (Refer Figure-7).

This modification made the radar system very accurate and reliable.

Now the Cobalt 60 radioactive source is redundant and it will be disposed back to Germany after the Turnaround 2012.
Figure 7

Guided wave radar installed in high pressure urea reactor in May 2011
Picture-2 shows gas balance holes in the still well while Picture-3 shows Liquid entry holes in the still well.

Salient features Of the modified guided wave radar system with still well

- Make- Vega, Model- VEGAPULS 66, SAFUREX
- The modified radar system is giving trouble free operation since May-2011
- The radar nozzle is heat traced
- Reduction of false echo due to less transition via the horn antenna
- Due to guided wave /Still well installation there is no interference from internals
- Higher concentration of the energy emitted by the radar due to focusing in the stand pipe, which also result in higher reflected energy level which results in better signals
- The behavior of the liquid surface will be less turbulent in the stand pipe which results in better signal
- The expected damping effect caused by NH3 vapors on the radar signal will be less in a stand-pipe as compared to free space configuration
F. FERTIL Effort-2: Replacement of radioactive density meter from tuning fork type density meter in carbamate line

- A Cesium 137 radioactive source (a point source) was utilized for measuring the Density of Ammonium Carbamate solution at the suction of HP Carbamate pumps # P-3301A/B/C/D. This radioactive source was removed and successfully replaced with the latest and modern Tuning Fork based Density meter in the year 2009.
- The removed radioactive source will be disposed back to the German supplier as per UAE Government's FANR guidelines after the Turnaround 2012.

The natural frequency of a tuning fork is determined by its shape and material. If the tuning fork is hollowed out and filled with a liquid, the vibrating frequency is determined by the liquid’s density. This is the operating principle of a tuning fork density meter.
- A piezoelectric cell vibrates the fork at a resonating frequency. When the liquid enters the hollow tubes of the fork the oscillations get damped. Both these frequencies (piezoelectric cell and tuning fork) are transferred to a detector and delta f forms the basis of density calibration as the output signal.
- Tuning type density meters are not affected by flow, pressure and viscosity.
- Mostly a temperature compensator is inbuilt.
Picture 4: A typical cross-section of a hollow tuning fork type density meter

Specifications of tuning fork meter installed in carbamate line
G. FERTIL Effort-3: Removal of radioactive device for dust level from main product conveyor

- From the year 1983 till 2009, a Cesium 137 radioactive source (a point source) was used for measuring the Urea Dust on Belt Conveyor # X-4717 as the original process of manufacturing of Urea prills generated urea dust.
- Measurement and removal of urea dust was mandatory to maintain the final product quality.
- During the year 2009, FERTIL modified the process, and dust free Urea Granules are being produced without the necessity for measuring the dust level and thus totally eliminating the need for the radioactive source.
- This source was removed and disposed back to the German supplier safely in the year 2011 as per UAE Government's Federal Authority for Nuclear Regulation (FANR) on nucleonic disposal.

H. FERTIL Effort-4: Future Prospects

- Based on the successful experience gained with the Guided Radar Wave system in high pressure Urea reactor, another Cesium 137 radioactive source installed in the FERTIL-1's Urea Plant HP stripper Level measurement will be eliminated in future—along with the HP Stripper replacement.
- Because of the mechanical geometry of the vessel only guided wave radar device having a stand pipe can be applied for the stripper bottom.
I. Conclusion

- Encouraged by the overwhelming results in its endeavor to eliminate use of radioactive devices from the site, M/s FERTIL has suggested strongly the EPC contractor for its expansion plant (FERTIL-2) to look into prospects of using radar technology and tuning fork technology in the new plant.

- Currently, Gamma Ray (X-ray) technique is being used for detecting welding defects across the globe which involves application of strong radioactive sources like Iridium 192 and Cobalt 60.

- In order to avoid radiation hazards, in many countries, some industries have already started using phased array UT, TOFD and other non-radioactive techniques for the same. FERTIL is exploring the possibility of using different proven alternative NDT methods in place of Gamma Ray inspection in the future.

- Radiation free workplace will provide a peaceful environment and boost the morale of the employees and the society and the company’s reputation will be enhanced as an environment friendly & occupational health compliant.
THANKS
1. **Safe, Sustainable Phosphate Production**
   Julian Hilton – Chairman, ALEFF GROUP, UK

2. **Phosphogypsum Management and Use: Opportunities and Issues**
   Julian Hilton – Chairman, ALEFF GROUP, UK

3. **Utilization of Low grade rocks by optimizing operation parameters in manufacturing Phosphoric acid with Better Efficiency**
   G M Patel, Technical Director, CFIC, India

4. **Smart fertilizers for sustainable agriculture: The state of the art and the recent developments**
   Youssef ZEROUAL, Research & Development Direction Industrial Pole, OCP, Morocco

5. **Enhancement of Hot leach plant Operational Sustainability**
   Ala'a Al Omari, Senior Process Engineer, APC, Jordan
25th AFA International Fertilizers Technology Conference
Sustainability Driving the Future
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Safe, Sustainable Phosphate Production

Julian Hilton
Chairman, ALEFF GROUP
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Phosphogypsum Management and Use: Opportunities and Issues

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Utilization of Low grade rocks by optimizing operation parameters in manufacturing Phosphoric acid with Better Efficiency

G M Patel
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India
**Utilisation of Low grade rocks by optimising operation parameters in manufacturing Phosphoric acid with Better Efficiency**

Abstract:

Phosphoric Acid producers are increasingly confronted with the continuous and regular fall in P$_2$O$_5$ grade of Rock Phosphate and at the same time with the increase of their impurities content. Thus the search of new solution becomes necessary in order to adopt existing facilities to development of basic raw material that is Rock phosphate. The use of low grade rock phosphate normally means an important decrease in (a) extraction of P$_2$O$_5$ from Rock Phosphate and (b) P$_2$O$_5$ concentration of manufactured Phosphoric Acid. Many of impurities present in Rock Phosphate affect PA plant performance in some way but degree of influence varies with other impurities’ interactions amongst each other in process. The effects of some impurities are well known and understood while for others’ effects particularly involving in minor levels are less clear and this applies to change in the crystal growth most important factor for better extraction efficiency of P$_2$O$_5$. Therefore phosphoric acid manufacturers who process low grade rock phosphate have to accept lower standard or improve over poor performance by modifying operating conditions and/or plant design and possibly consider use of additives. A better understanding of Phosphoric Acid manufacturers for effects of impurities in Rock Phosphate to select Rock Phosphate on economic implications applied to their own plants. These effects of impurities need not necessarily same for different manufacturers.

***********************************************************************************************************

Executive Summary

All phosphate rocks contain impurities. By its very nature, rock phosphate exists in natural deposits alongside other minerals, and even wrapped up as complexes with a variety of other mineral species. “Bone phosphate of lime” – the BPL in phosphate rock – is otherwise known as tricalcium phosphate. If you want it pure you must go to the laboratory supplier, because it never exists as such in nature, but as more complex minerals known as apatite. A 100% BPL phosphate rock is, therefore, quite unknown.

A French expert Mr. J Frochen has described “Rock Phosphate as living ore” and this is what makes phosphate technology so diverse and viable according to the phosphate ore origin. Each Rock has its own behavior when ground, attacked, crystallized, and filtered. The resulting phosphatic acid will have its own colour viscosity and impurities. The impurities contained in the rock phosphate are the main responsible factors for the individual behaviour of each rock. It should be also noted that particular ore will also behave differently in different plant even though having same dihydrate route. It is, therefore, necessary to consider all the above aspects while accepting the rock for phosphoric acid plant in a most techno-economical manner, which can lead to better extraction efficiency on sustainable basis.
Phosphoric Acid is an important intermediate, both for the production of fertilizer and for other products. The first commercial product of wet process Phosphoric Acid, with separation of calcium sulphate probably occurred about in 1850 in France and England. At that time the main use of Phosphoric Acid produced was for production of elemental phosphorus for matches. In 1870 a plant was erected in Germany to produce Phosphoric Acid from rock phosphate, which was too low grade (16% P₂O₅) and too high in Iron and Alumina to make Super Phosphate which by then had become a popular fertilizer. Again, it is interesting to know that this rock would now be recorded as a hopelessly unsuitable for Phosphoric Acid production. However, by 1900 about 12 companies were producing Phosphoric Acid in Europe to use in Triple Super Phosphate, which was used in the sugar refining, or for fertilizer. Starting in 1935 electrical furnace process began to compete with the wet process and by 1955 production of electrical furnace acid was nearly equal to that of wet process acid in United States. Really after 1955 the soaring demand for concentrated fertilizer had dramatically increased the production of wet process acid by various process routes.

**Chemistry of Process:**

The main chemical reaction in the wet (sulfuric acid) process may be represented by the following equation using pure fluorapatite to represent phosphate rock.

\[
Ca_{10}F_2(PO_4)_6 + 10H_2SO + 10\ nH_2O \rightarrow 10CaSO_4nH_2O + 6H_3PO_4 + 2HF
\]

Where n=0, ½ or 2, depending on the hydrate form in which the calcium sulfate crystallizes.

The reaction represents the net result of two stages. In the first stage, phosphoric acid reacts with the apatite forming monocalcium phosphate, and in the second stage monocalcium phosphate reacts with sulfuric acid to form phosphoric acid and calcium sulfate. These two stages do not necessarily require two reaction vessels; they usually take place simultaneously in a single reactor.

Phosphate rock contains many impurities both in the apatite itself and in accessory minerals. These impurities participate in numerous side reactions. Most phosphate rocks have a higher CaO: P₂O₅ ratio than pure fluorapatite. The additional CaO consumes more sulfuric acid and forms more calcium sulfate. The HF formed by the reaction reacts with silica and other impurities (Na, K, Mg, and Al) to form fluosilicates and other more complex compounds. A variable amount of the fluorine is volatilized as SiF₄, HF, or both. (The amount volatilized and the form depends on phosphate rock composition and process conditions). As a result of side reactions, numerous impurity compounds (some of them very complex) are formed.

**Type of Process:**

Commercial wet process may be classified according to the hydrate form in which the calcium sulfate crystallizes:
1. Anhydrite – CaSO\(_4\)
2. Hemihydrate – CaSO\(_4\) . ½ H\(_2\)O
3. Dihydrate - CaSO\(_4\). 2H\(_2\)O

The hydrate form is controlled mainly by temperature and the concentration of H\(_3\)PO\(_4\) and H\(_2\)SO\(_4\) in the liquid phase. At present there is no commercial use of the anhydrite process, mainly because the required reaction temperature is high enough to cause severe corrosion difficulties. Processes in commercial use are as follow:

<table>
<thead>
<tr>
<th>Crystal Form(s)</th>
<th>Number of Separation Steps</th>
<th>Usual Conc. Of Product Acid, %P(_2)O(_5)</th>
<th>Usual Temperature °C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Reactor</td>
</tr>
<tr>
<td>Dihydrate</td>
<td>1</td>
<td>26 – 32</td>
<td>70 – 85</td>
</tr>
<tr>
<td>Hemihydrate</td>
<td>1</td>
<td>40 – 50</td>
<td>85 – 100</td>
</tr>
<tr>
<td>Hemihydrate - dihydrate</td>
<td>1</td>
<td>26 – 30</td>
<td>90 – 100</td>
</tr>
<tr>
<td>Hemihydrate - dihydrate</td>
<td>2</td>
<td>40 – 50</td>
<td>90 – 100</td>
</tr>
<tr>
<td>Dihydrate-Hemihydrate</td>
<td>2</td>
<td>35 – 38</td>
<td>65 – 70</td>
</tr>
</tbody>
</table>

**Selection of Phosphate Rock:**

Many phosphoric acid plants are built in countries where phosphate rock must be imported. The plant is often designed on the basis of some standard phosphate rock. However, it is often prudent to build into the plant sufficient flexibility to permit use of rocks from different sources. This versatility will enable the producer to take advantage of competitive situations and to avoid disruption of supply when the intended source is inadequate or interrupted by hostilities, disasters, or other circumstances. Many plants find it advantageous to use a blend of rocks from different sources. The extra expense in making the plant more versatile usually can be repaid many times over by savings resulting from freedom of choice in the world market. Some examples of steps to increase versatility of the plant are:

1. Extra grinding capacity for harder rock;
2. Extra filtration capacity to provide for rocks that cause less rapid filtration;
3. Slurry handling systems that will cope with acid-insoluble impurities in the rock, and
4. More corrosion-resistant construction for rocks that have corrosive impurities.

When the plant is built at or near the mine, there is still the likelihood that the rock composition will vary. In addition, there are other questions to be
considered relating to the economic optimum balance between costs of extra beneficiation as compared with the cost of utilizing lower grade rock.

The selection of a phosphate rock source is sometimes viewed as a simple matter of obtaining a given amount of $P_2O_5$ in the rock delivered to the plant at the lowest price. However, phosphate rock is a very complex raw material, which affects the plant operation in numerous ways, some of which may be unpredictable. Therefore, a thorough evaluation of all quality factors should be made before selecting a phosphate rock or changing from one source to another.

A complete chemical and mineralogical analysis of a phosphate rock is helpful in evaluating its usefulness for making phosphoric acid. However, this information is not sufficient in itself; trial runs in a plant or pilot plant are needed for a reliable evaluation unless the rock is one that has been used extensively in other similar plants with known results.

The following quality factors may provide a general guide for selection of phosphate rock for phosphoric acid production. The economic effect of many of the factors can be evaluated quantitatively to arrive at a comparative value of alternative sources of phosphate rock.

**Major quality factors:**

Starting with a standard grade of rock, the more common quality factors for wet-process phosphoric acid production and their effect are:

1. Lower grade (%$P_2O_5$) means that more tonnage must be bought, transported, handled, and (usually) ground;
2. An increase in the CaO:$P_2O_5$ weight ratio increases the sulfuric acid requirement. (Any CaO present as CaSO$_4$ should be excluded in calculating this ratio);
3. Magnesium oxide may form precipitates with fluorine in the reactor, which may blind the filter cloth; therefore, high MgO content can be a problem. When phosphoric acid is used to produce ammonium phosphates or polyphosphates, water-insoluble (but citrate-soluble) magnesium ammonium phosphate compounds may be formed. These compounds form troublesome impurities in liquid fertilizers;
4. Increase of the $Fe_2O_3 + Al_2O_3$ content above 2 – 3% decrease the plant capacity, often decrease the $P_2O_5$ recovery, and cause post-precipitation problems (sludge). However, up to about 5% may be tolerable in some cases;
5. It is desirable to have enough reactive silica (SiO$_2$) to form SiF$_4$ and/or fluosilicates so as to avoid formation of free HF, which is corrosive. Excessive silica or other acid-insoluble impurities may cause erosion of equipment and possible accumulations in digestion vessels depending on particle size, character, and plant design. Also, a high percentage of silica in the rock would increase the required filter area;
6. Chlorine contents above about 0.01% cause increased corrosion of stainless steel. More expensive alloys may tolerate a Cl content of 0.10% or perhaps higher;
7. High organic matter may increase foaming problems (by stabilizing the foam), increase viscosity, and hinder filtration. The effect depends on both the character and quantity of organic matter. Some rocks must be calcined to remove organic matter to take them usable;
8. Carbon dioxide (CO₂) contributes to foaming and increases consumption of antifoam reagents;
9. All commercial phosphate rocks contain fluorine (F); no special effect has been noted due to variations in fluorine content within the range of experience. Effects of fluorine on scaling, corrosion, and post-precipitation are related to other elements that combine with fluorine, including Na, K, Al, Mg, and Si;
10. Some rocks, which contain sulfides, release hydrogen sulfide (H₂S) upon acidulation. This gas is toxic. Also sulfides tend to increase corrosion;
11. Many other less common impurities may be present in sufficient quantity to require consideration (TiO₂, SrO, BaO, Cd, etc.);
12. Hardness is a factor in that harder rocks require more grinding capacity;
13. The particle size of the rock as received affects the amount of crushing and grinding required. Very fine particle size may lead to dust losses in handling.
14. Low reactivity of the rock may require finer grinding;
15. Filterability of the rock-acid slurry is one of the most important characteristics of a phosphate rock for use in phosphoric acid production. Factors influencing filterability are complex and not completely understood. However, if a plant is to be designed to use a specific rock, an acceptable filtration rate can usually be attained through experimental means by adjusting operating conditions, addition of crystal modifiers, or pretreatment of the rock.

**Impurities and their effect in Phosphoric Acid production:**

**P₃O₅**

The Phosphatic mineral in phosphate rock deposits is fluorapatite, 3Ca₃(PO₄)₂·CaF₂. In completely pure form this substance would have a P₃O₅ content of 42%, equivalent to around 91% BPL, and consists entirely of calcium phosphate and calcium fluoride. Commercial phosphate rock of 80% BPL, 37% P₃O₅ is rather rare today. 70 - 72% BPL material, 32-33% P₃O₅, can be regarded as normal, although rock types with grade substantially below 70% BPL have been used for many years now. In some cases today 60% BPL material is considered economically viable.

As the grade of rock goes down in this way, the calcium content increases, and so does the CaO/ P₃O₅ ratio, which is the major indicator of sulphuric acid consumption. For example, to make a tonne of P₃O₅ as phosphoric acid from 75% BPL phosphate rock, about 2.5 tonnes of sulphuric acid are needed; if 65% BPL materials used, the figure is more like 3 tonnes or possibly more, depending on the other impurities present. The amount of by-product gypsum
is correspondingly larger, which significantly increases the required active filter area. So, although calcium is a natural constituent of apatite minerals, the extra calcium associated with lower-grade phosphate rocks may reasonably be considered an impurity, since it has a profound effect on the economics of processing them.

**Fluorine** is present in almost all phosphate rocks because of the calcium fluoride content of fluorapatite. Depending on the type and origin of the rock, fluorine may represent 2-4% of the total weight. Sulphuric acid reacts with fluorides in the attack section of the phosphoric acid plant, liberating hydrogen fluoride, HF. This is a highly corrosive vapour at the prevailing temperatures, but if sufficient silica is present in the phosphate rock – and it usually is – the much less corrosive fluosilicic acid is formed instead. Indeed, where the phosphate rock has an unusually low silica content, reactive silica may be added, in the form of clay or other convenient material, to ensure that all fluorine in the rock is converted to fluosilicic acid.

Depending on the reaction conditions, part of the fluosilicic acid is evolved as vapour and the rest remains in the liquid phase, forming fluosilicates with other species in the reaction medium. Some of these fluosilicates go on to form sludges in the product acid, while most of the remaining free fluosilicic acid appears as vapour in the evaporator exhausts when the acid is concentrated. Air pollution regulations in many countries do not permit free discharge of any fluorine-containing vapours, and some form of scrubbing device is usually installed to control emissions.

**Silica** - Though beneficial in suppressing hydrogen fluoride generation, silica in larger quantities can be a nuisance during processing. It passes through the phosphoric acid process largely unchanged, not only adding to the filter duty but also eroding agitators, pumps and pipes.

**Carbonate** is also a common impurity in phosphate rock. It can be present as carbonate apatite, limestone, dolomite or calcite, and in other forms on occasion. Rock from sedimentary deposits often contains carbonate in a form which imparts reactivity, whereas rocks of igneous origin, even in association with calcite as carbonatite, are usually rather unreactive. Often, very reactive carbonate-containing rock is used for direct application fertilizer, since it will quickly solubilise in the presence of soil acids. On reaction with sulphuric acid, carbonate tends to effervesce, creating foams which are stabilized by the presence of organic matter in the rock. This can cause severe difficulties in a phosphoric acid plant, since output may have to be restricted to prevent the reactor from overflowing, which would result in product loss, would be a danger to personnel and would expose parts of the plant not designed for it to an unacceptable Corrosion risk. For this reason, rock phosphate with a high organic content is
often calcined after beneficiation to eliminate the organic material; but that also reduces reactivity because the carbonate is destroyed as well.

Various additives have been successful in controlling foam stabilization, including oils, long-chain alcohols and more esoteric preparations. Organic materials can also lead to discoloration of the filter acid (“black acid”) and may “blind” the filter.

The most common cationic impurities in phosphate rock are iron, aluminium, magnesium, sodium and potassium. Iron and aluminium are usually present in similar amounts, a litter more aluminium than iron. In moderate quantities they have little impact, apart from affecting the sulphuric acid requirement in a relatively small way. Indeed, the presence of some aluminium in phosphoric acid is generally held to be beneficial to crystal formation and therefore to filterability, and it also has a tendency to reduce corrosion. But at higher concentrations both iron and aluminium form insoluble gels of complexes with phosphates and fluosilicates, which increase the viscosity of the acid and “blind” the filter cloth during acid manufacture and may later settle as sludge during storage.

Magnesium, sodium and potassium all tend to form complex phosphates and fluosilicates, which either impair crystallization of calcium sulphate or increase the viscosity of the acid; their effect is therefore mainly felt at the filter and in subsequent operations on the acid, such as concentration and handling of the concentrated acid. Magnesium, in particular, has a marked effect on viscosity if present in appreciable quantities. Many other impurities in the rock which come through in the acid also give rise to sludges and secondary precipitation when the acid is concentrated to merchant grade or super phosphoric acid.

Other cationic impurities tend to be specific to particular types of rock. For example, igneous phosphates often contain rare earth elements (lanthanides), as well as strontium and barium, which tend to inhibit recrystallization of calcium sulphate. These elements therefore affect the type of crystallization technology, which is suitable for phosphoric acid production. Igneous rocks from specific origins often contain unique impurities, such as titanium dioxide in Tapira rock (Brazil) and copper in Phalaborwa rock (South Africa).

Of the other anionic impurities besides fluorine, chlorine is undesirable at levels above 300 ppm (0.03%) and is extremely undesirable above 1,000 ppm because it is too corrosive, especially in association with hydrogen fluoride and sulphuric acid. Special materials are required in the reaction sections of phosphoric acid plants designed to use high-chlorine rocks.

**Impurities and their effect on fertilizer production:**
Impurities in phosphate rock involve extra costs in processing it to acid and many stay in the acid in some form once it is made, to go on to affect subsequent processing and the manufacture of derivative products.

Feed phosphate production requires acid of high purity, since fluorine and other impurities in run-of-plant acid can render the product unsuitable for animal consumption.

Although phosphoric acid required for fertilizer manufacture need by no means be pure, impurities derived from the rock can have a major effect on the nature and properties of the products, particularly when ammoniation is involved. In triple superphosphate, for example, iron and aluminium can increase the caking tendency, although this problem is more usually associated with the impurities in the rock feed (i.e. the secondary rock) rather than impurities in the acid. All the cationic impurities implicated in sludge formation in phosphoric acid, as well as some that are not, tend to form water-insoluble complex phosphates when the acid is ammoniated, which lowers the water-soluble P$_2$O$_5$ content of the product. Magnesium forms ammonium magnesium phosphate, MgNH$_4$PO$_4$, as an insoluble precipitate.

**Influence of F, Al$_2$O$_3$ and SiO$_2$ contents:**

The inorganic elements in sedimentary rock that are well known to affect considerably the crystal habit and size of CaSO$_4$ are F, Al$_2$O$_3$, SiO$_2$ and to a certain extent MgO.

The presence of free fluorine ions leads to the formation of long thin needle crystals, which are difficult to filter. Al$_2$O$_3$ and SiO$_2$ are beneficial to crystallization because they reduce the free fluorine ions concentration and improve the form of CaSO$_4$ crystal. Moreover, it has been reported that the presence of active silica has a positive effect on the reduction of corrosion and crystallization of CaSO$_4$. By changing F/ SiO$_2$ ratio, needle – type crystals can be modified to agglomerates. The best crystals look like balls, because of their surface to volume ratio is at minimum.

Furthermore, important fundamental information about the effect of these impurities on the corrosion rates, crystallization of the precipitated CaSO$_4$ and the calculation method of **Fluoride Complexing Ratio (FCR)** can be found in the literature by M. Schorr.

\[
\text{FCR} = \frac{F}{1.12 \text{Al}_2\text{O}_3 + 1.27 \text{SiO}_2 + 0.94 \text{MgO}} < 1
\]

On the basis of this, FCR is calculated from the phosphates analysis data obtained taking into account the solubility factors of these impurities in PA.
When the ratio of FCR higher than one:

It results in poor slurry filtration characteristics, low filtration capacity and washing efficiency. When increasing the Specific Filtration Rate (SFR) higher than 4.6 t/m² pd P₂O₅ and after hours of retention time, the quality of slurry filtration deteriorates, completely uncontrollable, and consequently the attack. On account of bad filtration, the water – soluble P₂O₅ losses in gypsum increase asymptotically to higher than 5.0%. Microscopic examination discloses that the gypsum consists of long thin needle shaped crystals: (length 250 – 300; width 30 – 50 and thickness 2 – 3 microns). Beside it is in dark colour, very sticky with 33 – 37% of free water content and high thyrotrophic properties. Surface area of cake is about 3400 cm²/g.

The maximum P₂O₅ content attainable of the filtrate acid is between 25.5 to 26% of P₂O₅ (higher than 26% P₂O₅ increases slurry viscosity).

Reduction of FCR to 0.83 in the phosphate used:

This causes some improvements with plant performance:

- Increase the SFR from 4.6 to 5.5 t/m² pd P₂O₅.
- Increase acid concentration of the filtrate acid to 27% P₂O₅.
- Improve marginally the filterability and washability of gypsum. Washing efficiency can be maintained at the level of 98.5%.
- Produce gypsum containing big rhombic shaped crystals with 15 – 20% free water content.

Moreover, it has been observed that, when Al₂O₃ content in slurry liquid phase is less than about 0.08%, the gypsum becomes waxy, soft and white in colour consists of needle shaped crystals. Further increases in the content to higher 0.1% changes crystals habits from needle to rhombic shape.

Minor Element Ratio (MER)

\[
\text{MER} = \frac{\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3 + \text{MgO} + \text{MnO}_4}{\text{P}_2\text{O}_5}, \quad \text{all in %}
\]

A rock’s MER is indicative of its suitability for use in production of wet process phosphoric acid and subsequent conversion to fertilizer like DAP. If MER for phosphoric acid is below 0.10, and the suspended solids into composite acid is 2% or less then it is possible to manufacture 18:46:0 DAP grade. At slightly higher MER, a form of high nitrogen analysis like urea can be added to maintain grade. However, when MER value reaches the range of 0.135 to 0.155 the DAP product becomes off grade i.e. 16:48:0.

Impurities in Phosphoric Acid – their effects in manufacture of fertilizers:
1. **Calcium** – When fluorine is in excess of that required by aluminum, iron, chromium and vanadium, it can precipitate as CaF$_2$, provided that the soluble silica also has been satisfied. Investigation at several phosphoric acid plants showed that the acids contain higher calcium contents; two possible sources of this are: (1) the phosphoric acid unit was operated at high extraction temperatures, which caused an unusually large amount of calcium to be dissolved in the product acid from the plant; and (2) the amount of gypsum in the acid also was high because of the type of filter used or maintenance of the filter.

2. **Magnesium** – Like calcium, the magnesium ammonium phosphate was too poorly crystallized to be observed directly in the fertilizer. MgNH$_4$HFPO$_4$ could precipitate in the preneutralizer (lower pH), and MgNH$_4$PO$_4$, H$_2$O could be formed in the granulator where the pH is high. This compound can lose ammonia and water during drying of the product to produce an amorphous material. If the magnesium concentration in the DAP grade acid (~ 40% P$_2$O$_5$) is too high to make grade (14:46:0), it can be removed effectively from the acid by adding by-product H$_2$SiF$_6$ to precipitate MgSiF$_6$ to reduce the magnesium concentration to an acceptable level.

3. **Iron and Aluminium** – Chemical analyses of the water insoluble components from commercial diammonium phosphate fertilizers show that the Fe and Al precipitate is much more complex than the (Al, Fe) PO$_4$, nH$_2$O formula indicates. Iron and Aluminium also can precipitate as (Fe, Al) NH$_4$ (HPO$_4$)$_2$ when there is insufficient fluorine in the phosphoric acid to precipitate (Al,Fe)NH$_4$HPO$_4$F$_2$.x H$_2$O. The Al end member precipitates first, the Fe end member precipitates if sufficient fluorine is present. If insufficient fluorine is present, the Fe end member of the compound (Fe, Al) NH$_4$ (HPO$_4$)$_2$ precipitates first with the Al end member precipitating next. When (Fe, Al)NH$_4$HPO$_4$)$_2$ precipitates in the preneutralizer, it occurs as an amorphous gel which could contribute towards viscosity problems in the preneutralizer. This condition quickly dissipates with the temperature and retention times encountered in 18:46:0 production to produce large euhedral crystals of (Fe, Al) NH$_4$ (HPO$_4$)$_2$. In the preneutralizer, conditions of slightly higher temperatures and longer retention times have resulted in citrate-insoluble phosphate. The citrate-insoluble phosphate problem in 18:46:0 fertilizer was found to be related to the FeNH$_4$ (HPO$_4$)$_2$. Excessive quantities of iron and aluminium can be decreased in the phosphoric acid by better clarification of the insoluble sludge components from merchant-grade acids. Iron and aluminium are decreased to 0.2 to 0.3% Fe$_2$O$_3$ and 1.6 to 1.8% Al$_2$O$_3$ in wet process acid containing 54% P$_2$O$_5$ by addition of a soluble source of potassium.

4. **Zinc, Cadmium, Nickel, Manganese and Uranium** – Although each divalent trace element is relatively insignificant in quantity, their collective effect, particularly in western acids, is to neutralize a significant quantity of phosphoric acid as a low nitrogen content compound.

5. **Chromium, Vanadium** – Stability constants for complex ion formation of fluorine with chromium and vanadium are similar to those for fluorine and iron.

6. **Silica** – The silica content was associated with the water soluble fluorine and was calculated as (NH$_4$)$_2$SiF$_6$. At first, the water soluble fluorine was suspected to be (NH$_4$)$_3$ AlF$_6$; however, the absence of a significant water soluble aluminium component eliminated this possibility.
7. **Sulphate** – Only two sulphate containing compounds have been detected, viz; (NH₄)₂SO₄ and Ca₄SiAlSO₄F₁₃·12H₂O, which is an insoluble component carried over in the wet process phosphoric acid. (NH₄)₂SO₄ is the stable sulphate in equilibrium with the ammonium phosphates.

8. **Fluorine** – Other than ammonia and phosphate, fluorine is the most widely distributed element in 18:46:0 fertilizers. Fluorine occurs as Ca₄SiAlSO₄F₁₃·12H₂O, CaF₂, (Al, Fe)NH₄HPO₄F₂·xH₂O, (V,Cr)NH₄HPO₄F₂·xH₂O, and (NH₄)₂SiF₆. Precipitation of the complex metal ammonium fluoro-phosphates presents a potential method for converting residual fluorine derived from wet process phosphoric acid to an insoluble form in the 18:46:0 grade product rather than scrubbing the fluorine by expensive pollution abatement processes. Some commercial 18:46:0 producers are using their ammonia scrubbers for fluorine scrubbing by operating at a low mole ratio N:P; which is effectively the same as a preneutralizer slurry, only a little lower in pH. Usually about one-third of the acid used in the process is added to the scrubbers and the remaining acid is added directly to the preneutralizer. When all of the acid was added to the scrubbers and the mole ratio N:P was something less than 0.6; there was a significant loss of fluorine from the scrubbers. For this reason the amount of acid added to the scrubbers was limited.

9. **Phosphate** – The N:P adjustment can be used to augment either the nitrogen or phosphate level in the 18:46:0 product at the expense of the other component by precipitating NH₄H₂PO₄ (low N, high P₂O₅) or (NH₄)₃PO₄ (high N, low P₂O₅).

10. **Water** – Free water, which decreases both fertilizer components, is decreased by slightly higher temperatures and much longer retention times in the preneutralizer. Moisture can be decreased before complete ammoniation (first stage preneutralizer) if the fluorine concentration is low or in the preneutralizer if the fluorine is sufficiently high to prevent the precipitation of FeNH₄(HPO₄)₂.

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**IDEAL PHOSPHATE ROCK**

1. High P₂O₅/CaO ratio.
2. Low Organic Matter
3. Low Carbonate
4. SiO₂/F ratio to avoid excess of Fluoride in Phosphoric acid – minimizing corrosion/avoiding interference of crystal growth.
5. Low Alkali metal contact (Less scaling)
6. Low level of cationic impurities (less sludge) – low water insoluble P₂O₅ in fertilizer.
7. Sufficient cationic impurities to produce rhombic shaped dihydrate crystals – not required for hemihydrate.
8. High reactivity.
9. Be relatively soft.
10. Cl < 0.03%

\[ \text{MgO} \quad \text{MgO} \quad = \quad 0.095 \quad \text{for mainly 18:46:0 DAP} \]
\[ \text{P}_2\text{O}_5 \]
11. Hydrated silicate in the rock gives high filtration rate in Florida rock than calcinated rock.

12. MgO -does not precipitate during acidulation and also concentration.

   - Allowable MgO should be @ 0.016% of P$_2$O$_5$ content.
     \[ 0.576 = 0.6 \]

13. SA requirement = 1.706 X CaO

   ----- Wt. at 100%
   P$_2$O$_5$

   Or 97.5% of stiochiometric CaO/ H$_2$SO$_4$ ratio.

**Growing Dependence on Low Quality Rock Phosphates**

Developing process to accommodate the changes taking place in world raw material sources and supplies is a problem which applies in the field of natural phosphate processing for fertilizer manufacture as much as any. It is now becoming necessary to press into commercial use raw materials of lower quality than the minimum for which the traditional processes in current use were designed.

The concentration of presently exploitable phosphate reserves in a few countries; unforeseeable rises in export prices; the long distance of some importing countries from these sources and high transport costs resulting from the continuing rise in crude oil prices; the policy of the developing countries to utilize their own natural resources; and the vital importance of the fertilizer industry in providing essential food supplies – all these are factors which encourage the exploitation of new sources, even if their quality is lower.

Thus it is that there are on the market today phosphates with P$_2$O$_5$ content below 30% or with chlorine contents exceeding the limits permissible in “classical” wet-process phosphoric acid or nitro phosphate plants. Examples are some grades of Israel phosphate, Tunisian 65/68 BPL, Egyptian Hamrawein phosphate and Syrian phosphates. There are also now projects for commercializing some phosphates containing undesirable substances which are not suited to “classical” processes such as MgO-rich phosphates or sulphide-containing phosphates such as Egyptian Abu Tartur rock.

**The problems of impurities in low-quality phosphates**

Low quality phosphates raise problems as regards processes and engineering, which have to be solved either by adapting existing processing technology to their peculiar features or by developing suitable new technology.

Not only are rocks quarried from various deposits different but also rocks from the same deposit which have almost similar analyses may differ very much in their behaviour when processed. All phosphate rocks contain various impurities in differing ratios which have notable
effects on certain process stages in the manufacture of phosphoric acid. The main impurities are: iron, aluminium, magnesium, fluorine, chlorine, carbonate, sulphides, alkalis and organic matter.

Iron, aluminium and potassium tend to lead to the formation of precipitates consisting mainly of $\text{Fe}_3\text{KH}_{14}(\text{PO}_4)_8.4\text{H}_2\text{O}$ and $\text{Al}_3\text{KH}_{14}(\text{PO}_4)_8.4\text{H}_2\text{O}$, which diminish $\text{P}_2\text{O}_5$ efficiency. Aluminium and magnesium increase the viscosity of the product phosphoric acid. Apart from the problems caused by gaseous and liquid effluents, fluorine increases corrosion of metallic materials in the plant – a property it shares with residual sulphuric acid in the product – although this is normally less serious than the effect of chlorine, while the carbonates cause a much higher consumption of sulphuric acid and, together with organic matter, give rise to stable foams.

A number of properties should be considered besides the chemical analysis of phosphatic rocks when selecting them for the manufacture of the phosphoric acid, such as hardness, porosity and characteristics related to granulometry – particle size range and specific surface, for example.

Until recently, phosphate rocks of lower grade than 66% BPL (30.2% $\text{P}_2\text{O}_5$) have been considered economically unprocessable for phosphoric acid manufacture.

The new industrial processes may – indeed must – be flexible enough to overcome the problems caused by phosphate rocks of various qualities for the least possible increase in investment and operating costs.

Chlorine as a damaging impurity

From the economic point of view, high chlorine contents exceeding the limit acceptable for conventional phosphoric acid plants is most important, since high-chlorine rocks are quite abundant but can only be used in existing plants if they are partially rebuilt, which is very expensive.

The problem of the chlorine in phosphates is exacerbated by the fact that some principal deposits are located in areas where fresh water is scarce and consequently sea water or water from salt lakes is used in upgrading them, which increases their chlorine content.

The problem which disqualifies chlorine-containing phosphates from use in most phosphoric acid and nitro phosphates plants is, in fact, the great corrosiveness of the high-chlorine phosphoric acid towards the steels currently used in building such plants.

Corrosiveness of wet-process phosphoric acid to stainless steels

Passivation by phosphating

The corrosion resistance of austenitic Cr/Ni and Cr/Ni/Mo stainless steels to phosphoric acid is basically due to phosphating – the formation of an even film of phosphates on the surfaces exposed to the acid. The stability of this passive film (which consists usually of a layer of phosphate overlying a layer of oxide) depends on the degree of oxygenation of the chemical medium and on the chemical impurities, such as chloride, that it contains.
It may be considered that as long as the passivation layer is continuous the materials are resistant to corrosive attack by the medium. Some generalized corrosion of the whole surface may still occur as a result of dissolution and reforming of the oxide layer, which takes place as a continuous process of reduction-oxidation.

Around 100°C, even the AISI 316 Cr/Ni/Mo steels reach corrosion rates of 0.7-0.8 mm per year, which is about the highest permissible corrosion rate for most industrial purposes. Above 100°C, only high-alloy steels (Uranus type and others) are satisfactory, as will be explained further on.

As during the phosphoric acid manufacturing process the medium is not always the same, and since it unavoidably contains a number of impurities such as H2SO4, H2SiF6 and HF, the actual corrosion rates may be higher at a particular combination of temperature and concentration.

<table>
<thead>
<tr>
<th>Group</th>
<th>Corrosiveness</th>
<th>Phosphate</th>
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<tbody>
<tr>
<td>I</td>
<td>Low</td>
<td>South Africa (Phalaborwa)</td>
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<td></td>
<td></td>
<td>Nauru</td>
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<td></td>
<td></td>
<td>Senegal (Taiba)</td>
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<td></td>
<td></td>
<td>Florida (Tanyasa, Pebble)</td>
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<tr>
<td></td>
<td></td>
<td>Brazil (Araxa)</td>
</tr>
<tr>
<td>II</td>
<td>Medium</td>
<td>North Carolina</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Kola</td>
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<tr>
<td></td>
<td></td>
<td>Morocco (Khourighba, Usufie)</td>
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<td></td>
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<td>Turisia (Gafsa)</td>
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<td></td>
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<td>Togo</td>
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<tr>
<td>III</td>
<td>High</td>
<td>Sahara (BuCraa)</td>
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<tr>
<td></td>
<td></td>
<td>Syria*</td>
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<tr>
<td></td>
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<td>Jordan*</td>
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<td>Israel*</td>
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<td></td>
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<td>Mexico*</td>
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</tbody>
</table>

*High-Chlorine Phosphates

**Effects of individual impurities and alloy constituents**

Corrosive attack is worsened by high fluoride and chloride contents but is lessened by the presence of silica and alumina, which form complexes with fluoride. From also has a beneficial effect, as it increases the cathodic reaction and promotes the active-passive transition.

Chromium is the most favourable steel additive, as it diminishes the degree of passive corrosion and increases the possibility of active-passive transition. Molybdenum and, to a lesser extent, copper also have a positive effect on the active-passive transition. The main function of nickel as an alloying element is to form the austenitic structure.

Because there is such a multitude of factors affecting the corrosion performance of steels in wet-process phosphoric acid and also because of the variation in the specific conditions...
between processes, particularly the nature of the reaction medium, acid concentration and temperature, a wide range of alloy steels has been developed for phosphoric acid plant duty.

**Effects of reaction conditions**

The corrosion effect of phosphoric acid on special steels is strongly influenced by other factors besides impurities present, such as temperature, acid concentration, oxygen present in the acid as oxidizing compounds, Fe³⁺, Cr⁶⁺, and especially by the composition of the steel and metallurgical factors (for example, the sensitization which occurs when a stainless steel is heated in connection with welding).

**Process Systems and Calculations**

The phosphate rock user lives in a permanent state of doubt and suspicion about phosphate rock composition and analysis. Whatever will happen in a plant or with the quality of a commercial product, the user’s first reaction often is: “Hasn't the rock changed?” In fact, the rock is sometimes a welcome scapegoat – without a defender.

Once the phosphate ore is sent into the phosphoric acid plant, things do not improve; they get even worse. The components of the phosphate ore split into a three-phase system, each component having its own splitting coefficient. Solids, liquids, and gases leaving the phosphoric acid reaction system are not pure substances; they are complex mixtures.

Some of the phosphate rock remains unattacked within the calcium sulphate. The calcium sulphate produced is not pure but a mixed crystal containing dicalcium phosphate, and these crystals are mixed with a number of other crystallized substances, such as sodium silicofluorides.

The liquid phase, the product acid, contains, besides phosphoric acid, most of the impurities that originate from the phosphate rock and the process water, plus some of the sulphuric acid. However, these impurities are subject to further precipitation, called sludge, while the product acid is cooling an aging in the storage tanks.

The physical and chemical properties of phosphoric acid depend in large part on the impurities remaining with the acid. In heavily loaded acids the sum of impurities can amount to some 30 wt % compared to the P₂O₅ content of the acid. During concentration by evaporation, further changes occur. Fluorides and chlorides escape partially into the gas phase and other complex compounds precipitate as sludge, this time including complex phosphate compounds.

**Preparation of the Data**

The first step is to have at hand the information on which the material balance calculation will be based, as follows:

1. Production capacity in tons per day of P₂O₅. This capacity is a function of process design and feed phosphate rock characteristics. The two are inseparable. An
existing installation with a proven capacity based on a specific rock need not necessarily produce at the same capacity with a different rock.

2 Phosphate rock composition: This information should be as complete as possible. As a minimum, P₂O₅, CaO, and SO₃ content must be known.

3 Rector slurry solid content and P₂O₅ content (in the liquid phase): If no actual information is available, use 25% solids and 28% P₂O₅ in the liquid phase.

4 Gypsum quantity (better still, total solids) produced per ton of feed rock: It is best to determine this value through bench-scale testing because theoretical calculations are not always representative of reality. Nevertheless, a calculation procedure will not be presented in the following section. The water content of the gypsum cake at filter discharge should be known or assumed (from 20% to 40%).

5 P₂O₅ losses: If not already known, these losses will be estimated with an empirical equation.

Recycle Acid System

Recycle acid, also called return acid, is the liquid phase resulting from washing filter cake with process water. Thus the recycle acid contains the process water plus the amount of product acid that was retained within the filter cake before washing.

1. Process water going into the system satisfies the total water requirements for:
2. Product acid water content (or dilution water – about 50% by weight in 30% P₂O₅ acid)
3. Gypsum crystal water
4. Vaporization cooling of the reaction slurry

To have a smoothly operating phosphoric acid unit means having a smoothly operating return (or recycle) acid system. The problem is how to do this, because the recycle acid system is subject to destabilizing factors and consequently is difficult to control.

Recycle acid is transferred directly from the operating filter; there is no surge capacity, and it is subject to fluctuations both in flow rate and P₂O₅ composition, due to the following: (1) cake filterability variations, (2) residual cake moisture variations, and (3) operating inaccuracies such as filter slurry load, slurry composition, wash water load, filter speed, positioning of the wash rows.

These three factors also interact. If the operator controls wash water flow, he or she knows the water loading on the filter but does not know the amount of water that will go into the system, because the filter cake carries some of it away as residual cake moisture. The latter is dependent on crystal qualities, cake thickness, temperature, filter speed (drying time) and vacuum.

Also, at the end of the first filtration section (product acid section) the amount of phosphoric acid remaining in the cake is variable, which in turn causes variability in the volume of
filtrate available for transfer as product acid and as recycle acid. This amount of acid held up in the cake at the end of the first filtration section depends on:

1. Crystal or cake quality
2. Viscosity of the phosphoric acid (dependent on concentration and impurities)
3. Temperature of the slurry
4. Filter load or cake thickness
5. Solid content of the slurry
6. Filter speed
7. Vacuum of the filter system

**Heat Balance**

Heat balance for wet process phosphoric acid processes is difficult to calculate with sufficient accuracy from thermodynamic tables. The composition of the raw materials and the heavy impurity load of the phosphoric acid make evaluation inaccurate. We have consequently chosen a more pragmatic approach by taking the basic data for heat release from plant experience. By comparing a great number of heat balances from operating plants, we evolved a simple method for the determination of heat balance with sufficient accuracy, both for engineering design and for the operating of a wet process unit. Most of the heat released from the reaction medium originals from sulphuric acid dilution, and the reaction heat itself are, again, directly tied to the amount of consumed sulphuric acid. It is obvious subsequently that the heat / H₂SO₄ ratio will be more consistent than the heat / P₂O₅ ratio. Consequently, the heat equations we shall propose here will be based on that assumption.

**P₂O₅ Losses**

Definition of P₂O₅ Losses

Before dealing with the problems of P₂O₅ losses, we must first define what various groups of people understand by the term “losses.”

When one buys a phosphoric acid plant, the engineering contractors, in the heat of competition, guarantee a certain maximum level of P₂O₅ losses. These losses are measured, by means of certain procedures laid down in the contract, during the days where the test run occurs. During the test run, monitoring is, of course, at its most efficient level; there are usually no start-ups and shutdowns, and consequently the resulting value for the yield of recovery will be higher than under normal operating conditions. However, when it comes to normal production conditions, many factors intervene, such as start-ups, breakdowns, shutdowns, technical hitches, spills, cleaning, and so on, and thus the overall losses measured throughout the year will be quite a bit higher.

Finally, when the plant accountant balances the books with respect of purchases and sales of P₂O₅ he or she will find even more losses. If the plant is well managed, the increase in losses compared with the chemically measured losses will be only 0.5 – 1% of the total P₂O₅. Nevertheless, cases of losses in this category have been reported as high as 4% above measured losses (frequently during the initial production year). In general, however, once the
plant has formed its normal operating rhythm, these losses stabilize around the 1% mark and when measuring losses, it is a common practice to add this percentage to the measured losses. This added percentage is called “mechanical loss.

It is thus imperative that we resort to the accountant’s figures for a true picture of the actual losses. It is this type of losses that we will consider throughout this section of P₂O₅ losses.

**Fluorine**

Phosphate rock always contains fluorine. For F/ P₂O₅ ratios, the fluorine content in rock of sedimentary origin ranges in general from 0.10 to 0.14. Rock of igneous origin shows lower ratios, from 0.04 to 0.06.

Calculating with fluorides or establishing the fluorine balance of a phosphoric acid plant is a very difficult matter, for the following reasons:

1. Analyses of fluorine and fluorides are tedious and often inaccurate.
2. Fluorides, once they have entered the reaction system, become volatile compounds partially escaping the phosphoric acid slurry in various proportions.
3. Fluorides enter into many complex compounds, such as A1F₆³⁺ and SiF₆²⁻.
4. Fluorides build many compounds with limited solubility in phosphoric acid, varying with temperature and phosphoric acid concentration, so that fluorides are permanently found in gas, liquid, and solid phases (2).

**Scaling**

How to Predict the Scaling Tendencies of Rocks

Usually, there is much more sodium than potassium in phosphate rock and Na₂SiF₆ is the dominant precipitating fluoride compound during the reaction and filtration stage of phosphoric acid production. Every acid producer is familiar with the large, white, scaling plates of Na₂SiF₆ which occur along reactor walls, agitator shafts, and especially in the 30% product acid pipes, which have to be washed about once a week (speed of dissolution about 1 mm/hr with 30oC open cycle water).

With hemihydrate systems operating at higher P₂O₅ product acid levels the Na₂SiF₆ scaling still affects the 30% P₂O₅ level, but in this case it is the return acid section (the first wash after the product acid section on the filter). Steam heating and dilution have to be used to cope with that scaling case. Usually, there is very little potassium content in phosphate rock and K₂SiF₆ is therefore less common.

Occasionally, phosphate rock might be contaminated due to shipping or handling in storage (e.g., with KCl) and this can change the picture. In this case, the water wash sector pipe of the filter usually plugs completely, once a day, with K₂SiF₆ and NaKSiF₆.
Sodium is contained in most of phosphate rocks but may be increased by the use of process water containing sodium. This happens frequently in North Africa and in the Middle East, where the locally mined rock is converted into phosphoric acid and the local water currently contains more or less sodium chloride. This can bring great changes into the fluorine distribution ratio between the liquid and the solid phase in the slurry. 6F- precipitate with 2Na+, so, small sodium values cause greater fluorine variations.

COMPARING PROCESSES
Selection of the optimum process requires careful evaluation of capital and operating costs, requirements for raw materials and reagents, quality of products and by-products, utility situation, opportunities to recover valuable raw materials, and a variety of other issues. Every project has its own set of needs, costs and opportunities, so a detailed evaluation is necessary to pick the process. Factors which often vary so greatly that they have overwhelming influence on process selection include:

- Performance of phosphate rock in the various processes
- Phosphate rock cost, delivered
- Sulfur cost, delivered
- Value of exported electric power
- Gypsum utilization or disposal situation
- Opportunity to recover uranium

The main issues are discussed below in a qualitative manner, based on typical or average situations. Any project that is being seriously considered should involve a comprehensive evaluation of each of these issues, including cost information that is specifically tailored to the site.

To help provide an overview of issues to consider, the three processes are rated in the attached “Di, Hemi, and Hemi-Di Processes Comparison Table. This table relates to average situations, but one must recognize that any individual project may have circumstances that are far from typical.

CAPITAL COST – REACTOR/FILTER SYSTEM
A Di process will usually have the least expensive main reactor. Experience with dihydrate reactors over several decades has demonstrated that many plants are operating at capacities that are more than double original design capacity. Such experience is utilized to confirm that new reactors can be much smaller than those of a few decades ago. Hemi reactor size requirement has also tended to decrease as plant experience is gained, but the Hemi process has a shorter track record to draw from.

Filter size requirement varies greatly with the type of phosphate rock that is utilized. Pilot plant testing of the phosphate rock can predict filtration rate before the plant is designed. It has been my observation that filtration rate tends to average somewhat higher with a Di process than with a Hemi process. However, there are many exceptions, so a valid comparison between the two processes must consider experience in real plants and pilot plant testing.

Since the Hemi process operates at hotter temperatures, metals tend to corrode somewhat faster than in the Di process. Consequently, metals in agitators, pumps, and filter wetted parts will usually be somewhat more expensive in a Hemi plant. Flash coolers in Hemi reactors can be significantly smaller and require less circulation rate than those in Di plants. However, Hemi plants require more fume collection capacity and efficiency than Di plants.

The entire reactor/filter system for a dihydrate process will usually be smaller and less expensive than for a Hemi process. A Hemi-Di process requires a Hemi reactor/filter system.
followed by a simpler and smaller dihydrate reactor/filter system. Consequently, reactor/filter
capital cost is very high in a Hemi-Di plant.

CAPITAL COST OF OTHER PLANT SECTIONS

The Hemi process has advantages outside of the reaction and filtration sections that tend to
allow the total plant capital cost to be significantly less than with a Di process. The first
advantage is that the Hemi reaction does not require the phosphate rock to be ground as
finely as does the Di process. The popular Yara (Hydro) Hemi process can use rock
particles as large as 2 mm (9 mesh), compared to a typical 35 mesh requirement with the Di
process. This means that a Hemi plant can use phosphate concentrate and other phosphate
up to 2 mm in size without any processing. In contrast, a Di process usually requires rock to
be finely ground in a ball mill, requiring major expense for capital, operation, maintenance,
and energy. A Di plant makes filter product acid at around 27% P₂O₅ concentration,
compared to about 42% P₂O₅ acid from Hemi filters. Consequently it requires additional
evaporators to concentrate this acid, along with substantial investment for additional cooling
water and acid storage facility. A Hemi plant normally has lowest capital cost for a new
plant, because it usually avoids rock grinding (except with pebble-sized rock), it requires
much less (if any) evaporation of acid, cooling water is minimized, there is no 27% P₂O₅
acid to handle, and product acid clarification is usually unnecessary.

Although a Di process might have a less expensive reactor and filter section, it would
require all of those extra plant sections and expanded capacities. Consequently, the whole
plant containing the Di process would normally cost around 20-25% more than a Hemi
process plant. A Hemi-Di process shares Hemi’s advantages of eliminating or down-sizing
of those plant sections. However, Hemi-Di requires a second (but simpler) set of reaction
and filtration facilities, which roughly offset savings in other sections. I would guess that the
whole Hemi-Di plant would cost no more than a whole Di plant, when cost of rock grinding,
evaporators, acid handling, and cooling are considered.

PHOSPHATE ROCK & SULFURIC ACID REQUIREMENT

Most loss of product in a phosphoric acid is in the filter cake, so filter recovery has the
largest influence on how much raw materials are required. This must be evaluated on a
case by case basis. Licensors guarantee performance including recovery at the filter cake
for the specific plant and conditions. Di and Hemi plants typically achieve filter recovery in
the mid-90% range, with Di plants averaging perhaps a percent or so higher than Hemi
plants. Hemi-Di recovery (based on filter cake) is typically 98-99%. There will be
considerable additional losses beyond filter cake losses. Phosphoric acid is lost by
entrainment from flash coolers and evaporators, leakage from seals, filter mechanical
losses, dumping of acid during maintenance and cleaning, and accidental spills. The total of
such losses may amount to a percent or two of product in a typical plant. Hemi & Hemi-Di
plants have much less evaporator entrainment losses, because very little evaporation of
acid is required. Only Di plants are exposed to losses from handling 27% P₂O₅ acid because
Hemi & Hemi-Di don’t produce the weak acid. Hemi-Di plants have additional exposure to
general material handling losses around reactors and filters, because they have more
reactors and filters. There can be opportunities to recover what had been lost. Many plants
recirculate the acidic water from the gypsum stacks and/or cooling water systems. Some of
this acidic water is used to wash the filter cake. Most cake wash water proceeds through the
filter and ends up in product acid. Thereby, over half of all phosphoric acid which had been
lost into this acidic water is eventually recovered from the recirculated water.

Any plant that recirculates acidic water from the gypsum stack will recover most of the water
soluble losses in the filter cake. However, water insoluble losses from a Di plant (or the Di
filter in a Hemi-Di plant) remain locked in the dihydrate gypsum crystals, so it cannot get
recovered. This refers to losses that are reported as CI losses (citrate insoluble – undissolved rock) and CS losses (citrate soluble – co-precipitated dicalcium phosphate in gypsum crystals – the majority of filter losses).

A Hemi plant that recalculates acidic water from the gypsum stack has an added recovery benefit. This is because the hemihydrate gypsum crystals will release co precipitated dicalcium phosphate out of the crystals and into the surrounding water which recover most of the water soluble losses from the filter cake. For example, a typical Hemi filter cake contains co-precipitated dicalcium phosphate (citrate soluble P\textsubscript{2}O\textsubscript{5} ) equivalent to 3.5% of the feed. After discharging from the filter the hemihydrates crystals gradually dissolve while forming dihydrate crystals. The co-precipitated dicalcium phosphate dissolves in the acidic water and very little re-precipitates into the dihydrate crystals. Thus about half of that 3.5% loss (1.75%) gets recovered when recirculated water is used to wash the filter cake. P\textsubscript{2}O\textsubscript{5}

Recovery Rankings for the three processes are typically as follows. High recovery means low phosphate rock requirement.

1st: HEMI-DI
   High recovery 98-99% is the reason for this fancy process

2nd: HEMI with Recirculation of Water from Gypsum Stack
   Recovery of an extra couple percent of lost P205 gives Hemi the advantage over Di.

3rd: TIE: HEMI & DI
   Di usually has a slight edge with recovery based on filter cake, but Hemi avoids evaporator entrainment and weak acid handling losses. A Hemi reactor needs significantly less sulphuric acid than a Di reactor, primarily because of the reduced ratio of sulphate to phosphate in the reactor acid. Acid from Hemi reactors typically contain 2% free SO\textsubscript{4} and 43% P\textsubscript{2}O\textsubscript{5} (a ratio of 0.46), whereas Di reactor acid is typically 2% free SO\textsubscript{4} and 27% P\textsubscript{2}O\textsubscript{5} (a ratio of 0.74). Another small advantage with Hemi is that slightly less sulphuric acid reacts with aluminium impurities. In the Hemi process these effects amount to needing about 2.5% less sulphuric acid than with a Di process with similar recovery. Sulphuric acid consumption will track with P\textsubscript{2}O\textsubscript{5} recovery, except that Hemi & Hemi-Di have about 2.5% advantage – due primarily to low-sulphate product. The processes typically rank in this order regarding sulphuric acid consumption: Hemi-Di, Hemi, and Di.

ACID CONCENTRATION
Most dihydrate phos acid plants make 25-29% P\textsubscript{2}O\textsubscript{5} product. Higher product concentration is impractical, because it would involve pushing operating conditions into the unstable hemi/di transition boundary. Hemi plants produce phosphoric acid directly from filtration at concentrations between 38% and 46% P\textsubscript{2}O\textsubscript{5} . Optimum concentration has been around 43% P\textsubscript{2}O\textsubscript{5} which is near the “sweet spot” where a Hemi plant performs best. Rapidly increasing energy value may entice anyone who operates or designs a Hemi plant to raise product concentration to further enhance energy efficiency. Higher product concentration would require somewhat larger reactor and filters, and recovery might decline. However, these tradeoffs may be wise, considering the energy benefits to be gained. Hemi-Di plants benefit from water balance and cake washing situations that make it practical to make even higher concentrations of phosphoric acid – ranging from 40% to 50% P\textsubscript{2}O\textsubscript{5}.

ENERGY EFFICIENCY
Energy efficiency is essential in dealing with global warming. The Hemi process’ forte is efficient use of energy. Its high product acid concentration avoids the need for the huge
quantity of evaporator steam that would otherwise be required to make product concentration suitable for further processing. Ongoing trends of soaring energy costs and need to conserve energy will further magnify this advantage in coming years. The biggest source of energy for a typical phosphate chemical complex is sulphuric acid production. Surplus heat from burning of sulphur is absorbed by steam, which is used to generate all electric power required by the complex plus an export of power. Energy efficiency of a phosphate complex is greatly enhanced by use of the Hemi phosphoric acid process. A 1,500 T/D P₂O₅ phosphoric acid plant will save about 2500 T/D in evaporator steam by making filtered acid at 42% P₂O₅ compared to dehydrate process acid at 26% P₂O₅. This surplus steam would typically be used to generate electric power. Total electric power production is near 60 megawatts for a 1500 metric T/D P₂O₅ phosphate complex. The surplus electric power could be exported to the power grid for sale, or it could be wheeled to the owner’s mine or other nearby facilities. Future electric power values are likely to increase substantially as other sources of energy become increasingly expensive.

A 1500 T/D Hemi or Hemi-Di plant would typically save another 3 MWs of electric power by not having to grind rock, and by having much smaller acid evaporation requirement. Hemi & Hemi Di plants also save the electric motor power that Di plants need to operate additional evaporators, cooling water pumping, and acid handling facilities. Hemi-Di plants do require substantial power for the second reactor and filters, thus offsetting part of the motor power savings. It is important to note that any utilization of energy from waste heat is environmentally friendly. This electric power is produced with incremental net results of no pollution, no greenhouse gas, no solid waste, and no consumption of fuel. No other source of energy can top this for ecological responsibility - whether it uses coal, oil, gas, nuclear fuel, wind, or solar energy.

Energy Efficiency rankings for the three processes would be:

1st: HEMI needs little or no evaporator steam
   Avoids rock grinding (usually)
   Less power for evaporation, acid handling, and cooling water

2nd: HEMI-DI same advantages as Hemi
   However, the second reactor and filters need more power.

3rd: DI A distant last place.

AVOIDING ROCK GRINDING

The Hemi phosphoric acid process can use rock which is much coarser than that required for conventional dihydrate processes, so grinding is not required for most of the world’s phosphate rock sources. Particle size requirement for Hemi is typically -9 mesh (-2 mm), versus -35 mesh (0.42 mm) for typical dihydrate processes. The Hemi process can handle damp rock with up to about 15-20% moisture. Most commercial phosphate rock sources worldwide are suitable in particle size and moisture content for feeding directly to a Hemi plant without drying or grinding. This includes coarse concentrate and some screened phosphate rocks.

An important exception is that the pebble rock which makes up a significant portion of central Florida phosphate is much too coarse to feed directly to any phos acid plant. Pebble rock could be ground to -2 mm size in relatively low energy roller, impact, or hammer, mills with closed circuit screening. This pebble rock is available dripping wet with about 10% moisture, and drying would be quite expensive. Consequently, the recommended method would be to grind the damp rock without drying, followed by wet screening and recycle of damp +2 mm material to the mill. Such milling requires only a fraction of the power and capital cost that a ball mill requires.
OPERATOR, MAINTENANCE, AND CLEANING COST

Both Hemi and Hemi-Di benefit from elimination of rock mills and evaporators, and have smaller acid handling and cooling water sections than a Di plant. Hemi reactors and flash coolers stay cleaner than those in Di plants. Di filters stay cleaner than Hemi filters. A Hemi-Di process has a second reaction and filtration second to operate and maintain. A Hemi plant should have a significant advantage over either Di or Hemi-Di, because there is much less equipment to operate and maintain.

Hemi reactors have a major stability advantage, because they operate in a stable zone, well above the hemi/di transition boundary. Substantial changes in temperature and concentration can be tolerated without approaching the transition. Operating control is less critical, and the reactor is more forgiving to upset conditions or sudden changes in rock feed characteristics. This accounts for praise by those that operate the plants that they are easier to operate, more stable, and more forgiving than dihydrate plants. There is relatively little scale formation in the reactors and flash coolers, because of operating in the stable zone, and because there is lower solubility of calcium sulfate. Hotter conditions in Hemi reactors and filters cause faster corrosion to agitators, filter metal surfaces, etc. Optimum metals for Hemi service are typically one step up from metals that would be optimum for dihydrate service. Hemi reactor agitators are typically in the 904L or Ferallium 255 class, although existing 317L agitators have lasted fairly well in plants that were retrofitted from di to hemi. Upper agitator shafts in either hemi or di reactors require rubber coating. Filter pans are normally 317L or either process, but Hemi plants with highly corrosive acids should use 904L. Belt filter vacuum boxes are typically 904L.

OPERATING STABILITY

Either a hemihydrate or dihydrate process can operate stably if the conditions are clearly in either the hemihydrate or dihydrate zone. Dihydrate plants must limit reactor concentration in order to keep below a transition zone between hemihydrate and dihydrate. When concentration or temperature gets a little too high, the gypsum crystals form as a mixture of dihydrate and hemihydrates crystals. These crystals are small, which reduces filtration rate. Wherever the slurry cools, scale forms inside the reactor, pumps and piping. For economic reasons dihydrate plants must push slightly into the transition zone, but good control can minimize problems. If a dihydrate reactor is allowed to get seriously over optimum temperature or concentration, filtration becomes extremely slow, and equipment scaling is severe. Crystals in a typical dihydrate plant are a mixture of some hemihydrates among mostly dihydrate crystals. Dihydrate plants tend to have far more scale formation in reaction and flash cooling systems than hemi plants. Hemi reactors have a major advantage, because they operate in a stable zone, well above the hemi/di transition zone. Substantial changes in temperature and concentration can be tolerated without getting into the transition zone. Operating control is less critical, and the reactor is more forgiving to upset conditions or sudden changes in rock feed characteristics. This accounts for praise by those that operate the plants that they are easier to operate, more stable, and more forgiving than dehydrate plants. There is relatively little scale formation in the reactors and flash coolers, because of operating in the stable zone, and because there is lower solubility of calcium sulfate. The "Calcium Sulfate Crystallization Graph" shows a hemi/anhydrite transition above the hemi zone. In actual practice this transition is so high that it is rarely a problem, except occasionally in some hemi-di plants which push reactor acid concentration to 48-50% P₂O₅.

In a Hemi plant conditions in filtration pass through the Hemihydrate/Dihydrate transition line. Crossing this transition caused problems for early Hemi plants. However, technology has been developed which allows this transition to be crossed with minimal scaling in the
filter system. Part of this technology has been use of an anti-scaling reagent that greatly slows the conversion of hemihydrate crystals to dihydrate crystals, thus reducing scaling.

**COOLING WATER REQUIREMENT**

Hemi & Hemi-Di plants have less need for the huge flow of cooling water normally required by phos acid evaporator condensers - perhaps none at all. A relatively small flow of cooling water is required for flash cooler condensers, fume scrubbing, equipment washing, etc. This water does not need to be as cool as the 33-35°C (92-95°F) required for 52-54% P₂O₅ evaporators in a dihydrate phos acid plant. Water at around 38°C (100°F) will be adequate for scrubber water, equipment wash, etc., and more than adequate for flash cooler condenser water. Hemi & Hemi-Di plant cooling pond and associated pumps and piping are a fraction the size of comparable equipment in a Di plant.

**ACID STORAGE AND CLARIFICATION**

Phosphoric acid storage and clarification facilities in a Hemi or Hemi-Di plant are about one third that required for a dihydrate plant. There will be agitated storage tanks for 42% acid (and possibly some 30% acid for DAP scrubber feed). Clarification is not necessary because the 30% and 42% phosphoric acids have both come from filtration, and because the high purity of Hemi acid makes further clarification unnecessary for product analysis purposes. Di plant would typically require storage and clarification for 26% and 42% acid, plus agitated storage (and often clarification) for 52-54% acid.

**PHOSPHORIC ACID PURITY & BENEFITS TO FERTILIZER ANALYSIS**

Phosphoric acid from a Hemi or Hemi-Di plant is purer than that from a Di process, with lower sulfate, aluminum, fluoride, and solids content. DAP, MAP, and TSP produced from this acid will be about 2 percentage points higher in P₂O₅ than that from a dihydrate plant. This facilitates production of on-grade DAP and TSP from phosphate with high impurity levels. MAP grade would rise, thus reducing shipping cost. Effect of acid purity on DAP nitrogen content is more difficult to predict, because %N is affected not only by product purity, but also by efficiency of ammonia absorption. Calculated DAP grade benefit is over 0.5 percentage points in N, but this assumes adequate ammonia absorption. Effect of Hemi acid purity on DAP grade was demonstrated at the Belledune plant, which was converted to Hemi in 1986, using 66-67 BPL central Florida rock. Before the Hemi conversion is was difficult to meet 18-46-0 DAP grade, using settled 40% P₂O₅ acid. Upon Hemi start-up, grade jumped to about 47.5% P₂O₅ and easily exceeded the 18% N requirement, using un-settled 40% acid. A simple modification was employed to prevent over-formulation of DAP.

**REAGENT REQUIREMENTS**

Nearly all phosphoric acid reactors require defoamer. Hemi and Hemi-Di plants sometimes add clay to the hemi reactor to modify crystal shape and/or absorb corrosive free HF. Hemi-Di plants sometimes add clay to the second reactor to facilitate transformation of hemi gypsum crystals to dihydrate form.

**WATER CONSUMPTION INTO THE PROCESS**

A Di process must consume much more water into the process than a Hemi or Hemi-Di process, largely due to the effect on water balance for producing 27% versus 42% P₂O₅ product. Water consumption can be good, bad, or of little consequence, depending on the circumstance. A plant receiving ground rock slurry from a wet ball mill would have to have a Di process. That much water would drown a Hemi reactor. However, a Hemi reactor does
not need finely ground rock, so a wet ball mill should not be involved anyway. There may be other reasons to want to consume extra water into a reactor. For example, one client expressed interest in a Hemi conversion, but the plant received 70% sulphuric acid at very low cost. There was too much water in 70% \( \text{H}_2\text{SO}_4 \) for the Hemi process to work, so the plant kept its Di process. The Di process could have an advantage where phosphate rock is received as slurry by pipeline, because it might be able to consume the entire slurry without de-watering. Such rock slurry would have to be partly de-watered to feed a Hemi plant. For plants in a desert or other location where water is very expensive, the Hemi reactor’s lesser need for water is an advantage. The Hemi plant also has an advantage at the gypsum discharge end. Free moisture in filter cake is about the same for a Di or Hemi filter. However, Hemi filter cake contains far less water of hydration, because of the difference between calcium sulphate hemihydrate versus calcium sulphate dihydrate. Plants in deserts often discharge gypsum to the gypsum stack as filter cake, rather than as slurry. In such plants the difference in total water content in the gypsum is important. Hemi gypsum cake is “self drying” because hemi gypsum absorbs most of the free water from the filter cake as gypsum converts from hemi form to dihydrate form. In desert conditions, this leads to another advantage of discharging Hemi filter cake. This “self drying” gypsum will never seep free water downward. Thus there is no real need for using an expensive water-proof liner under a hemi gypsum stack. In some situations it might be necessary for the plant owner to convince regulatory authorities not to mandate a multi-million dollar expense for a useless liner. The same self drying gypsum advantage is achieved with a Di-Hemi or Hemi-Di-Hemi process. It is not achieved with a Hemi-Di process, because Hemi-Di discharges dihydrate gypsum from the Di filters.

**PROCESSING IMPURE ROCK**

There is increasing evidence that the Hemi process performs well with some types of Phosphate rocks those are impractical to process with conventional dihydrate processes. This includes rock with very low \( \text{P}_2\text{O}_5 \) concentrations and unusually high levels of iron, aluminium, and magnesium impurities. Such rock is either left in the ground, blended with higher grade rock, or processed for further purification.

A company that has both Hemi and Di plants routinely routes the lowest grade rock to the Hemi plant, because it processes it more easily. At the Di plant is unable to make on grade DAP from clarified acid; when the plant was converted to Hemi, it immediately exceeded DAP grade by a wide margin.

**GYPSUM UTILIZATION**

Gypsum from phosphoric acid plants can be utilized to produce a variety of products. Such phospho-gypsum has been used for road-bed material, cement ingredient, sulphate fertilizer, agricultural soil conditioner, or gypsum wall board. Further processing of the gypsum can produce limestone, ammonium sulfate, sulfuric acid, glass, and ceramics. Suitable high purity phospho-gypsum can be produced from either a Hemi-Di process or a Di-Hemi process.

Gypsum of moderate purity is obtained by re-washing gypsum cake from phosphoric acid filters. Hemi, Di-Hemi, and Hemi-Di-Hemi processes produce gypsum filter cake that is self drying, which can be a major advantage for drying requirements when gypsum is utilized. This self-drying occurs because hemihydrate gypsum absorbs most of the free water from filter cake when it converts to dihydrate gypsum.

**CONCLUSION**

Developing process to accommodate the changes taking place in world raw material sources and supplies is a problem which applies in the field of natural phosphate processing.
for fertilizer manufacture as much as any. It is now becoming necessary to press into
commercial use raw materials of lower quality than the minimum for which the traditional
processes in current use were designed.
The concentration of presently exploitable phosphate reserves in a few countries;
unforeseeable rises in export prices; the long distance of some importing countries from
these sources and high transport costs resulting from the continuing rise in crude oil prices;
the policy of the developing countries to utilize their own natural resources; and the vital
importance of the fertilizer industry in providing essential food supplies – all these are
factors which encourage the exploitation of new sources, even if their quality is lower.
Thus it is that there are on the market today phosphates with \( \text{P}_2\text{O}_5 \) content below 30% or
with chlorine contents exceeding the limits permissible in “classical” wet-process phosphoric
acid or nitro phosphate plants.
Low quality phosphates raise problems as regards processes and engineering, which have
to be solved either by adapting existing processing technology to their peculiar features or
by developing suitable new technology.
Not only are rocks quarried from various deposits different but also rocks from the same
deposit which have almost similar analysis may differ very much in their behaviour when
processed. All phosphate rocks contain various impurities in differing ratios which have
notable effects on certain process stages in the manufacture of phosphoric acid. The main
impurities are: iron, aluminium, magnesium, fluorine, chlorine, carbonate, sulphides, alkalis
and organic matter. Therefore phosphoric acid manufacturers who process low grade rock
phosphate have to accept lower standard or improve over poor performance by modifying
operating conditions and/or plant design and possibly consider use of additives. A better
understanding of Phosphoric Acid manufacturers for effects of impurities in Rock Phosphate
to select Rock Phosphate on economic implications applied to their own plants. These
effects of impurities need not necessarily same for different manufacturers.
<table>
<thead>
<tr>
<th>Sr No</th>
<th>Parameter</th>
<th>Di hydrate</th>
<th>Hemi hydrate</th>
<th>Hemi – Di</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Capital Cost</td>
<td>Plant involves grinding evaporator and bigger cooling tower and a clarifier added to a hemi plant. Reactor 2m3/t P2O5</td>
<td>20% lower than di plant; Reactor is smaller and plant can be loaded to have a Volume of 1.5m3/ton P2O5</td>
<td>Same as di plant due to added reactor and filter</td>
</tr>
<tr>
<td>2</td>
<td>Rock grinding</td>
<td>50kw/ton P2O5</td>
<td>No grinding power</td>
<td>No grinding power</td>
</tr>
<tr>
<td>3</td>
<td>Evaporation</td>
<td>Bigger units as 2 tons Water is to be evaporated per ton P2O5 for concentrating from 26% to 54% P2O5</td>
<td>Smaller unit as 0.5 tons water is to be evaporated per ton P2O5 for concentration from 42 to 54% P2O5</td>
<td>Smaller unit – 0.45 Ton of water/Ton of P2O5 for concentration from 43 to 54% P2O5</td>
</tr>
<tr>
<td>4</td>
<td>Cooling water</td>
<td>More qty needed cooling water at 33’c</td>
<td>Less and cooling water can be higher at 38’c</td>
<td>Same as hemi plant</td>
</tr>
<tr>
<td>5</td>
<td>Operating cost</td>
<td>More due to grinding (50KW) and evaporation units (300KW) equivalent power</td>
<td>Less due to smaller evaporator and steam needs</td>
<td>Higher due to 2 reactors and filters – Power 30KW/T P2O5 more than Hemi plant</td>
</tr>
<tr>
<td>6</td>
<td>Filter recovery</td>
<td>At 95%</td>
<td>Less about - 92%</td>
<td>Highest at 98%</td>
</tr>
<tr>
<td>7</td>
<td>Product acid Strength</td>
<td>28% P2O5</td>
<td>40 – 42% P2O5</td>
<td>42% - 43% P2O5</td>
</tr>
<tr>
<td>8</td>
<td>Purity suitable for DAP</td>
<td>Impurities more can affect high grade fertilizer production</td>
<td>Purer acid suitable direct use in DAP manufacture</td>
<td>Same as hemi plant</td>
</tr>
<tr>
<td>9</td>
<td>Water consumption</td>
<td>More due to dihydrate cake and filter product is lower concentration of 28%. Gypsum storage needs liner</td>
<td>Hemi hydrate has lesser water and gypsum is self drying and acid of 42% P2O5 has less water. Gypsum storage is easy</td>
<td>Semi as hemi plant</td>
</tr>
</tbody>
</table>
EFFECT OF REACTION CONDITIONS ON CALCIUM SULPHATE CRYSTALLISATION

Temperature°C

260
240
220
200
180
160
140
120
100
80
60
40
20

PERCENT $P_2C_S$

5 10 15 20 25 30 35 40 45 50 55 60

Anhydrite $CaSO_4$

Hemihydrate

Dihydrate $CaSO_4 \cdot 2H_2O$

$CaSO_4 \frac{1}{2} H_2O$

Typical Operating Ranges:
Dihydrate
Hemi
## Table III

**Summary of the Effects of Impurities in the Phosphoric Acid (70 % P\textsubscript{2}O\textsubscript{5}) and alloying elements in Steel on Corrosion Resistance.**

<table>
<thead>
<tr>
<th>Impurities in Acid</th>
<th>Alloying elements in Steel</th>
<th>Effect on corrosion Rate in Passive state</th>
<th>Effect on Active Passive transition</th>
<th>Forms complex with F</th>
<th>Contributes in Cathodic protection</th>
<th>Net Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td></td>
<td>Steep rise</td>
<td>Negative</td>
<td></td>
<td></td>
<td>Negative</td>
</tr>
<tr>
<td>Cl</td>
<td></td>
<td>No effect</td>
<td>Negative</td>
<td></td>
<td></td>
<td>Negative</td>
</tr>
<tr>
<td>H\textsubscript{2}SO\textsubscript{4}</td>
<td></td>
<td>Indirect +ve or –ve effect on Al/Si complex formation</td>
<td>Negative</td>
<td></td>
<td></td>
<td>Negative</td>
</tr>
<tr>
<td>Si\textsuperscript{4+}</td>
<td></td>
<td>Reduction due to complex binding with F</td>
<td>Positive due to complex binding with F</td>
<td>Yes</td>
<td></td>
<td>Positive</td>
</tr>
<tr>
<td>Al\textsuperscript{3+}</td>
<td></td>
<td>Reduction due to complex binding with F</td>
<td>Positive due to complex binding with F</td>
<td>Yes</td>
<td></td>
<td>Positive</td>
</tr>
<tr>
<td>Fe\textsuperscript{3+}</td>
<td></td>
<td>No effect</td>
<td>Positive by increasing Cathodic process</td>
<td>No</td>
<td>Yes</td>
<td>Positive</td>
</tr>
<tr>
<td>Cr</td>
<td></td>
<td>Heavy reduction</td>
<td>Positive</td>
<td></td>
<td></td>
<td>Positive</td>
</tr>
<tr>
<td>Mo</td>
<td></td>
<td>No effect</td>
<td>Positive</td>
<td></td>
<td></td>
<td>Positive</td>
</tr>
<tr>
<td>Cu</td>
<td></td>
<td>No effect</td>
<td>Slightly Positive</td>
<td></td>
<td></td>
<td>Slightly Positive</td>
</tr>
<tr>
<td>Ni</td>
<td></td>
<td>No effect</td>
<td>No effect</td>
<td></td>
<td></td>
<td>No Effect</td>
</tr>
</tbody>
</table>
Smart fertilizers for sustainable agriculture: The state of the art and the recent developments

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Abstract:

Fertilizers are the vital input materials for the sustainable development of crop production. They play an important role in food security. The main goal of applying fertilizers is to provide nutrients, mainly P and N, to plants to increase and sustain optimal crop yield. However, fertilizers, if misused, could be lost in the environment or become non available to plants. To improve fertilizer nutrient use efficiency, new generation of fertilizers, so-called smart fertilizers, has been developed and applied in the modern agricultural production practice. Among this kind of fertilizers we meet low release/controlled release fertilizers, nitrification and urease inhibitors stabilized fertilizers, water-soluble polymer coated fertilizers and biosmart fertilizers. Recent developments on smart fertilizers and the role that they could play in sustainable agriculture are reviewed in this paper.

Introduction:

Global agricultural production needs to grow accordingly to population growth. It needs to face the great challenge of food supply with limited arable lands and with less resources. So, ways must be found to grow crops more sustainably.

Fertilizers, whether from inorganic or organic sources, will be continuously used to increase and sustain crop production. They play an important role in food security. However fertilizers, if misused, could be lost in the environment or become non available to plants.

It is vital to further develop techniques that continue to increase crop yield, improve fertilizer use efficiency and mitigate the pressure on environment to guarantee food supply, and environment protection.
New generation of fertilizers, so-called smart fertilizers, more efficient at lower doses, has been developed and applied in the modern agricultural production practice for greater productivity. Smart fertilizer, during the period of plant growth, provides nutrients that plant root and soil need. It brings the nutrient into root zone in the form that it can be taken. Consequently, smart fertilizers seek to optimize the use of nutrients. Among this kind of fertilizers, can be cited slow release/controlled release fertilizers, stabilized fertilizers, water-soluble polymer coated fertilizers and biosmart fertilizers. All these innovative smart fertilizers play an important role in decreasing fertilizer losses and increasing fertilizer use efficiency and are undergoing quick development.

This paper presents a review on smart fertilizers and highlights the recent developments and innovations works carried out on these products and the role that they could play in sustainable agriculture. The characteristics, advantages and limitations of this new generation of fertilizers are discussed.

**Slow release/controlled release fertilizers**

Slow and controlled-release fertilizers are fertilizers containing a plant nutrient in a form which delays its availability for plant uptake and use after application or which extends its availability to the plant significantly longer than a reference.

Slow and controlled-release fertilizers can be classified into:

- Fertilizers in which a physical barrier controls the release. Fertilizers can be coated with inorganic materials (sulphur- or mineral-based coatings) or can be coated with organic polymer coatings,

- Organic-N low-solubility compounds. These can be biologically decomposing compounds such as Urea-Formaldehyde or chemically decomposing compounds such as isobutyledene-diurea,

- Inorganic low-solubility compounds like metal ammonium phosphate or silicate–phosphate glasses.

The use of slow and controlled-release fertilizers may contain multi-nutrients (N, P, K), bioactive elements (bio-stimulants, Pesticides), water-retention agents. By using slow and controlled-release fertilizers high ionic concentrations resulting from the quick dissolution of conventional soluble fertilizers are avoided.
Slow and controlled-release fertilizers can assort with the crops nutrients demands and the nutrients supply, therefore increase the yield. It is believed to be the quickest and most convenient way to decrease the loss of fertilizers and increase fertilizers use efficiency as proved by several field trials throughout the world. Combining soluble and controlled-release fertilizers in plant nutrition can be an economical and effective strategy.

Despite the potential to increase nutrients use efficiency due to the gradual supply of the slow- or controlled-release fertilizers, the use of such products in commercial agriculture is limited by their cost compared to conventional fertilizers. Therefore, currently, the slow or controlled-release fertilizers are marketed in niches such as nurseries, turf grass, and gardening.

Actually, different researches are in progress to develop new generation of slow and controlled-release fertilizers. Thus, nanostructured formulations which permit to fertilizer to intelligently control the release rate of nutrients to match the uptake pattern of crop are proposed. Multiple-coated slow-release NPK compound fertilizers with superabsorbent and water-retention. Also Bio-release smart fertilizer in which nutrient release is governed by organic acids secreted by plants and microbes are in development.

Slow and controlled-release occupy only a small portion in the total amount of production and consumption of fertilizers. The use of the slow or controlled release fertilizers in commercial agriculture is limited by their cost compared to conventional fertilizers. The world food needs and the environment issues may help to promote the use of less soluble fertilizers and increase slow and controlled-release demand.

**Stabilized nitrogen fertilizers**

It is well known that nitrogen use efficiency is usually low. Less than 51% of the N applied is recovered by the aboveground parts of culture. Nitrogen derived from fertilizers and not taken up by plants may be immobilized in soil organic matter or may be lost to the environment. Stabilized fertilizers can minimize the potential of nutrient loss to the environment, as compared to reference soluble sources.

Stabilized fertilizers which are those amended with additives that reduce the transformation rate of fertilizer compounds, resulting in an extended time of availability in the
soil. Stabilized nitrogen fertilizers are those treated with inhibitors, such as nitrification or urease inhibitors, that may avoid the rapid transformation of N into forms that are less stable in certain conditions.

**Urease inhibitors**

NH$_3$ volatilization can be a significant N loss mechanism for urea. The use of urease inhibitors to reduce NH$_3$ volatilization from enzymatic hydrolysis of urea has thus been considered one effective strategy to increase N efficiency of urea-based N products. Urease inhibitors are applied to urea by coating fertilizer granules or by blending with liquid fertilizers.

There were more than 100 types of urease inhibitor which were developed in the last three decades. The main types include quinines, acidamide, polyacid, polyphenol and humic acid. The most widely used are NBPT (thiophosphoric triamide) and HQ (hydroquinone). HQ receives wide attention for its low price compared to other urease inhibitor. Lately, attention has been focused on the most widely tested urease inhibitor NBTPT. Coal humic acid improves the growth of crops by facilitating the absorption of nitrogen and increase the fertilizer use efficiency of urea nitrogen beside its good inhibiting effect. Many metals are able to inhibit urease activity, among them Ag, Hg, Cd, Cu, Mn, Ni, and Zn. Boric acid was also reported to have an inhibitory effect on urease.

Urease inhibitors has been tested in several countries, usually with satisfactory results. One potential way to enhance the effectiveness of urease inhibitors is by using a mixture of them.

New urease inhibitors of the phosphoroamide family are being developed namely phosphoroamide-derived compounds. And new developments are underway to make compositions more environment friendly and to protect the urease inhibitor against chemical and/or biological degradation.

The interest in urease inhibitors is well justified because urea is the most important conventional N fertilizer worldwide and the risks of NH$_3$ volatilization loss significantly contribute to low fertilizer use efficiency. However, urease inhibitors cannot completely control NH$_3$ loss when urea is applied to soils.
**Nitrification inhibitors (NI)**

Nitrification inhibitors are chemicals that reduce the rate at which ammonium is converted to nitrate by interfering with the metabolism of *Nitrosomonas* bacteria, slowing the nitrification process. This leaves more N in ammoniacal form, thus reducing the chance of leaching.

Several products were developed and used as NI. The main types include DCD (dicyandiamide) and nitrapyrin (2-chlorine-6-(trichloromethyl)-pyridine).

Nitrification inhibitors have been tested in several countries, with satisfactory results. The use of such products enhances quality and yield of cultures. New nitrification inhibitors highly effective, cheap and innocuous nitrification inhibitors are being developed. Researchers are conducted to develop compositions more environment friendly and to protect the nitrification inhibitors against chemical and/or biological degradation.

A joint application of urease and nitrification inhibitors can control the overall process so as to decrease the loss of NH$_3$ by volatilization and the loss of NO$_3$ by leaching. However, the combined use of NI, UI is, in practice, not economical.

Despite that they have taken some effect in agricultural production, inhibitors have not been widely applied throughout the world. Inhibitors are still under testing and research and most of them are expensive, have some toxic effects on crops, and can cause an environmental pollution. So more researches are needed to develop highly effective, safe, cheap, and innocuous urease/nitrification inhibitors.

**Water-soluble polymers for coating P fertilizers**

It is known that water-soluble P can be converted to water insoluble P after reaction with soil minerals, which can result in a decrease of P availability. Coating fertilizer with some water-soluble polymers which have a high surface charge density can inhibit P precipitation by acting as a platform for sequestration of P-fixing cations, such as Ca and Mg in high pH soils and Fe and Al in low pH soils. Some studies showed that fertilizers coated with these polymers performed significantly better than uncoated fertilizers.

The polymer can be used as a coating on granular phosphates or blended into fluid P fertilizers. The use of this technology seems to present several advantages such as to improve
phosphate efficiency and crop maturity, to reduce some cations toxicity and to enhance agronomic yield and quality. However, there is little information on the soil chemistry of these polymers-coated P fertilizers published in the peer-reviewed scientific journals and questions remain unanswered regarding the mechanisms of reducing P fixation by the polymer as reported by Chien et al. (Chien et al. 2009).

Smart biofertilizers

Smart biofertilizers are fertilizers (liquid or solid) composed by an organic and/or mineral fraction enriched by some bioproducts that can stimulate and activate plant growth or inoculated by micro-organisms (bacteria fungi and algae) that are considered as beneficial for agriculture and used as biofertilizers.

The use of this kind of products allows enhancing agricultural yields by improving mass balances of organic and mineral fertilization. Organic fraction contributes to improve soil texture, pH, and other physical properties of soil. Microbial action may be multiple and involve a number of mechanisms including diazotrophy, antagonism, production of growth factors, dissolution of certain organic and inorganic compounds in order to make them more available to the plant.

Indeed, certain soil microorganisms have inherent capacity to dissolve part of the fixed phosphorus in soil and make it available to the crop by secreting certain organic acids. With the increase in available P$_2$O$_5$ level, overall plant growth can be increased. Some of them also exhibit anti-fungal activities and thereby fungal diseases may be controlled indirectly. Inoculation of phosphate solubilizing microorganisms can increase crop yield by 5-10%.

Other microorganisms manage to fix atmospheric nitrogen in the soil and root nodules of legume crops and make it available to the plant. Certain growth promoting substances released by these cultures are useful for increasing the seed germination, plant growth and ultimately the yield.

Mycorrhizae, that are obligate symbiots but not host-specific, form an extension of the effective root area of the plant, which increases the absorption and translocation of immobile nutrients. Several elements (e.g., P, S, Zn, Cu, Ca, N, K, Sr, and Cl) can be taken up by
mycorrhizal hyphae and transported to the root. The potential for increasing plant growth and yield by inoculation depends on the selection of the correct fungal isolate for the crop host, inoculum type (e.g., spores, infected root pieces) and formulation.

However many challenges remain to be overcome for the application of smart biofertilizers. Among them are:
- the selection of appropriate strains considering host plant specificity, colonization efficiency, adaptation to climatic and edaphic conditions.
- the determination of optimal concentration of inoculants.
- the scale up and production of the organism under commercial fermentation (maintaining quality, stability, efficacy).
- the development of better formulations to ensure survival and activity in the field and compatibility with chemical and biological treatment.

Conclusion:

Fertilizers will be continuously used to increase and sustain crop production. However, the potential losses of fertilizers in the environment due to inappropriate application should be addressed.

It is vital to develop techniques that continue to increase crop yield, improve fertilizer efficiency use and mitigate the pressure on environment to guarantee the food supply, and environment protection. The agronomic performances of smart fertilizers have been proved, and they can be used to achieve this goal which aims to sustain crop production and to minimize nutrient losses and environmental impacts.

Research and development shall be performed to improve the efficiency of these non conventional fertilizers and to insure new alternative innovative technology in terms of fertilizer production and use.
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Enhancement of Hot leach plant Operational Sustainability

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SUBMITTED TO

The Arab Fertilizer Association

SESSION

'Current developments and driving issues in Sustainability in fertilizer industry'.
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Introduction

About APC

The idea of the Potash project was based on the Potash Plant located on the north-western shores of the Dead Sea during the British Mandate. The old plant was destroyed but the idea remained alive and a Pan Arab company was formed in 1956 to implement a project for the production of Potash using the minerals of the Dead Sea.

The site is located 110 kilometers south of Amman and 200 kilometers north of Aqaba. The site is a Solar Evaporation Pond System of an area of 150 square kilometers and processing plants for the ore.

The investment in the original project, including substantial infrastructure was nearly 480 Million USD. Financing was obtained through loans from international finance institutions and aid agencies as well as Arab development funds. The project began in 1976 with tests and experiments to determine the parameters of various technologies and ideas in a very hostile environment. Construction began in 1979 and was completed in 1982. At the end of construction, about (117) kilometers of seepage proof dykes were built (other dykes built later on). These were more than 8 meters wide at the top and were an engineering challenge to be built on top of a non-stable sea bed. The excavation carried out during the construction period was of a colossal magnitude, 16 million cubic meters of earth material was displaced.

Potash production began in 1983 and has since progressed with various schemes aimed at optimizing and expanding this production. The initial plant was built to a capacity of 1.2 million tones of product.

This was expanded in the late eighties to handle 1.4 million tones and key modifications were undertaken with the Solar System to enhance the production of the ore accordingly. A second plant based on different technology and of a capacity of 0.4 million tones was built in 1994 and this brought the total production capacity to 1.8 million tones. Then another cold crystallization plant of 0.45 million tones was built in 2010 and this brought the total production capacity to 2.45 million tones. Further expansion is currently under evaluation to bring the total potash capacity to 3.2 MMTP.

The capital of the Arab Potash Company is 83.318 million Jordanian Dinars. It has a concession from the Jordanian Government to exploit, manufacture, and market the mineral resources of the Dead Sea, until 2058.

The Arab Potash Company employs over 2000 personnel and has offices in Amman, Safi and Aqaba. It owns extensive housing and recreational facilities near its plants, and in addition, it provides the surrounding region with assistance in social, medical, economic and vocational development.
Potash Production Process Description

The Dead Sea is located in the Dead Sea Rift, which is part of a long fissure in the Earth's surface called the Great Rift Valley. The 3,700 mile (6,000 km) long Great Rift Valley extends from the Taurus Mountains of Turkey to the Zambezi Valley in southern Africa. The Dead Sea lies 424.28 m below sea level, making it the lowest elevation and the lowest body of water in the world.

A molecule of water takes up to 12 months on the trip from the Dead Sea through APC’s solar ponds system and back again after shedding its cargo of minerals.

Due to the high evaporation rate in these ponds, most of the Sodium Chloride is deposited and the water content of the brine is reduced. At the end of the salt ponds, the brine is transferred to the Pre - Carnallite Pond, PC -2, by gravity flow. This pond acts as a controller for the brine composition to be at the Carnallite point. From the Pre - Carnallite pond brine is pumped into two branches of series Carnallite ponds to produce potash raw material which is carnallite (KCl.MgCl2.6H2O). The precipitated Carnallite is harvested as a slurry from beneath the brine and delivered to booster pumps on the dikes and then to the refineries through floating pipes.

The original plant employs hot leach technology to process the Carnallite to extract potash, but the newer facilities employ cold crystallization. In the hot leaching unit, the Carnallite slurry is received, dewatered and decomposed in two stages in an agitator tanks. The resulting solids from the decomposition are a mixture of potassium chloride and sodium chloride: this mixture (known as sylvnite) is dewatered and washed. The resulting cake is conveyed to the sylvinite processing stage.

In the next sylvinite processing stage, the sylvinite cake is leached using agitator tanks in a two-stage process. Heated lean brine, returned from the crystallization process, is used for leaching the KCl solids. The hot brine, now saturated with KCl, is clarified in a hot
thickener. The thickener’s overflow is pumped to the crystallization process, and the underflow slurry containing NaCl crystals is dewatered, repulped with waste brine and then pumped to the tailings area.

The hot brine from the thickener overflow, which is saturated with sodium and potassium chlorides, is cooled successively in a six-stage vacuum crystallizing system from 93°C to 42°C. Upon cooling, KCl decreases in solubility and crystallizes under controlled conditions.

The potash slurry from the crystallizers is directed to the product hydro cyclones, where partial dewatering takes place. The underflow of the cyclones is sent to centrifuges for further dewatering. In the drying stage, the cake from the centrifuges is conveyed to an oil-fired rotary dryer to remove the last traces of moisture entrained with the crystals. From the dryer, the product is sent to a fluidized bed cooler and then to the screening system, while the dust is collected, using a cluster of high-efficiency cyclones.

The product coming from the dryer goes to the screening unit, where it is segregated into two product grades: standard and fine. Standard potash is cooled by using a fluidized bed cooler. An anti-caking agent is added to all products in carefully controlled amounts to minimize the natural tendency of potash to agglomerate during storage and shipment. Free-flowing properties are thus ensured to facilitate handling of these products by the customer.
Methodology

The principal goal of the Arab Potash Company, as any other industrial companies, is to attain the best performances, efficiencies and recovery of individual equipment and units respectively. Consequently intensive studies had been carried out to figure out the major bottlenecks in the plant, then an optimization study to resolve all bottlenecks and obstacles in refineries.

The main objective of this study was to investigate the actual capacities of the existing hot leach and identify opportunities for optimizing their capacities.

This paper will highlight on two of the major de-bottlenecks in the hot leach plant (Plate heat exchanger and screening unit).

**Falling Film Heat Exchanger**

The existing plate heat exchanger is a major process stage to heat up the circuit, the existing plate heat exchangers are failed to maintain operational readiness > 95%, and this failures occurs always during start up/pumps switching and wear and tear in rubber since it became fragile as a result of high temperature and long service. This also results in increasing the running cost as a result of losses of steam and frequent maintenance.

Existing brine heaters.

Based on, the followings three alternatives have been studied to increase reliability of the heat exchangers: -
- Maintain the current plates.
- Replacement the existing type with other different types.
- Replace the material of construction.
The above three alternatives have been studied technically and cost wise; the finding is to replace the existing plate heat exchanger with falling film heat exchanger. This will reduce the maintenance cost, the operation cost by saving around 10 TPH of steam, and avail more safety working area.

The HLP plant increases would result mostly by ensuring the brine feed to crystallizers is always saturated, thus increasing their KCl content and thus crystallizers are operated at their optimum, with the proper control of brine temperature. This will both increase production and reduce the current specific steam consumption numbers.

To achieve a falling film heat exchanger, order had been issued for Whiting/ Canada to supply falling film heat exchanger of a design capacity that cope with a production of 2.0 MMTY.

The material of construction is Titanium for tubes and carbon steel for shell.

The Falling film heat exchanger has put successfully, safely and smoothly into service on May 6th, 2011 by APC concern staff and it is preheating the brine at operator requested flow rates and discharge temperatures. The FFHX heater is designed to heat brine from 75°C to 110°C at brine flow rate = 2300 m³/h by using 135 t/h steam condensing at 120°C and 1 BAR(g).

FFHX is a vertical shell and tube heat exchanger; it is industrial equipment to heat solutions, especially with heat sensitive components. In all cases, the process fluid to be heated flows downwards by gravity as a continuous film. The fluid will create a film along the tube walls, progressing downwards (falling) - hence the name. The fluid distributor has to be designed carefully in order to maintain an even liquid distribution for all tubes along which the solution falls.

In the majority of applications the heating medium is placed on the outside of the tubes. High heat transfer coefficients are required in order to achieve equally balanced heat transfer resistances. Therefore, condensing steam is commonly used as a heating medium.
The first step before putting the FFHX was checking all equipment that has been installed correctly, hydraulic and hydrostatic tests had been conducting by filling the pipes and FFHX shell side with clean water and check for tube leaks on tube side by filling tube side with clean water and check for leaks.

The tube side hydrostatic test was conducted by pressurizing the water using the brine feed pump to a pressure of 3.65 BARg (equivalent to 3.55 BARg at the top of the heat exchanger). No leaks were found into the shell side; therefore the tube side hydrostatic test was a success. It was unable to perform a full shell side pressure test since the structural steel work has not been designed to support steam pipe work full of water. The bottom tube sheet had been tested by adding water until the shell side pressure read 0.466 BARg, on opening the man way in the bottom liquor chamber. No tube leaks were found; therefore the shell side hydrostatic test was a success.

Continuous start up has been started on May 7th, 2011; the major concern is causing high differential temperatures which will pull the tubes out of the tube sheets (carbon steel expands at a different rate to titanium). Therefore shell side and tube side are started and stopped gradually and at the same time to reduce temperature differences.

Once the operation conditions had been close to the normal operation. The control system put into automatic, i.e. the heater heats brine from 75°C to 110°C at brine flow rate of 2300 m³/hr

During operation, operators start to record process data on log sheets, check condensate level and field gauges, check for leaks, check associated equipment e.g., pumps and valves and keep a log of problems.
**Process Evaluation**

- The efficiency of the FFHX is determined by calculating the heat transfer coefficient \( U \), it measure of how well heat is transferred – [kW/m\(^2\)/°C]. lower heat transfer coefficient means that tubes start to foul or flow is poorly distributed onto tubes.

\[
Q = U \cdot A \cdot DT_{lm}
\]

\[
Q = m \cdot C_p \cdot dT
\]

- \( Q \) = heat transferred [kW]
- Determined by: brine flow rate x specific heat capacity x temperature rise of brine.
- \( A \) = heat transfer surface area of tubes.
- \( DT \) = temperature difference between shell side (condensing steam) and tube side (brine temperature).

The process data has been simulated to calculate the overall heat transfer coefficient at different operation conditions by changing the feed flow rate from 2100 m\(^3\)/hr to 2300 m\(^3\)/hr, brine feed temperature from 70 °C to 80 °C at saturated steam (1 bar (g) & 120 °C): -
The required steam quantity per each run has been determined as illustrated in the below graph:

![Required Saturated Steam @ Different Feed Brine Temperature](image)

The current values of “overall heat transfer coefficient” are higher than the designed value; that because the FFHX works below the designed capacity.

![FFHX Overall Heat Transfer Coefficient](image)
Finally, the main benefits achieved from replacement of the plate heat exchanger by falling film heat exchanger are:

- Reduce the operational cost by saving of steam, ensuring the brine feed to crystallizers is always saturated, thus increasing their KCl content and thus crystallizers are operated at their optimum, with the proper control of brine temperature.
  - The specific consumption of fuel with respect to HLP potash production (kg fuel/ton KCl) was reduced from 47.4 to 44.46 (Positive effect)
  - The specific consumption of steam with respect to HLP potash production (kg steam/ton KCl) was reduced from 557 to 522 (over the respective periods mentioned above). (Positive effect)

- Reduce the maintenance cost.
- Avail more safe working area (high-quality insulation).
- Decrease the downtime which is resulted of using old and deteriorated equipment.
- Improve the housekeeping by decreasing leaks.

**HLP Screening Revamp Project**

APC product Handling area operates with various solids handling equipment, including bucket elevators, screw conveyors, screens, product cooler equipment, bins, etc.

The product at the exit of the dry is conveyed to the screening section where it is classified into different grades, i.e., standard, and fine, while part of standard, fines and dust are directed to the compaction unit where they are compacted to produce a granular product.

To achieve desired sizes of the fine and standard potash, dryer product is sieved and screened first in six parallel screens in which extra coarse particles are separated from the dried product. The remaining dryer product is sent to another six parallel secondary screens for further screening.

For the granular product, part of standard, fines and dust is compacted, crushed, and screened first in two parallel hummer screens to separate extra coarse flakes out of compactors' output. Then the undersize grade is fed to four screens to separate potash granules from finer particles.
The existing screens were built on 1982 with a capacity of 1.2 MMTPY, in 1987; HLP production capacity was increased from design capacity of 1.2 to 1.4 MTPY, the modifications were on the carnallite and sylvinite areas and no modification has been carried out on the screening unit and till now no major modification has been carried out on the screens themselves to increase the capacity.

The screening and compaction unit process route will remain as is but with minor modification in the number of equipment such as decreasing the number of operated screens, belt conveyers, bins, screws as seen in the primary sketch below.

The most significant problem which has an adverse effect on the screens' performance is the critical condition of the frame, body and cover of the screens. The screens cover show signs of deterioration as a result of corrosion and erosion, inspection report shows that covers of number 14 and 16 primary screens and number 21 and 25 secondary should be changed.

Therefore and based on the critical situation of screen covers, capacity, infrastructure and available space; APC take decision to revamp HLP dry screens by replacing the existing six primary and six secondary screens with low numbers of new screens with 270 TPH capacities.

Project alternatives have been studied, and a comparison between the proposed screens drawings and the field is carried out, the findings are:

- The main feed bins will replaced by two chutes.
- Three main screw conveyers will be removed and use chute for fine material to fed fine bin.
- Replace six primary screens model Rotex 81 and six secondary screens model 521 by two new screens.
- The Two mineral Rotex multi-deck screens model 4240-2 of a capacity of 135 TPH per each with their auxiliaries (chutes, magnetic separator, automatic slide gates) are installed at HLP screening unit to replace the exiting 12 No screens (6 primary + 6 secondary) with their auxiliaries (screws, bunkers).
The project had been executed within 75 calendar days and the new mineral separators have put successfully and smoothly into service.

**Process Evaluation: -**
The main the performance is satisfactory as illustrated below; the physical analysis of standard potash is within the accepted rang, the difference between Tyler Mesh (10-65) was above 90%.

And up-to-date, the main achieved benefits are: -
- Decrease the running cost of the screening units by decreasing the number of operated equipments such as screens and screw conveyers.
- Decrease the down time which is resulted from using old and deteriorated equipment.
- Improve the product quality by increasing the efficiency of the screens.
- Obtain more free area.
- Safe the environment by decreasing dust emission.
- Improve the housekeeping by decreasing leaks.
- Avail more safe working area
1. **KBR PURIFIERTM Technology and Project Execution Options for Ammonia Plants**
   
   Avinash Malhotra - Director, Technology Fertilizers & Synthesis Gas, KBR, USA

2. **Application of ALSTOM’s Chilled Ammonia Process in the Fertilizer Industry**
   
   Peter Erich Arnold - Director Sales, ALSTOM, Germany

3. **Sustainable ammonia plant operations: The impact of shift operation**
   
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4. **Online Installation of New Exchanger for Sustained Production**
   
   Faisal F. Al-Shahrani, SF4 Operation Manager, SAFCO, S. Arabia

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KBR PURIFIERTM
Technology and Project Execution Options for Ammonia Plants

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KBR PURIFIER™ Technology and Project Execution Options for Ammonia Plants

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KBR PURIFIER™ Technology and Project Execution Options for Ammonia Plants

ABSTRACT

Synthetic ammonia has been in commercial production for about 100 years. As late as 50 years ago the plants were small and inefficient – typically about 100 tons/day and consuming as much as 12 GCal/t of energy. Given that the theoretical minimum energy input is about 5 GCal/t, combined with the tremendous growth in ammonia demand during the mid-twentieth century, the history of the development of ammonia technology is one of increased plant capacities and reduced energy consumption. This development continues today. In this paper we present how KBR Purifier technology has helped to advance this historical trend.

As ammonia plants became larger and more efficient, projects became more expensive and complex, so in parallel with technology developments there have been developments in project execution. This paper presents several options that KBR uses in delivering ammonia projects to its licensee.
BACKGROUND

Kellogg Brown & Root LLC (KBR) has a portfolio of ammonia technology options to meet clients’ needs. One of these options is our PURIFIER™ Process, which has been used in eighteen ammonia plants. The first Purifier Plant went on stream in the United States in 1966. The seventeenth Purifier Plant, a 2200 metric ton/day unit for BFPL (now YPFL) in Australia was commissioned in April 2006. An eighteenth Purifier plant was commissioned in China. KBR is presently in various stages of designing one new 2,700 mtpd, six new 2,200 mtpd ammonia plants, two new 1,800 mtpd ammonia plants, one new 1,500 mtpd ammonia plant, one new 1,320 mtpd ammonia plant and another new 1,000 mtpd ammonia plant using PURIFIER™ Process. In India two ammonia plants have been revamped and another ammonia plant in India is being revamped to use PURIFIER™ Process.

PURIFIER™ PROCESS

Overall Scheme

The KBR PURIFIER™ Process is illustrated in Figure 1. The desulfurized feed is mixed with medium pressure steam, and the mixture is preheated in the convection section of a top fired primary reformer. The preheated mixed feed is then distributed to tubes suspended in the radiant section. The tubes contain nickel reforming catalyst. The heat for the endothermic reforming reaction is provided by combustion of fuel gas and waste gas from Purifier. The burners are located between the rows of catalyst tubes and operate with downward firing. In this manner, the tubes are heated from both sides. Also, the heat flux is the highest at the top of the tubes, where the process temperature is the lowest. That results in a relatively even load on the tubes. The outlet manifolds and the riser tubes are located inside the reformer furnace, for heat conservation.

The primary reformer uses the latest refractory and insulation technology. Ceramic fiber lining in the radiant section provides rapid thermal response due to low heat storage. Super duty hard refractory is used where flames may contact the sidewalls. This reformer design allows operation of the primary reformer with only two percent oxygen (on dry basis) at the exit of the radiant section.

In the secondary reformer, the partially reformed gas from the primary reformer is reacted with air. In a traditional ammonia plant, the air flow rate is set to provide the amount of nitrogen required for the ammonia synthesis reaction. In a Purifier™ ammonia plant, up to 50 percent excess air is used. The oxygen in
the air burns some of the process gas, to provide heat for the reforming reaction. The gas then flows downward through a bed of nickel reforming catalyst, where the temperature decreases due to the endothermic reforming reaction.

The excess air in the Purifier™ process provides heat for more reaction in the secondary reformer. This reduces the size of the primary reformer by about one third, and lowers the process outlet temperature (~700 °C) substantially, as compared to a traditional ammonia plant. The lower operating temperature results in a longer tube and catalyst life. The shift of reforming duty from the primary to the secondary reformer is advantageous, because the heat in the secondary reformer is recovered 100 percent in the process, with no stack loss.

The secondary reformer has a dual-layer refractory lining. An outside water jacket protects the shell against hot spots in the event of a refractory failure. KBR uses all refractory combustion chamber design, which avoids the use of a conventional
metallic burner, which requires routine inspection and maintenance. The effluent from the secondary reformer containing about 2.0% (dry basis) methane is cooled by generating and superheating high pressure steam prior to shift conversion.

Radiant duty of the primary reformer furnace in the Purifier Process is only about 60% whereas power requirement of the process air compressor is about 1.5 times more than that in a conventional ammonia plant. Due to this unique combination, the oxygen content of the gas turbine exhaust provides a good match with the requirement of combustion air for the primary reformer furnace burners. The exhaust of the gas turbine driver of the process air compressor is thus integrated with the primary reformer furnace.

No forced draft (FD) fan and combustion air preheater is required in Purifier process. The gas turbine driven air compressor is started-up standalone without requiring imported steam thus required capacity of the OSBL package boiler is significantly less. Not only installed cost is reduced this way but energy efficiency of the ammonia plant is significantly increased with such integration commercially proven in numerous Purifier plants.

Shift conversion uses the traditional two-stage high and low temperature reactors. Carbon dioxide is removed by proven processes licensed from third parties such as UOP or BASF. Process condensate is recovered, stripped with medium pressure steam in the Condensate Stripper, and recycled as process steam to the reforming section. The synthesis gas from the CO₂ absorber overhead is heated in a feed/effluent exchanger and then passed over methanation catalyst to convert residual carbon oxides to methane.

In preparation for drying, the methanator effluent is cooled by heat exchange with methanator feed and cooling water. The methanator effluent, then combines with recycle synthesis loop purge gas and are further cooled with ammonia refrigerant to about 4°C. The chilled gas from the condensate separator drum goes to the syngas dryers. Two dryers are provided. They contain mol sieve desiccant and operate on a 24-hour cycle. Exiting these driers the total of water, CO₂ and NH₃ content is reduced to less than 1.0 ppmv. The regeneration of the molecular sieve dryers is done with the waste gas from the Purifier.

The cryogenic Purifier does the final purification of the raw synthesis gas. It consists of three pieces of equipment, a feed/effluent exchanger, a low speed expander and a rectifying column with an integral overhead condenser. The dried feed to the Purifier with H/N ratio of about 2.0 is first cooled in the top part of the feed/effluent exchanger by exchange with the purified gas and waste gas. It then flows through a turbo-expander where feed is expanded and energy is recovered to develop the net refrigeration required for the cryogenic unit. The expander effluent is further cooled and partially condensed in the bottom of the exchanger and then enters the rectifier
column. All of the methane, about 60% of the argon and all the excess nitrogen coming to the Purifier are removed as rectifier “bottoms”. Liquid from the bottom of the rectifier is partially evaporated at reduced pressure in the shell side of the rectifier overhead condenser to provide reflux for the column.

It is further reheated by exchange with Purifier feed gas and then leaves as a waste gas to regenerate the molecular sieve dryers. The waste gas is then used as fuel in the primary reformer. The synthesis gas containing about 0.25 percent argon and an H/N ratio of three is reheated by exchange with Purifier feed and then goes to the suction of the synthesis gas compressor.

The purified gas is compressed to about 150 bars while combining with unreacted recycle gas. Compressor discharge is heated by feed/effluent exchange, and enters the horizontal converter. In the converter ammonia conversion is raised from about two percent to nineteen percent while passing over three beds of magnetite catalyst. Converter effluent is cooled by generating high pressure steam, by feed/effluent exchange, with cooling water, and finally in KBR’s proprietary “Unitized Chiller”. A conventional refrigeration system provides the necessary chilling. A small purge stream is recycled to upstream of the dryers in order to recover the hydrogen and nitrogen. Cold ammonia product is exported from the synthesis loop to storage.

TECHNOLOGY FEATURES

There are several technology features of the KBR PURIFIER™ Process, which results in very efficient, reliable and lower TIC ammonia plant. These are as discussed below.

- Process air compressor driven by a gas turbine with exhaust of gas turbine used as combustion air to primary reformer.
- 30% smaller primary reformer compared to non-purifier ammonia plants. Mild operating conditions for primary reforming. KBR can provide single primary reformer for 3,500 mtpd ammonia plant. No need of pre-reformer or reforming exchanger.
- Excess air to the secondary reformer – milder temperature (~700°C) condition
- Non metallic mixing chamber – no metallic mixer/burner in the secondary reformer
- Removable tube bundle natural circulation type of reformed gas waste heat boiler.
- More CO2 production in the reforming section due to excess air. Consequently it is possible to produce the CO2 required to convert all ammonia to urea in the CO2 removal unit, even with lean natural gas feed stock. No need to recover CO2 from flue gases.
- KBR’s cryogenic Purifier to remove inerts from the raw synthesis gas resulting in 10% smaller synthesis loop equipment.
- Three beds with two exchangers cold wall horizontal magnetite converter. KBR can provide single horizontal converter for 3,500 mtpd ammonia plants. No need to provide hot wall synthesis converters.
- Unitized ammonia chiller – possible to include two to four stages of chilling of synthesis gas in one equipment
- No purge gas recovery is required unit since Purifier also performs the duty of purge gas recovery unit.

**Purifier Experience, Energy Consumption and Reliability**

**Experience**

The first Purifier Plant went on-stream in the United States in 1966. Its energy consumption was 8.2 Gcal/MT, high by today’s standards but well below the industry benchmark at that time, which was over 10 Gcal/MT. Since this time sixteen more Purifier Plants have come on-line. Eighteenth Purifier plant is being commissioned in China. As mentioned earlier, KBR is in various stages of designing three 2,200 mtpd ammonia plants, two 1,800 mtpd ammonia plants and another 1,500 mtpd ammonia plant using PURIFIER™ Process.

**Energy Consumption**

KBR has been a leader in reducing energy consumption in ammonia plant. It commissioned in 1982 a 1350 ton/day ammonia plant for BASF, Germany, with expected energy consumption of **6.53 Gcal/mt**:

<table>
<thead>
<tr>
<th></th>
<th>Expected Gcal/MT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas</td>
<td></td>
</tr>
<tr>
<td>Feed</td>
<td>6.06</td>
</tr>
<tr>
<td>Fuel</td>
<td>1.72</td>
</tr>
<tr>
<td>Subtotal</td>
<td>7.78</td>
</tr>
<tr>
<td>Export Steam</td>
<td>-1.52</td>
</tr>
<tr>
<td>Net</td>
<td>6.26</td>
</tr>
<tr>
<td>Electricity</td>
<td>0.27</td>
</tr>
<tr>
<td><strong>Total Energy</strong></td>
<td><strong>6.53</strong></td>
</tr>
</tbody>
</table>

**TABLE 1: BASF ENERGY CONSUMPTION EXPECTED FROM FLOW SHEET**

The CNOOC 1500 ton/day ammonia plant started up in late 2003 on Hainan Island, China. The performance test was run in 2004 and some results of the test are shown in Table 2. The measured numbers are from the test data and the expected numbers are from the process flow sheets. Expected energy consumption was 6.49 Gcal/mt. This is lower than any of the earlier Purifier designs and believed to be the lowest energy consumption plant in the world.
Since 2010, KBR has further improved its Purifier technology and is able to offer expected energy consumption less than 6.20 Gcal/mt.

Reliability

Purifier-based ammonia plants have proven to be the most reliable design in the industry. Data from a recent survey\(^3\) indicate that Purifier Plants have a four percent higher on-stream time than non-KBR ammonia plants. The longest runs between shutdowns have been reported by Purifier Plants—runs of 1395 days, 1375 days\(^4\), 960 days, and 920 days. But this reliable track record should not be a surprise. The Purifier Process is clearly a more flexible process than other designs, which makes it “user friendly.”

Project Execution Options:

Now we shift the focus of this paper to project execution. There are varieties of projects execution plans available to owners. Project Execution Options depend upon one major decision by Owner:

- Owner first selects technology
- Owner does not first select technology

If Owner selects technology first, Owners will typically have licensors prepare Basic Engineering Design (BED). Owner then has the following options for Project Execution:

<table>
<thead>
<tr>
<th></th>
<th>Gcal/MT-LHV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measured</td>
</tr>
<tr>
<td>Natural Gas</td>
<td></td>
</tr>
<tr>
<td>Feed</td>
<td>6.25</td>
</tr>
<tr>
<td>Fuel</td>
<td>1.93</td>
</tr>
<tr>
<td>Subtotal</td>
<td>8.18</td>
</tr>
<tr>
<td>Export Steam</td>
<td>-1.72</td>
</tr>
<tr>
<td>Net</td>
<td>6.46</td>
</tr>
<tr>
<td>Electricity</td>
<td>0.03</td>
</tr>
<tr>
<td>Total Energy</td>
<td>6.49</td>
</tr>
</tbody>
</table>

Table 2: Comparison of CNOOC Energy Consumption Measured at Performance Test vs. Expected Values from the Flow Sheet
• Option A: Reimbursable or Cost Plus.
• Option B: Convertible LSTK (Lump Sum turnkey) or Open Book. Owner also selects Contractor besides licensor
• Option C: Owner: Asks 2~3 contractors of process licensor to bid LSTK based on BED/FEED package.

If Owner does not select a technology first, he then issues an ITB requesting LSTK bids from Contractors, who have access to various technologies. Some time owners pre-qualify contractors for various technologies. We will call this contracting approach Option D.

**Option A: Reimbursable or Cost Plus:**

Owner, after having selected the technology, asks process licensor to prepare BED & license for a fixed price. Owner further:

- Selects Detail Engineering Contractor (DEC)
- DEC develops MTOs (Material Take Off)
- Procures equipment and materials with the assistance of Licensor for Long Lead Items (LLI) and with assistance of DEC for the rest of equipment and materials.
- Selects and sub contracts the construction

**Option B: Convertible LSTK or Open Book Contract**

Owner, after having selected the technology, invites bids from various contractors for preparing an Open Book Estimate (OBE). The principle of the OBE method is that cost is totally transparent between Owner and Contractor. Contractors prepare bids, which broadly include the following:

- License and BED fees are fixed
- Engineering fees/rates for reimbursable work are fixed
- Fee for profit, residual risk, contingency
- Agreement on LDs
- Agreement on Terms and Conditions

Owner evaluates commercial bids from contractors, with or without assistance of Licensor, and awards the contract. Contractor performs the following work on a reimbursable basis:
- Front End Engineering Design (FEED) or sufficient basic and detail engineering for OBE
- Prepares technical and commercial requisition for LLI and gets quotes. Owner and Contractor select the best vendor/technical offer for LLI equipment, and negotiate price/commercial terms.
- Contractor develops MTO and gets prices for bulk material.
- Contractor prepares bids for construction sub-contractors and gets quotes.
- Vendors for equipment and materials, and sub-contractors for construction are selected.
- OBE is prepared and agreed between Owner and Contractor.

OBE is then converted to LSTK price after incorporating previously agreed fee for profit, residual risk, and contingency. Owner thus awards a LSTK contract after phase 1. In this option Owner is able to purchase equipment and systems of his choice (owners) and quality, and select construction contractor or sub contractors, who meet owner’s quality standards.

Option B is also illustrated in the following:
Option C – Competitive EPC bidding based on Licensor’s BED

Owner selects technology, and awards license/BED work to Licensor. In the first phase Licensor performs the following on fixed fee basis

- Executes BED
- Detail requisitions for long lead items
- Limited FEED work.
- Prepares “Invitation to Bid” (ITB) for LSTK quotes from selected contractors, who are licensed to use selected Licensors technology.

In the next phase licensor performs the following work on reimbursable basis

- Owner/Licensor invites bids from selected contractors

- In parallel quotes are obtained from equipment vendors for LLI, for which detail requisitions were prepared in the earlier phase. Owner and Contractor select the best technical and commercial offers for LLI equipment, and negotiate price/commercial terms.

- Contractors are able to provide very competitive LSTK bids since some of the FEED work, e.g., MTO for piping, instruments, civil, structure etc., was done in the earlier phase and defined in ITB.

- Owner informs contractors about the selected vendors for LLI equipment.

- Owner evaluates the LSTK bids from selected contractors.

- Owner awards LSTK contract to selected contractor. Owner passes on the purchase orders for LLI to the LSTK contractor.

Option C is also illustrated in the following:
Major difference between Option B and C is that in Option B only one contractor, who is licensee of the selected technology, does FEED work, to covert OBE to fixed price. Whereas in Option C a number of contractors, who are licensee of the selected technology, bid on LSTK basis, after the Licensor has done BED and some FEED work. It is possible to get a lower LSTK price in Option C since a number of contractors bid for the same technology package. However, the schedule may be longer than Option B since ITBs need to be issued to contractors and bids need to be analyzed.

**Option D**

In this option, Owner does not first select the technology. Contractors, who have access to various technologies, will bid on LSTK basis. Some time owners pre-qualify contractors for various technologies.
This option of Project Execution is exhaustive requiring much longer schedule because:

- Owner pre-qualify contractors for various technologies 4~6 months.
- Owner prepares or appoints a consultant to prepare a detail ITB (Invitation to bid). This effort usually requires 4~6 six months.
- Contractors submits bids in 4~6 months
- Owner conducts technical & commercial clarifications lasting 2~3 months.
- Based on above Contractors then submit final commercial bids in 2~3 months
- Owner selects contractor – Total time 12 ~ 18 months
- Contractor executes project in 30~36 months
- Total time required to complete project is 46~60 months after decision to go for LSTK type of project execution mode.

**Comparison of Options:**

<table>
<thead>
<tr>
<th></th>
<th>Option A</th>
<th>Option B</th>
<th>Option C</th>
<th>Option D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cost Plus or Reimbursable</td>
<td>Convertible LSTK or Open Book</td>
<td></td>
<td>LSTK</td>
</tr>
<tr>
<td><strong>TIC</strong></td>
<td>Lowest</td>
<td>Medium</td>
<td>Medium (-)</td>
<td>Highest</td>
</tr>
<tr>
<td><strong>Schedule</strong></td>
<td>Shortest 30~32 months</td>
<td>Medium 32~34 months</td>
<td>Medium (+) 34~36 months</td>
<td>Longest +48 months</td>
</tr>
<tr>
<td><strong>Quality of Equipment, Material &amp; Construction</strong></td>
<td>Highest</td>
<td>Highest (-)</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td><strong>Owners Risk</strong></td>
<td>Highest</td>
<td>Medium</td>
<td>Medium</td>
<td>Lowest</td>
</tr>
</tbody>
</table>

In Option A, TIC will be generally lowest since the client is serving as managing contractor, and therefore, there is no profit element for this activity. Owner also has option to buy equipment and material of highest quality and also maintain quality during construction. However Owner takes the highest risk in this option. To mitigate the risk, owner requires a very competent technical, commercial, project, and construction management team. This risk can also be reduced by appointing a program management contractor for the project.

Option D is other extreme, where the Owner takes minimum project management and TIC risk. However TIC will generally be highest unless contractors are in a situation where they hungry for work. Contractor will need to put in his price the risk money for forward escalation & contingency. In times of rising equipment and material costs this
can be a substantial number. Overall time required in this option is highest of all options.

Options B and C are very viable options, which optimize TIC, risk, schedule and quality of equipment and material. These options are very well tested in industry.

SUMMARY

KBR’s Purifier™ technology is a well proven technology. This process offers the following benefits to ammonia producers:

- Low operating cost
  - Very low energy consumption
  - Reduced maintenance costs

- High reliability
  - Well-proven commercial designs
  - Greater operational flexibility
  - Ease of handling process upsets

- Lower capital cost
  - Smaller primary reformer
  - Eliminates the purge gas recovery unit
  - Has smaller synthesis loop and refrigeration system due to high purity make-up gas in Purifier™

Four Project Execution Options have been explained.

- Option A - Reimbursable or Cost Plus
  - Lower TIC
  - Shorter schedule
  - Higher owner’s risk

- Option B Convertible LSTK or Open Book or Option C
  - Very viable options
  - Optimize TIC, owner’s risk, and schedule
  - Better quality of equipment and materials

- Option D LSTK Basis
  - Higher TIC
  - Overall longer schedule from concept to mechanical completion
  - Lower owner’s risk
REFERENCES


Application of ALSTOM’s Chilled Ammonia Process in the Fertilizer Industry

Peter Erich Arnold
Director Sales, ALSTOM
Germany
Introduction to Alstom’s CO₂ Capture Systems Organisation

ALSTOM Carbon Capture GmbH

25th AFA Int’l. Fertilizer Technology Conference & Exhibition
ALSTOM Carbon Capture GmbH

Since then ALSTOM Carbon Capture GmbH acts as worldwide technology center and European execution center within the Alstom CO$_2$ Capture Systems organisation.

130 specialists of all EPC relevant disciplines qualify with an excellent track record in the oil & gas and petrochemical industry including an outstanding reference position in CO$_2$ removal units from natural gas and other process streams.

- 1965 Lummus GmbH founded as Lummus Crest project office in Munich
- 1969 Relocation to Wiesbaden
- 1989 Lummus Crest acquired by ABB
- 2007 Chicago Bridge & Iron Company acquired Lummus
- 2009 CB&I Lummus GmbH acquired by Alstom
Ways to CO₂ Storage and Utilisation

<table>
<thead>
<tr>
<th>Product</th>
<th>Product Demand Mt/a</th>
<th>CO₂ Consumption Mt/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical Storage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>e.g. Saline Aquifers</td>
<td>under consideration</td>
<td></td>
</tr>
<tr>
<td>CCS Carbon Capture &amp; Storage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urea</td>
<td>150</td>
<td>110</td>
</tr>
<tr>
<td>CCS Carbon Capture &amp; Storage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methanol</td>
<td>50</td>
<td>15</td>
</tr>
<tr>
<td>CCS Carbon Capture &amp; Storage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbonates</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>CCS Carbon Capture &amp; Storage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enhanced Oil Recovery (EOR)</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>CCS Carbon Capture &amp; Storage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Food &amp; General Use</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>CCS Carbon Capture &amp; Storage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemical Storage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>e.g. Methanisation</td>
<td>under development</td>
<td></td>
</tr>
</tbody>
</table>

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Chilled Ammonia Process Technology Overview

**Principle**

- Cooled flue gas is treated with ammonium carbonate in solution, which reacts with CO₂ to form ammonium bicarbonate
- Raising the temperatures reverses the above reactions – releasing pressurized CO₂

**Advantages**

- Energy-efficient capture of CO₂ (low OPEX)
- High CO₂ purity and high delivery pressure
- Tolerant to oxygen and flue gas impurities
- Stable reagent, no degradation possible
- No emission of trace contaminants
- Low-cost and globally available reagent
- Value by-product, i.e. ammonium sulphate
- Sustainable process (environmentally friendly)

*for Urea and Methanol production CO₂ is delivered to reactor*
Recovery of CO\(_2\) for Urea Process

✓ Urea is produced from ammonia and carbon dioxide. When urea is synthesized with natural gas as a raw material the available CO\(_2\) may be insufficient in view of the balance between ammonia and off-gas CO\(_2\). In such cases, CO\(_2\) is recovered from the exhaust gas of the reformer, to supply it for urea synthesis to adjust the ammonia/CO\(_2\) balance, thereby enabling urea to be produced in large quantities.

✓ A number of ammonia and urea complexes of recent date has been designed to export part of ammonia produced without being converted to urea. Such ammonia-urea complexes exporting ammonia have potential to produce additional urea by capturing CO\(_2\) from flue gas of reformer, boilers or furnaces.

✓ The Chilled Ammonia Process recovers CO\(_2\) from flue gas emitted during the urea production process and provides the captured CO\(_2\) as feedstock for urea synthesis. CO\(_2\) contained in the flue gas emitted from the reformer during the ammonia production process is absorbed into the solvent, which is a largely used commodity chemical. The technology can be designed to recover 90% of the CO\(_2\) in flue gas.

✓ Introducing CO\(_2\) capture drastically reduces CO\(_2\) emission while increasing urea production, i.e. sustainable growth.

✓ Main applications: fuel switch (from naphta to natural gas), grass roots and capacity expansion.
Recovery of CO2 for Urea Process

Chilled Ammonia Process can be integrated in the Urea Process

- 90% capture rate with any flue gas stream (reformers, boilers, furnaces, etc)
- the recovered CO2 is available at 99.8+ %vol (food grade can be achieved)
- the recovered CO2 is available at 20+ bar at battery limit (without compression)
- it does not present solvent degradation (it does not react with O2)
- it uses ammonia as make-up for solvent (aqueous ammonium carbonate)
- solvent make-up always available as it is a product of the ammonia synthesis
- it does not use any foreign substances (such as amines)
- it produces ammonium sulfate as value by-product (small amounts)

Integrated, reliable and cost-effective process!
Recovery of CO₂ for Methanol Process

- Methanol is manufactured with natural gas as the feedstock. For methanol synthesis, the best H₂:CO ratio is 2:1. If H₂ and CO are synthesized by reforming the natural gas, then the H₂:CO ratio is higher than 2, having H₂ in excess.

\[ \frac{H_2 - CO}{CO + CO_2} = 2.0 - 2.1 \]

- The output of methanol can be maximized through the recovery of CO₂ from reformer flue gas, allowing the addition of CO₂ into the process. CO₂ is recovered from steam reformer flue gas to optimize the H₂:CO ratio for methanol synthesis, thereby enhancing methanol production.

- The Chilled Ammonia Process recovers CO₂ from flue gas emitted during the methanol production process and provides the captured CO₂ to optimize H₂:CO ratio. CO₂ contained in the flue gas from the reformer is absorbed into the solvent, which is a largely used commodity chemical. The technology can be designed to recover 90% of the CO₂ in flue gas.

- Introducing CO₂ capture drastically reduces CO₂ emission while increasing methanol production, i.e. sustainable growth.

- Main applications: grass roots and capacity expansion.
Recovery of CO₂ for Methanol Process

Chilled Ammonia Process can be integrated in the Methanol Process

- 90% capture rate with any flue gas stream (reformers, boilers, furnaces, etc.)
- the recovered CO₂ is available at 99.8+ % in volume (food grade can be achieved)
- the recovered CO₂ is available at > 20 bar at battery limit (without compression)
- it does not present solvent degradation (it does not react with O₂)
- it uses ammonia as make-up for solvent (aqueous ammonium carbonate)
- it does not use any foreign substances (such as amines)
- it produces ammonium sulfate as value by-product (small amounts)

CO₂ can be fed either upstream or downstream the reformer unit in order to adjust the CO:H₂ ratio (Sₚ).  

\[
\frac{\text{H}_2 - \text{CO}_2}{\text{CO} + \text{CO}_2} = 2.0 - 2.1
\]

Integrated, reliable and cost-effective process!
Mountaineer Validation Facility in New Haven

- Testing of Chilled Ammonia Process for > 2 years (18,000 hours)
- AEP’s Mountaineer Plant (1,300 MWe) - coal fired (West Virginia)
- In 2009 CAP applied to to a slip-stream of flue gases (20 MWe)
- CO₂ stored into deep formations (1.5 miles beneath plant surface)
- The following main results have been proved by the testing activity:
  - CO₂ Capture Design Capacity = 100,000 tons/year
  - CO₂ Capture Rate: 90% demonstrated (75% as design)
  - CO₂ Stream Purity of 99% minimum
  - Ammonia losses in line with predictions / simulations
  - Energy Penalties in line with predictions / simulations
  - Capture Plant availability greater than 90%
  - Robust steady operation during all operation modes
- Next step is to implement the 250MW plant (FEED completed)
- Important contribution to risk mitigation / management

Mature Technology!
Chilled Ammonia Process
Technology Centre Mongstad – Product Validation Facility

Technology Validation Program

- European CO₂ Technology Centre Mongstad (TCM) for flue gases from natural gas CHP plant and a catalytic cracker (refinery)
- Alstom’s Chilled Ammonia Process being one of the two selected technologies
- Designed to capture 80,000 t CO₂/year
- Status of the Chilled Ammonia Validation Plant
  - FEED completed in November 2008
  - Concrete part of absorber completed in June 2010
  - Plant start-up in June 2012
Sustainable ammonia plant operations: The impact of shift operation

Yaqoob Kamal,
Johnson Matthey
UK
Sustainable ammonia plant operations
The impact of shift operation

Overview

• What defines a “sustainable” shift operation?
• The impact of catalyst choice on LTS operation
• Additional options for improving shift operation and efficiency
What do we mean by sustainable shift operation?

- Catalysts and operations that
  - Improve profitability
  - Improve efficiency
  - Give reliable operation
  - Lower environmental emissions
  - Reduce use of resources and energy in catalyst manufacture

What do shift catalysts do in an ammonia plant?

- LTS converts down to <0.4% CO
- Operates at equilibrium for most of its life
- CO slip defined by inlet operating temperature

\[ CO + H_2O \rightleftharpoons CO_2 + H_2 \]
What defines a “sustainable” LTS catalyst?

- Sufficient activity to operate at minimum possible inlet temperature (defined by gas dew point)
- Robust and gives long lives
  - Reducing need for catalyst replacement
- Low levels of methanol by-product
- Reliable operation

Overview

- What defines a “sustainable” shift operation?
- The impact of catalyst choice on LTS operation
- Additional options for improving shift operation and efficiency
Case study 1: outstanding performance

- **Process**: Ammonia
- **Location**: Middle East
- **Capacity**: 1,200 tpd
- **Catalyst**: KATALCO\textsubscript{JM} 83-3

Inlet $T = 200^\circ$C, CO slip $= 0.2\%$

Equilibrium reached in top 50% of bed
Case study 2: low by-product methanol

Process • Ammonia
Location • Europe
Capacity • 1,500 tpd
Catalyst • KATALCOJM 83-3X

KATALCOJM 83-3X is proven to reduce methanol make by 85%
What makes operation of this catalyst so good?

<table>
<thead>
<tr>
<th>Feature</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>High activity allows operation at low inlet temperature thus reducing CO slip</td>
<td>✔</td>
</tr>
<tr>
<td>Good stability minimises pressure drop</td>
<td>✔</td>
</tr>
<tr>
<td>Low methanol variant to give lowest possible methanol by-product formation</td>
<td>✔</td>
</tr>
<tr>
<td>Resistance to poisoning to give long catalyst lives</td>
<td>✔</td>
</tr>
</tbody>
</table>

- Key thing with LTS catalyst lives is poisons resistance – this is what defines how much catalyst, how long it will last and therefore when you need to change it.

Poisoning deactivates LTS catalysts

- Most common poisons
  - Sulphur
    - Feedstock
    - Compressor lube oils
  - Chloride
    - Feedstock
    - Steam quality
    - Air
    - Compressor lube oils
LTS - sulphur poisoning

Self guarding sulphur retention

Sulphur species first adsorb onto the copper component.

The sulphur species becomes mobile, reacting with the free ZnO to form ZnS.

Further reaction leads to the formation of bulk ZnS.
Self guarding sulphur retention (continued)

It is only when the bulk of the catalyst pellet is fully converted to ZnS that the H₂S finally attaches and remains on the Cu species, at which time it is fully poisoned and no longer able to catalyse the shift reaction.

What reduces an LTS catalyst life?

- Poisoning is the primary LTS deactivation mechanism
- Most common poisons
  - Sulphur
    - Feedstock
    - Compressor lube oils
  - Chloride
    - Feedstock
    - Steam quality
    - Air
    - Compressor lube oils
The impact of chloride poisoning

Chloride retention by self guarding catalysts

The Hydrogen Chloride molecules approach the catalyst surface and the Chlorine attaches to the Copper molecules, while the Hydrogen attaches to the Oxygen. Water is then released from the catalyst structure. Once adsorbed, the chloride species becomes mobile within the microstructure of the catalysts subsequently reacting with the free zinc oxide on the catalyst surface, forming a surface zinc chloride species. Further reaction leads to the formation of bulk zinc chloride species.

It is only when copper chloride is formed after the catalyst has been fully poisoned that the copper is no longer active for the shift reaction, and it sinters to form the large copper crystallites that we saw on the previous slide.
How do these poisons affect catalyst life?

<table>
<thead>
<tr>
<th>S Concentration</th>
<th>Cl Concentration</th>
<th>Life Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 ppb</td>
<td>50 ppb</td>
<td>3-5 year</td>
</tr>
<tr>
<td>15000 ppm</td>
<td>500 ppm</td>
<td>8-10 year</td>
</tr>
</tbody>
</table>

Where are you?

Options for LTS system designs

<table>
<thead>
<tr>
<th>Chloride guard</th>
<th>Self guarding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top 15% of bed not used for shift reaction</td>
<td>Entire bed available for shift reaction</td>
</tr>
<tr>
<td>Reduced LTS activity of bed</td>
<td>Maximised activity of bed</td>
</tr>
<tr>
<td>Designed for Cl retention</td>
<td>Equivalent Cl retention</td>
</tr>
<tr>
<td>Low S retention</td>
<td>Very high S retention</td>
</tr>
<tr>
<td>Additives required to give materials strength</td>
<td>Strength inherent in product</td>
</tr>
</tbody>
</table>

JM customers able to take advantage of KATALCO_JM self guarding properties in their operation
Examples of other plants that have experienced excellent operation

Overview

• What defines a “sustainable” shift operation?

• The impact of catalyst choice on LTS operation

• Additional options for improving shift operation and efficiency
Other means to improve shift sustainability

- High pressure drop
  - plant inefficiency
  - possible losses in production
- Older generation plants operate well above the original nameplate capacity
- Non optimal vessel loadings
  - “hidden” sources of pressure drop
- STREAMLINE can reduce pressure drop in these plants

Pressure drop through support balls

- Critical area for dP is in the annulus around the collector
- Bulk of flow around collector is radial flow
- Increasing velocities through critical area lead to high dP

Without STREAMLINE

- dP = 6.9 psi (0.48 bar)

With STREAMLINE

- dP = 6.14 psi (0.01 bar)
Case study 3: STREAMLINE I

- **Process**
  - Ammonia

- **Location**
  - Asia Pacific

- **Capacity**
  - 600 TPD design running at 730 TPD

- **Catalyst**
  - Traditional support ball system

More than 1.4 bar (20 psi) dP saved allowing an additional 50 TPD ammonia production.
Benefits of STREAMLINE I

**Simplicity**
- Same operating principle as previous support system
- Easy to install and discharge
- No welding to shell

**Efficiency**
- Reduction in pressure drop can reduce compressor power requirement
- Possibility for more rate at the same pressure drop
- If air compressor limiting can increase rate through front end

Conclusions

- Sustainable LTS catalysts and operations
  - Improve profitability
  - Improve efficiency
  - Give reliable operation
  - Lower environmental emissions
  - Reduce use of resources and energy in manufacture
Online Installation of New Exchanger for Sustained Production

Faisal F. Al-Shahrani
SF4 Operation Manager, SAFCO
S. Arabia
ONLINE MODIFICATION FOR PLANT OPTIMIZATION

New Sophisticated Method In Fixing Additional Heat Exchanger in SAFCO-IV Ammonia Plant

CONTENTS

- INTRODUCTION
- OBJECTIVE
- OVERVIEW & PLANT DIFFICULTIES
- PROPOSED SOLUTIONS
- MITIGATION ACTIONS
- EXECUTION
- OUTCOME
- CONCLUSION
INTRODUCTION

- SAFCO IV, Ammonia is the first World's largest single stream Ammonia Plant having design capacity of 3300MTPD.
- Commissioned in 2007
- Design Name Plate: 1,100,000 MTPY
- Process Technology: Mainly UHDE process and BASF for CO2 removal unit

OBJECTIVE

To share SAFCO Experience in:

Overcoming plant load limitation in SAFCO-IV ammonia plant by having online installation of plate heat exchanger using hot tapping technique
OVERVIEW

SF-4 ammonia plant load was curtailed to 97% due to a limitation in CO2 removal unit because of lean solution flow reduction from 750 m³/hr to 580 m³/hr resulted in high CO2 slippage around 5000 ppm.

A choking in the lean-semilean heat exchanger was identified as the reason of lean solution flow reduction.
EXCHANGER CHOKING

What if the tube sheet plugged by stripper rings

Semi Lean Solution

Lean Solution

115 °C
750 m³/hr

104 °C

84 °C

74 °C
780 m³/hr

Lean/Semi Lean Solution

PLANT DIFFICULTIES

lean/semi-lean cooler got blockage

Lean pump NPSH reduced

lean flow reduced from 750 to 580 m³/hr

Plant load limited & feed gas reduced

More hydrogen consumption in methanation reaction

CO2 slippage was increased to maximum allowable limit 5000ppm

Inert gas increased in synthesis loop
PROPOSED SOLUTIONS

OFF-LINE SOLUTION
Initially the Cleaning of the heat exchanger was proposed to overcome the lean flow reduction & plant load limitation

- Urea production losses is 36,000 MT
- Ammonia production losses is 12,500 MT
- 10 days total shut down of ammonia & urea plants

ON-LINE SOLUTION
Finally SAFCO Explored the possibility of having online installation of plate exchanger parallel to the lean-semilean existing exchanger with following concerns:

- Difficulties in executing 18" hot tapping.
- Time limitation to arrange new exchanger prior to pump trip.
- Difficulty in controlling flow distribution for additional exchanger
- Area of installation
MITIGATIONS ACTIONS

Mitigation actions were carried out by manipulating process parameters till the execution of the modification.

- Increasing Stripper level
- Reduce steam/carbon ratio
- Reducing lean flow temperature
- Increasing MDEA concentration
- Increasing semilean flow
- Reducing LP steam pressure

EXECUTION

- Plate exchanger was selected, delivered within 6 weeks
- Special machine was arranged to execute 18" hot tapping
- Engineering package through MOC was carried out
- Successful commissioning
- Plant load resumed
MODIFIED PROCESS FLOW

OUTCOME

- Synthesis loop inert gas reduced
- Avoidance of pump cavitation
- Restoration of Plant load
- Improvement of lean solution flow
- CO2 slippage reduced
Future Plan

- Upgrade the stripper packing material from CS to SS to prevent the source of broken packing at exchanger inlet.
- Stripper re-boiler to be inspected during TA-2012 and accumulated packing pieces to be removed
- Isolation provision to be provided at the both sell side and tube side of the existing lean-semilean exchanger
- Study to enhance the CO2 removal unit performance & identifying the root cause of CO2 stripper packing failure
PHOTOGRAPHS

inlet tube-sheet

Blocked tubes

PHOTOGRAPHS

Broken Packing rings

Outlet tube-sheet
Conclusion

Daily Ammonia production restored back from 3180 MTPD to normal 3345 MTPD.
Ten days estimated shut down to clean existing heat exchanger was averted.
Total financial benefit from this idea execution was 19.85 million USD.

Thanks
Economics of synthesis gas generation concepts for substantial capacity enlargements of ammonia plants

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Germany
Economics of synthesis gas generation concepts for substantial capacity enlargements of ammonia plants

by

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Dortmund, Germany

Prepared for Presentation at
25th AFA International Fertilizer Conference and Exhibition
Dubai
July 9 - 11, 2012
ABSTRACT

Capacity enlargements of production facilities such as ammonia plants offer their owners the opportunity to increase turnover and revenue in moderate steps. In principal, capacity expansions involve considerably smaller risks than the erection of a new plant. The overall investments are much smaller, project implementations take less time and the amounts of extra product for which customers have to be found are limited. In many cases, capacity enlargements are economical and therefore attractive to plant operators.

For newly commissioned ammonia plants capacity expansions up to about 15% above nameplate capacity can usually be realized with fairly moderate costs. Only a few equipment items within the entire plants usually constitute bottlenecks and require more significant measures.

Further capacity increases are feasible and in many cases still economical but usually require substantial upgrading of growing numbers of the process units. Such capacity expansions are therefore considerably more expensive in relative terms, i.e. related to the additional amount of product. Hence, it is ever more important to select the most cost effective solution.

The presentations looks at the economics of alternative concepts for an additional 30% capacity increase of an existing ammonia plant which had already been subjected to expansions. The investigation concentrates on the syngas generation section and compares alternatives such as enlargement of the existing steam reformer and an autothermal reformer (ATR) in parallel to the existing syngas generation. The results show that - even in this capacity range - oxygen-based syngas generation concepts are competitive if all factors contributing to overall revamp costs are accounted for.

Contents:

Introduction
Target of the investigation
Basics of capacity enlargements
Compared process concepts
Results of the economical comparison
  - Operating costs
  - Capital costs
  - CAPEX / OPEX comparison
Summary
INTRODUCTION

The paper presents the results of an extensive investigation carried out by ThyssenKrupp Uhde to establish an economic ranking for several different process concepts applicable to achieve significant capacity expansions in natural gas based ammonia production plants.

In general, capacity enlargements can be an attractive option to plant owners to generate increased revenue with considerable less risk compared to the erection of new plants. The required investments are significantly smaller, the project implementation times are much shorter and – since the extra capacity is limited – there is less danger that the markets will not absorb the additional product when the new capacity comes on-stream.

The investigation was based on the scenario that the plant to be upgraded has already undergone capacity expansions which used up the reserves in the existing process equipment as well as all options to achieve larger capacities of the process units which constitute the bottlenecks with limited modifications. In such cases considerably larger number of process units have to be upgraded to increase plant capacity further. As will be shown, only significant capacity enlargements such as the 30% increase targeted in this investigation can be economically justified.

TARGET OF THE INVESTIGATION

The investigation was carried out to generate reliable data about the economic viability of oxygen based reforming in ammonia plants, especially in the situation of capacity expansions of existing plants.

So far fully autothermal reforming is seldom applied in natural gas based ammonia plants. Most of these plants use an autothermal reforming step in their secondary reformers usually operated with plain air. The split of reforming duties between the externally heated primary reformer and the autothermal secondary reformer is dictated by the oxygen content of the ambient air.

Process schemes using larger shares of autothermal reforming such as the Purifier and KRES concepts from KBR or the GHR / secondary reformer concept by Johnson Matthey have so far not really established themselves in the market. This is also valid for process concepts entirely based on autothermal reforming such as the Megammonia Process from Lurgi / Casale.

ThyssenKrupp Uhde has investigated this subject with respect to newly built plants and reported the conclusions at the Nitrogen & Syngas Conference 2010 in Bahrain. The main result of our analysis was that fully ATR-based ammonia plants can be expected to have investment cost advantages compared to plants based on the conventional steam reformer / secondary reformer concept at very large capacities.

Given the natural uncertainty inherent in such investigations it can be said that the capacity range with similar capital costs for both process schemes is likely to extend from 3500 to 4500 mtpd, i.e. little above the capacities of the SAFCO IV and Ma’aden ammonia plants.
Responsible for this are the very different erection cost dependencies for the steam reformer and the air separation unit with respect to plant capacity. These two units dominate the cost relationship between the process concepts.

We also reported at the Nitrogen & Syngas Conference 2010 what ThyssenKrupp Uhde is doing to prepare itself for this scenario, i.e. plant operators deciding to make use of the economy of scale inherent in larger capacities and opting for the capacity range beyond the SAFCO IV and Ma'aden plants.

The investigation reported in this paper was set up to determine whether oxygen-based reforming and especially fully autothermal reforming can also be competitive in the area of capacity expansions. So far this was considered impossible due to the large costs of the required air separation unit, except for rare cases in which relatively cheap oxygen was already available. However, the result of this investigation has revealed a more complex picture as will be shown below.

An existing older ammonia plant was chosen as reference to provide a realistic basis for the investigation. Its fairly conventional block flow diagram is shown in Fig. 1.

![Fig. 1: Block flow diagram of the reference plant](image)

The capacity of the reference plant at the time of this study was 1680 mtpd. This is considerably more than its original nameplate capacity as the plant had already been subjected to several capacity enlargements and modifications. A revamp study carried out for the plant
had shown that only limited potential for additional capacity was available in the existing equipment.

In view of this an expansion target of 30% extra capacity was chosen. The investigation was to show the ranking of the different expansion concepts for the gas generation section. Therefore, only one process concept was applied to extend the capacity of the ammonia synthesis.

**BASICS OF CAPACITY ENLARGEMENTS**

Extending the capacity of a chemical process plant in general requires a larger throughput of the feedstock(s), resulting in larger flowrates in almost every part of the plant. The larger flowrates have to be treated in the same manner as in the original plant. This requires the following measures:

- **Larger process gas flowrates**
  
  If no measures are taken to increase cross sectional areas along the flowpath the larger flowrates inevitably increase pressure losses. Higher pressure drop means higher loads on compressors and drivers. A 30% increase in volume flowrates associated with the envisaged capacity expansion would result in an almost 70% higher pressure drop across the synthesis gas generation section. Hence, it is worthwhile to look at options to mitigate the effect of higher flowrates on pressure losses.

  In principal, a higher natural gas inlet pressure could compensate the additional pressure drop in the gas generation section. However, in most cases the potential for this will be rather limited as the equipment design pressures are usually directly related to their original operating pressure levels.

  With respect to pressure drop the arrangement of additional equipment parallel to existing equipment is obviously preferable compared to sequential arrangement. Parallel arrangements require more elaborate piping and additional flow control devices to assure the desired flow distribution. Hence, the superior solution is usually more costly.

  In some cases changes of reactor concepts from axial to radial flow of the process gas through the catalyst beds may still be an option.

- **Transfer of the larger amounts of heat**
  
  The larger heat duties which have to be transferred to or extracted from the process gas can be met via expansions of the heat transfer surfaces, improved heat transfer coefficients or larger temperature differences. In certain areas a change in outlet temperatures caused by larger temperature differences can be tolerated, e.g. if the associated effects are simply moderate drops in plant energy consumption.

- **Analyses of the various reaction steps**
  
  Every catalyst deteriorates and looses activity with time. Larger flowrates speed up this ageing process. Hence, if no further measures are taken, reductions in service life of the catalyst charges are to be expected after revamp implementation.
This effect can be compensated for via a more active catalyst or larger catalyst volumes. Obviously, what can be done and what is economical to do depends on the individual state of each reactor. In many cases – as in the one reported in this paper – it may be appropriate to leave the CO conversion and the methanation reactors as they are and accept the reduction catalyst service life.

Since the increased flowrates inflict higher fluid forces to the catalyst particles in the beds it should be checked for each reactor that this effect does not lead to significant movement of the top layer of the catalyst bed or even fluidization and the associated grinding effect, generating dust and mechanical deterioration.

- Separation of species down to required levels

In several process steps of an ammonia plant separation of undesired species from the process gas takes place. The most critical area is the CO\textsubscript{2} removal. However, there are several other unit operations such as the desulphurization as well as the removal of water in the process air compression, downstream of the CO conversion or during synthesis gas compression and last but not least the separation of the produced ammonia from the recycle gas in the ammonia synthesis.

All these process steps have been designed for certain volume flowrates. Once their capacities are exceeded, they usually respond with fast drops in performance, i.e. with sharp rises in outlet concentration of the species to be removed. Also, some undesired effects may be observed such as entrainment of liquid into the process gas.

**COMPARED PROCESS CONCEPTS**

**AMMONIA SYNTHESIS**

Since the main focus of this work is to look explicitly on concepts for the syngas generation section, only one process concept has been employed to rise the capacity of the ammonia synthesis. The basis of this approach is TK Uhde’s Dual-Pressure-Concept. Its main feature is an additional once-through (OT) synthesis converter at an intermediate pressure level between synthesis generation and ammonia synthesis.

Fig. 2 contains a block flow diagram of the upgraded plant's back-end. The dark symbols represent the existing equipment, the brighter symbols with broken edges indicate the required new items.

For the envisaged relatively large capacity expansion it can be assumed that the synthesis compressor will not be able to cope with the significantly larger flowrate. Hence, an auxiliary compressor parallel to the first and second stage of the existing syngas compressor has been selected, essentially taking the additional gas up to the intermediate pressure level.

The additional syngas is then mixed with the gas coming from the second stage of the existing syngas compressor and the combined gas is then passed through the OT synthesis. This process unit comprises of a gas/gas heat exchanger to provide the elevated converter inlet temperature, the actual OT synthesis converter, a steam generator / boiler feed water preheater and a final cooling train. This sequence of coolers takes the process gas tem-
perature down to a level sufficiently low enough to separate most of the generated ammo-
nia via condensation from the synthesis gas.

Fig. 2: Capacity expansion scheme for the ammonia synthesis

Subsequently, the remaining process gas is passed on to the third stage of the synthesis
gas compressor for further compression up to the pressure level of the ammonia synthesis
loop. Essentially, the flowrate of the gas transferred to the ammonia synthesis is the same
as in the original plant. Also, the composition is basically the same. Exceptions are moderate variations of the inerts depending on the revamp concept and an additional minor ammonia content.

SYNTHESIS GAS GENERATION

The envisaged expansion of the plant capacity also demands a corresponding expansion
of the plant's synthesis gas generation capacity. This plant section can be divided into the
reforming section and the treatment section for the raw synthesis gas. The reforming sec-
tion as the far more critical and cost intensive part shall be looked at in detail in this study.
The following three process alternatives have been selected for this comparison:

I. Enlargement of existing primary / secondary reforming section
II. Secondary reformer operation with oxygen-enriched air
III. Autothermal Reformer (ATR) parallel to existing reforming section

Below at first the main features of these alternative reforming sections are discussed in
detail.
Concept I: Enlargement of existing primary / secondary reforming section

Upgrading of the primary and secondary reformer is the conventional revamp approach. Fig. 3 presents a block flow diagram of the plant's synthesis gas generation section for this revamp concept. The brighter colour and the broken edges again indicate the unit operations which have to be modified as well as the additional equipment.

Fig. 3: Block flow diagram of revamp concept I

Without modification the desulphurization reacts to the larger natural gas flow with a reduced service life of the adsorber beds and increased pressure loss. In the existing plant preheating of the feed for desulphurization and of the primary reformer feed (feed/steam mixture) is done in the waste heat section of the primary reformer. Modifications of the respective heat exchanger coils are required to achieve the additional heat transfer.

Within the reforming section the split of reforming duties between the two reformers remains essentially unchanged. Hence, both reformers have to transfer approximately 30% larger heat duties to the process gas. In principal, the following options are available to lift the overall heat duty of an externally fired steam reformer:

- increased average heat flux
- larger heat transfer area
  - larger reformer tube diameter
  - longer reformer tubes
- additional reformer tubes

For the primary reformer of the reference plant the addition of the respective number of tubes would be the only feasible option. The other options have already been exploited or – in the case of longer tubes – are only theoretical options in view of the associated costs. Enlargement of the existing oven box and integration of the additional reformer tubes cer-
tainly is a fairly complicated exercise. Nevertheless, it can be done if the reformer offers certain design features and it has been carried out.

To cope with the larger process gas flowrate and the associated larger heat duty, the secondary reformer has to be replaced or at least significantly upgraded. An auxiliary compressor must be installed parallel to the existing process air compressor to provide the additional amount of process air. The process air preheating coils in the waste heat section of the primary reformer have to be modified for the additional heat transfer. An additional waste heat boiler must be installed parallel to the existing boiler.

**Concept II: Secondary reformer operation with oxygen-enriched air**

Fig. 4 again contains a block flow diagram of this process alternative. The basic approach of concept II is to provide the additional heat duty for the larger process gas flow via the secondary reformer. Using ambient air to supply the required larger oxygen flow to the reactor would introduce a considerable amount of excess nitrogen into the process gas. This can be avoided via operation with oxygen-enriched air, the alternative selected for this investigation.

The additional oxygen must be imported or provided by an air separation unit within battery limits. Generating the oxygen within battery limits is obviously associated with significant additional capital investment. However, it has the advantage, that the purity of the oxygen can be adjusted to the process requirements which are not very high. Also, integration of the mechanical drives in the air separation unit into the plant's steam system is possible.

**Fig. 4: Block flow diagram of revamp concept II**

The existing primary reformer of the reference plant remains essentially unchanged. The secondary reformer needs to be replaced or at least significantly modified to be able to operate with the three times higher heat duty. The modifications required for the other process steps in the synthesis gas generation section are fairly similar to concept I.
Concept III: ATR parallel to existing reforming section

The basic approach of this alternative is a stand alone ATR parallel to the existing reforming section. Fig. 5 contains the block flow diagram of this process concept. The existing reforming section remains essentially unchanged. Since the additional reforming is done entirely through autothermal reforming, this concept requires more oxygen than concept II.

Fig. 5: Block flow diagram of revamp concept III

The block flow diagram of the synthesis gas treatment section downstream the reforming section is shown in Fig. 6. This section also has to cope with the considerably larger flow-rates induced by the capacity expansion.

As the flow diagram illustrates all heat exchangers in the process gas cooling train have either to be backed by additional parallel heat exchangers or replaced by larger units to be able to meet the larger heat duties.

CO conversion and methanation reactors have been checked with respect to catalyst volumes. They can handle the increased process gas flow without modification, albeit with significant reductions in catalyst lifetimes. Hence, it would essentially be a budget driven decision whether the existing converters are kept, backed by booster reactors or replaced by single larger vessels.

The CO$_2$ removal section requires an additional absorber to cope with the extra process gas.
RESULTS OF THE ECONOMICAL COMPARISON

To establish an economic ranking between the revamp concepts, the individual operating costs and capital investments have been calculated for each revamp concept. Based on these figures a final CAPEX / OPEX comparison has been carried out. Below the methods used and the obtained results are outlined.

OPERATING COSTS

The costs associated with the individual energy consumptions of the revamp concepts are expected to dominate the operating costs. The other cost components such as staff wages, maintenance, tax, etc. are assumed to be fairly similar for the compared process concepts and thus do not affect the economic ranking.

The following utilities have been accounted for in the calculations:

- **Import**
  - Feed gas
  - Fuel gas
  - MP steam
  - Electric energy

- **Export**
  - Purge gas from ammonia synthesis

The individual utilities consumptions of the revamp concepts have been determined via elaborate AspenPlus-based material and heat balances. In order to generate comparable overall consumption figures these balances include:

- the process flowpath
- the entire waste heat utilization system including the steam generators
- the steam system with all major steam consumers
Table 1 presents the specific utilities consumptions for each revamp concept in terms of their energy content. A natural gas LHV has been used to calculate the energy intake via feed as well as fuel gas. Specific enthalpies are applied for steam. The imported electrical energy has been transformed into thermal energy via an overall steam system efficiency of 30%. Hence, the thermal energy equivalence of 1 kWh electrical energy is 0,012 GJ.

Table 1: Individual specific energy consumption of the revamp concepts

<table>
<thead>
<tr>
<th>Utility</th>
<th>Unit (Gcal/t\textsubscript{NH3})</th>
<th>I</th>
<th>II</th>
<th>III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed gas</td>
<td></td>
<td>5,45</td>
<td>5,80</td>
<td>5,77</td>
</tr>
<tr>
<td>Fuel gas</td>
<td></td>
<td>3,17</td>
<td>2,85</td>
<td>2,81</td>
</tr>
<tr>
<td>Imported MP steam</td>
<td></td>
<td>0,50</td>
<td>0,41</td>
<td>0,38</td>
</tr>
<tr>
<td>Electrical power</td>
<td></td>
<td>0,23</td>
<td>0,28</td>
<td>0,27</td>
</tr>
<tr>
<td>Purge gas</td>
<td></td>
<td>-0,41</td>
<td>-0,43</td>
<td>-0,42</td>
</tr>
<tr>
<td>Overall spec. cons.</td>
<td>Gcal / t\textsubscript{NH3}</td>
<td>8,94</td>
<td>8,91</td>
<td>8,81</td>
</tr>
</tbody>
</table>

Table 1 shows that the conventional reforming concept and the oxygen based alternatives have different distributions between feed and fuel gas. However, as shown in the bottom line of the table the overall specific energy consumptions of the revamp concepts only differ by about 1,5% with the ATR-based alternative slightly in the lead.

The absolute values of the consumption figures are fairly high compared to the values achieved by newly built ammonia plants. The main reason is the rather inefficient steam system of the existing older plant. The revamp parts are fully integrated with the existing plant to achieve the best possible overall consumption figures. Hence, to determine the individual utilities consumptions associated with the revamp concepts at first the overall consumption figures for the entire upgraded plants had to be calculated. The values presented in Table 1 are then derived by subtracting the consumption figures of the original plant from the figures for the upgraded plants.

CAPITAL COSTS

The assessment of the capital costs associated with the individual revamp concepts was carried out using the method commonly applied in investigations of this kind when a more detailed and hence costly approach can not yet be justified. It can be characterized by the following main features:

- The entire capital cost of a plant is expressed as the sum of the cost packages for all individual pieces of main equipment.
The cost packages from the individual main equipment items consist of the procurement costs and related parts of the other cost components associated with building a plant, such as engineering, piping, instrumentation, etc.

The procurement cost for a new piece of equipment can be derived from the cost of a similar component using a scaling method based on the operating parameter which is best reflecting the capacity of the component, such as e.g. heat duty, flowrate, power output, etc.

According to this method the entire capital cost of the revamp concepts were calculated as

\[
CC = \sum [(1 + \sum F_j) \cdot K_{\text{ref},i} \cdot (p_i / p_{\text{ref},i})^{\alpha_i}] 
\]

(1)

In Eq. (1) \( K_{\text{ref},i} \) represents the procurement costs for the reference components which have been taken from our cost data base. The \( p_i \) and \( p_{\text{ref},i} \) are the process parameters for the new and the reference equipment respectively, best representing the capacity. The exponents \( \alpha_i \) determine whether the component costs are

- fairly proportional to capacity \( (\alpha_i = 1,0) \)
- have a significant scaling effect \( (\alpha_i = 0,3 \ldots 0,8) \)
- are independent of capacity \( (\alpha_i = 0,0) \)

The \( F_j \) are escalation factors which represent the other major cost components associated with building a plant such as

- engineering
- instrumentation
- electrical
- piping
- procurement and expediting
- civil
- erection
- commissioning

Table 2 contains the main equipment items which were represented in the capital cost estimation for each revamp concept. Finally, the capital cost calculations led to the individual erection costs for the revamp concepts as listed in Table 3.

An important part of the real cost for a capacity expansion is the loss of production caused by the tie-in and commissioning of the revamp part. Erection time for the revamp section itself extends over several months. Obviously, a complete shutdown of production for such a long period would render any revamp totally uneconomical.

Hence, it is of major importance to carry out as much erection work with the plant in operation and keep the unavoidable downtime for the final tie-ins to a minimum. In general, this will usually be combined with a planned major shutdown, in which more time consuming service operations are also scheduled.
Table 2: Main equipment items represented in the capital cost assessment

<table>
<thead>
<tr>
<th>main equipment item</th>
<th>revamp concept</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>II</td>
<td>III</td>
<td>ATR</td>
</tr>
<tr>
<td>SMR enlargement</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SR with enrich. air</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>auxiliary air compressor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>air separation unit</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>steam reformer oven box expansion</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>combustion air fan</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>flue gas fan</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>secondary reformer replacement / modif.</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>autothermal reformer</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>fired heater</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>process air preheating</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>combustion air preheating</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>feed / steam preheating coil</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>natural gas preheating coil</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>steam generator</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>steam drum</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>OT synthesis</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>CO₂ absorber</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>auxiliary synthesis gas compressor</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

A comparison of the revamp concepts with respect to the extension of the activities requiring a total shutdown of the entire plant reveals significant differences between them.

- Concept III requires only tie-ins at relatively cold and therefore non-critical piping. It appears justified to assume that this work can be carried out during a normal major shutdown for maintenance.

- Concept II requires the modification of the existing secondary reformer or the tie-in of a new one. This operation involves work on critical, brick-lined piping. Hence, it seems justified to assume that this will extend the shutdown of the entire plant by one week.
Concept I requires difficult structural work to enlarge the oven box of the existing steam reformer. Even with a maximum amount of preassembling it seems likely that this would prolong the scheduled shutdown by at least four additional weeks.

The additional shutdown periods have been turned into capital costs and entered into Table 3. Based on an ammonia market price of 400 USD/mt and energy cost of 3.0 USD/MMBTU the daily loss in revenue amounts to 600,000 USD. Adding the tie-in costs to the erection costs finally leads to the individual implementation costs for each revamp concept as shown in the last line of Table 3.

Table 3 illustrates that as long as the production losses for the final tie-ins are neglected, concept I appears to be the most attractive solution for this kind of capacity enlargement. However, taking into account the real cost of implementation this picture is completely reversed and revamp concept III becomes the most promising one with respect to overall capital costs. Concept I then drops into second position with about 4% higher overall capital costs. Concept II turns out to be the least attractive one with about 7% higher capital costs compared to concept III.

### Table 3: Capital cost of the revamp concepts in USD

<table>
<thead>
<tr>
<th>plant section / cost component</th>
<th>Revamp concept</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>II</td>
<td>III</td>
</tr>
<tr>
<td>enlarged SMR</td>
<td>80,4</td>
<td>98,4</td>
<td>93,7</td>
</tr>
<tr>
<td>sec. ref. with enriched air</td>
<td>71,2</td>
<td>71,6</td>
<td>69,1</td>
</tr>
<tr>
<td>ATR</td>
<td>2,1</td>
<td>2,2</td>
<td>2,1</td>
</tr>
<tr>
<td>reformer waste heat section</td>
<td>3,9</td>
<td>2,9</td>
<td>3,1</td>
</tr>
<tr>
<td>overall erection cost</td>
<td>157,6</td>
<td>175,1</td>
<td>168,0</td>
</tr>
<tr>
<td>implementation cost</td>
<td>16,8</td>
<td>4,2</td>
<td>---</td>
</tr>
<tr>
<td>overall capital cost</td>
<td>174,4</td>
<td>179,3</td>
<td>168,0</td>
</tr>
</tbody>
</table>

**CAPEX / OPEX COMPARISON**

Finally, a CAPEX / OPEX comparison of the three revamp concepts has been carried out. It is based on the individual production costs per ton of ammonia which can be achieved by the revamp concepts. The individual production costs are calculated as the sum of specific operating and capital costs.

The specific operating costs are basically the specific energy consumptions as listed in Table 1 multiplied by the specific energy costs. Since the aim of this investigation is primarily
an economic ranking between the revamp concepts only energy costs are taken into ac-
count as OPEX. The other operating cost components related to e.g. personnel or mainte-
nance are expected to be similar for all revamp concepts. Hence, they would only add
equal absolute margins to the operating costs but would not influence the ranking.

A rather straightforward approach has been applied to calculate the specific capital costs. It
is based on a fixed payback period for the invested capital. The specific capital costs are
then calculated as the sums of invested capital plus entire interest to be paid during the
whole payback period divided by the amount of product generated during this period.

The method will always deliver the correct ranking, i.e. the revamp concept showing the
lowest production cost with this method will in any case be the most economical solution
whatever method is applied. More sophisticated methods are capable of reflecting the ac-
tual situation of a plant more closely but require data which are not available to us.

Different specific energy costs, capital payback periods and annual interest rates may in-
fluence the ranking of the concepts. To study this several scenarios have been calculated.
The following parameter values have been used:

> specific energy costs: 0,75 / 3,00 USD/MMBTU
> annual interest rate: 5 / 15 %/a
> payback period for rented capital: 5 / 15yrs.

Combining each of these parameter values eight scenarios can be derived. The results for
the four most important scenarios are listed in Table 4. The combination of low interest rate
and long payback period in principal favours capital intensive plants with low specific ener-
gy consumption. The combination of high interest rate plus short payback period puts
plants with comparatively low investment and eventually higher energy consumption in a
better position.

**Table 4: Specific production costs of the revamp concepts in USD/t<sub>NH₃</sub>**

<table>
<thead>
<tr>
<th>revamp concepts</th>
<th>enlarged SMR</th>
<th>SR with enriched air</th>
<th>ATR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>specific energy cost</strong></td>
<td><strong>annual interest rate</strong></td>
<td><strong>payback period</strong></td>
<td><strong>specific production cost in USD / t&lt;sub&gt;NH₃&lt;/sub&gt;</strong></td>
</tr>
<tr>
<td>USD/MMBTU</td>
<td>%</td>
<td>yrs.</td>
<td></td>
</tr>
<tr>
<td>0,75</td>
<td>5</td>
<td>15</td>
<td>128</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>5</td>
<td>329</td>
</tr>
<tr>
<td>3,0</td>
<td>5</td>
<td>15</td>
<td>212</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>5</td>
<td>412</td>
</tr>
</tbody>
</table>


Table 4 illustrates that the ATR-based revamp concept III is likely to have the lowest overall production cost under all scenarios. This is not too surprising since it shows the lowest specific energy consumption and also the lowest capital costs.

**SUMMARY**

An extensive investigation has been carried out by ThyssenKrupp Uhde to establish an economic ranking between three different concepts for the expansion of the synthesis gas generation capacities of existing ammonia plants. Rather unexpectedly, the ATR-based concept (III) turned out to be the most promising solution. The usually applied enlargement of the existing steam reformer (concept I) only takes the second position.

The investigation revealed only moderate differences in specific energy consumption between the compared alternatives. Responsible for the final ranking are mainly the advantages of the ATR-based concept in the overall capital costs for the revamp.

This overall capital costs include the actual erection costs for the revamp section but also the substantial costs for the plant owners through loss of production during the tie-in and commissioning of the revamp part. Compared to the ATR-based revamp concept III especially concept I (enlargement of the existing steam reformer) requires considerably more complicated and laborious work which demands a longer plant shutdown.

The capital costs required for a revamp of this kind are significant. Hence, even assuming a lower specific energy consumption, the specific production costs for which the revamp parts can produce ammonia would not be really low. However, at least for plants which have access to relatively cheap natural gas, such a revamp should still be attractive. There are still considerable margins between the specific production costs calculated in this study and the product market value to cover costs which are not accounted for in this investigation but cannot be avoided in plant operation.

Especially if such a revamp is combined with a general rejuvenation of a plant where several pieces of the main equipment have to be replaced anyway to keep the plant operative, such a revamp still appears attractive and worth a detailed investigation.
1. The Way to achieve Zero Liquid Discharge at Abu Qir Fertilizers Co.
   Fatma Badawy - Utilities Sectors Head, Abu Qir, Egypt

2. Challenges Experienced in Phasing out Radioactive Source Level Measurement in Urea Reactor at Albayroni
   Hassan Al-Khulaif - Process Engineer, Bayroni, S. Arabia

3. “GPIC Initiative to obtain Responsible Care® Certification as full member of GPCA”
   Mohamed Al Hashemi, GPIC, Bahrain

4. Composite fertilizers including Urea+ and NPK production in High Speed Drum Granulator
   Danil Safonov, International Affairs Manager, R&D Institute of Urea (NIIK) – Russia
The Way to achieve Zero Liquid Discharge at Abu Qir Fertilizers Co.

Fatma Badawy
Utilities Sectors Head, Abu Qir Egypt
The Way to achieve Zero Liquid Discharge at Abu Qir Fertilizers Co.

Chemist Fatma Badawy, Utilities Sectors Head, Abu Qir Fertilizers Co.

Presentation out line

1. Our vision

2. Introduction of Abu Qir

3. History of wastewater treatment at abu qir fertilizers co/

4. The way to Zero Liquid Discharge (ZLD)

Our vision

- Saving Water Resource with Sustainable Development

- One of the core elements of Abu Qir vision is keeping a clean environment & reducing the green house gases.

- Meeting Egyptian market needs of nitrogen fertilizers and expand export international markets.

Introduction of Abu Qir

Abu Qir Fertilities Co. is one of the biggest companies for production of nitrogenous fertilizers in the Middle East.

It consists of 5 nitrogen plants:

AQ (1) to produce urea prills with total capacity 1650MTD

AQ (2) to produce ammonium nitrate granules with total capacity 2400 MTD

AQ (3) to produce urea granules with total capacity 2000 MTD

NPK plant with total capacity 1000 MTD

UAN plant with total capacity 1600 MTD
History of Waste Water Treatment in AQ Fertilizer Plants

(1) At 1979 AQ(1) wastewater was 500 m$^3$/hr.

(2) At 1991 AQ (2) wastewater was 175 m$^3$/hr and the total for both became 675 m$^3$/hr by increasing only 33.6%.

Due to reusing of 200 m$^3$/hr of blow down from nitric acid cooling tower with low concentration to ammonia cooling tower which operate at high concentration and recycling 80m$^3$/hr ammonia process condensate after treatment from AQ(1) & AQ(2).

(3) At 1998 AQ (3) wastewater was 120 m$^3$/hr and all waste water for 3 plants became 470--600m$^3$/hr with decreasing 30% --- 11%.

Due to reusing of 150 m$^3$/hr of blow down from urea cooling tower of AQ 3 with low concentration to ammonia cooling tower which operate at high concentration beside 300 m$^3$/hr blow down of AQ(1) cooling tower Also re-used to ammonia cooling tower 3 recycling 120 m$^3$/hr urea process condensate from AQ(1) & AQ(3).

So by using the concept of recycle and reuse we decreased the wastewater quantities from 1345 m$^3$/hr to 470- 650 which represent 65% this is good control of effluent which is the first step of ZLD.

The rest quantity 470 m$^3$/hr which represent 35% need further treatment to be recycle. So this the Way to achieve Zero Liquid Discharge.

The Way to achieve Zero Liquid Discharge

With shortage of water resources in Arab regions and to save these water resources as much as possible to sustainable development Zero Liquid Discharge system become our challenge.
The steps to implement ZLD system are:

**Study the effluent system.**

**Operation:**

Study all the streams of the process unit for both condensate and cooling water to recycle and reuse the suitable one.

**Examples:**

A - Recycle.

- Recycle of the ammonia process condensate after stripping the condensate at ammonia stripper and polished at ion exchange filter as one of the boiler feed water stream.

- Recycle the urea process condensate after treatment at urea hydrolyser as one of makeup water stream for cooling system.

B - Reuse.

Reuse the low concentration blow down as a makeup for higher cooling system concentration.

---

**Cooling Water Procedure Outline of Abu Qir I&III**

- **Abu Qir III**
  - **Treated Water Tank**
  - **Make-up** 100 m³/hr
  - **Evaporation**

- **Abu Qir I&III Plants**
  - **Process Condensate**
    - After Urea Hydrolyser
  - **Make-up** 50 m³/hr

- **Abu Qir I Plants**
  - **Cooling Tower**
  - **Blow Down** 250 m³/hr

- **Ammonia Plant**
  - **Cooling Tower**
  - **Evaporation**

- **Heat Exchangers & Condensers Cooling**

---

**Blow down**

- 50 m³/hr
- 75 m³/hr
- 250 m³/hr

**Discharge**

- Waste Water System

---
Case (1)

Waste water quantities before recycling and re-use

<table>
<thead>
<tr>
<th></th>
<th>AQ 1</th>
<th>AQ 2</th>
<th>AQ 3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT blow down waste</td>
<td>400</td>
<td>350</td>
<td>350</td>
<td>1100</td>
</tr>
<tr>
<td>Reg. waste</td>
<td>25</td>
<td>20</td>
<td>20</td>
<td>65</td>
</tr>
<tr>
<td>Condensate waste</td>
<td>80</td>
<td>30</td>
<td>120</td>
<td>230</td>
</tr>
<tr>
<td>Total waste</td>
<td>505</td>
<td>400</td>
<td>490</td>
<td>1395</td>
</tr>
</tbody>
</table>

M3/hr.

![Graph showing waste water quantities]

- Blue bars represent CT blow down waste.
- Red bars represent Reg.

AQ 1, AQ 2, AQ 3 refer to different sources or facilities.
## Case (2)

### Waste water quantities after recycling and re-use

<table>
<thead>
<tr>
<th></th>
<th>AQ 1</th>
<th>AQ 2</th>
<th>AQ 3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CT blow down waste</strong></td>
<td>150</td>
<td>150</td>
<td>110</td>
<td>410</td>
</tr>
<tr>
<td><strong>Reg. waste</strong></td>
<td>25</td>
<td>20</td>
<td>20</td>
<td>65</td>
</tr>
<tr>
<td><strong>Condensate waste</strong></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total waste</strong></td>
<td>175</td>
<td>170</td>
<td>130</td>
<td>475</td>
</tr>
</tbody>
</table>

The table shows the waste water quantities after recycling and re-use for AQ 1, AQ 2, and AQ 3, with a total for each category. The bar chart illustrates the same data with categories for each area (1Abu Qir, 2Abu Qir, 3Abu Qir) and subcategories for CT blow down, Reg, and Condensate waste.
(2) **Maintenance:**

a- Prevent any leakage of water.

b- Applying the preventive maintenance system.

c- Update and renovate the equipments in due time.

(3) **Instrumentation:**

Monitor the process unit

By using the online instruments and regular laboratory checkup we monitor the process units.

(4) **Calculations:**

By Calculating all the inputs and outputs data and making the material balance periodically, we can know the deviation in the system and follow up them.

(5) **Mapping System:**

After calculating all the data, we can make a mapping system of the plants effluents with quality and quantity, which help us in taking the decision for the waste water treatment, reuse and recycle.

All these 5 items, will lead us to control our effluents and decrease them as much as possible.
Waste Water Streams:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>B.D. from Cooling Tower</td>
<td>3600</td>
<td></td>
<td>1200</td>
<td>2400</td>
</tr>
<tr>
<td>Sludge of flocculators</td>
<td>48</td>
<td>20</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>B.W. OF gravel filters</td>
<td>816</td>
<td>150</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>Waste of Reg.Demi. lines EDR Unit</td>
<td>696 840</td>
<td>200</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Waste from process plants</td>
<td>655</td>
<td>175</td>
<td>865</td>
<td></td>
</tr>
<tr>
<td>End Pipe</td>
<td></td>
<td>Pipe 1</td>
<td>Pipe 2</td>
<td></td>
</tr>
</tbody>
</table>

Measured = 350 – 450 m3/hr. 150 – 200 m3/hr.

Now, no way to save recourses with sustainable development unless ZERO LIQUID DISCHARGE which will be achieved by:

- Mapping for quantity and quality of the effluent at all conditions of the plants.
- Searching for different technologies of waste water treatment
- Selection the best available Technology, which has environmental view, economical view and applicable view.
Select Best Technology

Environmental View:

Egyptian law 8-2011 max limit

<table>
<thead>
<tr>
<th>temp.</th>
<th>color</th>
<th>odor</th>
<th>PH</th>
<th>TDS**</th>
<th>turbidity</th>
<th>oil</th>
<th>COD</th>
<th>BODs</th>
<th>NH3-N</th>
<th>T.N</th>
<th>PO</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td>mg/l</td>
<td>NTU</td>
<td>mg/l</td>
<td>mg/l</td>
<td>mg/l</td>
<td>mg/l</td>
<td>mg/l</td>
<td>mg/l</td>
</tr>
<tr>
<td>38</td>
<td>clear</td>
<td>free</td>
<td>6. - 9</td>
<td>(+or -) 2000</td>
<td>50</td>
<td>15</td>
<td>100</td>
<td>60</td>
<td>3</td>
<td>10</td>
<td>5</td>
</tr>
</tbody>
</table>
TDS** is (+ or -) 2000 mg/l of marine environment.

**Economic View:**

**Case (1)**

`Plants` 2000 m$^3$/hr. 650 m$^3$/hr.

**Case (2)**

`Plants` 1190 m$^3$/hr. 1650 m$^3$/hr. 512 m$^3$/hr.

**Future View:**

In the future we are facing a Shortage of water resources.

And our objective now is to save these water resources as much as possible.

So, Zero Liquid Discharge system is our challenge to achieve this objective and to adept with the environmental needs .
### Reject Analysis:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow rate</td>
<td>m³/hr</td>
<td>53</td>
</tr>
<tr>
<td>Temp.</td>
<td>°C</td>
<td>32</td>
</tr>
<tr>
<td>COD</td>
<td>ppm</td>
<td>&lt;100</td>
</tr>
<tr>
<td>BOD</td>
<td>ppm</td>
<td>&lt;10</td>
</tr>
<tr>
<td>NH₃_total</td>
<td>ppm</td>
<td>3.8</td>
</tr>
<tr>
<td>freeNH₃</td>
<td>ppm</td>
<td>Neg.</td>
</tr>
<tr>
<td>Comb.NH₃</td>
<td>ppm</td>
<td>3.8</td>
</tr>
<tr>
<td>NH₄ N</td>
<td>ppm</td>
<td>3</td>
</tr>
<tr>
<td>NO₃</td>
<td>ppm</td>
<td>9</td>
</tr>
<tr>
<td>NO₃ N</td>
<td>ppm</td>
<td>2</td>
</tr>
<tr>
<td>TN</td>
<td>ppm</td>
<td>5</td>
</tr>
<tr>
<td>TDS</td>
<td>ppm</td>
<td>15000</td>
</tr>
</tbody>
</table>
Recycle Analysis:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow rate</td>
<td>m3/hr</td>
<td>467</td>
</tr>
<tr>
<td>Temp.</td>
<td>°C</td>
<td>32</td>
</tr>
<tr>
<td>COD</td>
<td>ppm</td>
<td>neg.</td>
</tr>
<tr>
<td>BOD</td>
<td>ppm</td>
<td>neg.</td>
</tr>
<tr>
<td>NH3 total</td>
<td>ppm</td>
<td>3.3</td>
</tr>
<tr>
<td>Free NH3</td>
<td>ppm</td>
<td>neg.</td>
</tr>
<tr>
<td>comb.NH3</td>
<td>ppm</td>
<td>3.3</td>
</tr>
<tr>
<td>NH4 N</td>
<td>ppm</td>
<td>2.6</td>
</tr>
<tr>
<td>NO3</td>
<td>ppm</td>
<td>15</td>
</tr>
<tr>
<td>NO3 N</td>
<td>ppm</td>
<td>3.4</td>
</tr>
<tr>
<td>T N</td>
<td>ppm</td>
<td>6</td>
</tr>
<tr>
<td>TDS</td>
<td>ppm</td>
<td>100</td>
</tr>
<tr>
<td>CL</td>
<td>ppm</td>
<td>25</td>
</tr>
</tbody>
</table>

So, by reaching **ZERO LIQUID DISGARGE**, after we have recycled and re-used the Cooling Water Blow Down and the Process Condensate of the plants, we decreased about 65 % (from 1395 m3/hr to 475 m3/hr.) of the waste water.

And now after the new project to achieve **ZERO LIQUID DISGARGE**, we decreased about 96 % (from 512 m3/hr. to 53 m3/hr.) of the remaining waste water with a reject of 53 m3/hr having analysis adopted with the environmental laws.

The remaining 53 m3/hr. of waste water, we are going to work on it, studying it and analysis it to choose the proper technology for treating it, so there is no liquid discharge is remaining, which is **ZERO LIQUID DISGARGE**.
Conclusion:

Achieving the **Zero Liquid Discharge** system will fulfill the following requirements:

- Saving of fresh water reached about 64%.
- Saving Chemicals for Treatment reached about 50%.
- Minimizing waste water quantity reached the saving of waste water about 96%.
- Most important requirement is to Adapt with environmental needs.

Finally recycling and reusing the treated industrial waste water will be considered as one of the water resources to cover our company need.
Challenges Experienced in Phasing out Radioactive Source Level Measurement in Urea Reactor at AlBayroni

Hassan Al-Khulaif
Process Engineer, Bayroni S. Arabia
Challenges Experienced in Phasing out Radioactive Source Level Measurement in Urea Reactor at Albayroni

Abstract

In perspective of SABIC commitment towards occupational health and safety and a committed responsible care global company, Albayroni, a SABIC affiliate, studied an alternative for phasing out the radioactive source level measurement in its Urea Reactor.

Radar type level measurement technique for this particular application is found to be applicable for measuring of liquid level of Urea solutions under extreme process conditions. The devise is in operation since year 2010 without any operational or technical problems.

This paper highlights Albayroni experiences during phasing out the radioactive source with Radar technique, post commissioning difficulties and how those challenges were mitigated.

Contents

I. Introduction
II. Urea Plant Process Description
III. Urea Reactor Process Description
IV. Reactor Level Measurement Mechanisms
   A. Radioactive Source Level Measurement
      1. Measurement Methodology, Concept and Design
      2. Health and Safety Concerns
      3. Operational Concerns
   B. Radar Level Measurement
      1. Measurement Methodology, Concept and Design
      2. Advantages of Radar Level Measurement over Radioactive Level Measurement
V. Installation and Operational Challenges of Radar Level Measurement
VI. Conclusion
I. Introduction:

Al-Jubail Fertilizer Co. (Al-Bayroni) is a 50:50 joint venture between Saudi Basic Industries Corporation (SABIC) and the Taiwan Fertilizer Company (T.F.C). Al Bayroni was established on December 4th, 1979 to manufacture fertilizers. Commercial production of Ammonia and Urea fertilizer began in early 1983.

Ammonia Plant has a design capacity of 1000 MTPD while urea plant has 1600 MTPD design capacity.

In 1995 Al-Bayroni diversified into the manufacture of petrochemicals and started manufacturing of 2-EH (2-Ethyl Hexanol) in 1995 with a capacity of 470 MTPD and DOP (Di-Octyl Phthalate) in 1996 having 150 MTPD.

Responsible Care, the SABIC way...

Radioactive source phasing out - An example of “Responsible Care”

SABIC is a socially responsible global company and committed towards responsible care requirements, taking utmost care in all its processes, occupational health and safety, emissions control, continual improvement through researches, often revisiting and improving so as to cater the global changing needs and requirements.

Al-Bayroni is always looking at ways for enhancing occupational health and safety to its personnel thus striving to be a committed responsible care company. One such illustrative example is the Urea plant reactor radioactive source phasing out taken up in 2008 turnaround with Radar Level Transmitter.

II. Urea Plant Process Description

Urea is produced in Al-Bayroni site according to CO2 stripping process with design capacity of 1600 MTPD.

CO2 enters the bottom of the stripper and heated in counter current with urea solution coming from reactor. Ammonia reacts with stripped gas CO2 from H.P. stripper in the HP carbamate condenser.

Carbamate is formed with large amount of heat generation. This is cooled by generating steam in the shell side of the carbamate condenser.

In Urea Reactor, the slow endothermic reaction involving carbamate conversion to urea product is taking place.
(1) \(2\text{NH}_3 + \text{CO}_2 \rightarrow \text{NH}_2\text{COONH}_4 \) (Ammonium carbamate)

(2) \(\text{NH}_2\text{COONH}_4 \rightarrow \text{NH}_2\text{CONH}_2 \) (Urea) + \(\text{H}_2\text{O} \) (Water)

The reaction mixture, leaving the reactor via an overflow line, is discharged to the stripper, where the mixture is distributed over a large quantity of tubes, by means of liquid dividers between the gas tubes and the tubes sheet. \(\text{CO}_2\) gas introduced in counter current flow through the tubes, causes the partial \(\text{NH}_3\) pressure to decrease, as a result of which carbamate starts to decompose. HP steam is admitted around the tubes to provide the required heat.

The liquid from the stripper is discharged to the recirculation section. Reactor off-gas is entering the bottom of the HP scrubber to be condensed. The urea carbamate solution leaving the bottom part of the stripper is sent to the low pressure section for further carbamate decomposition and urea concentration of about 72%.

The urea solution is concentrated to about 99.7% wt. by evaporating the water in two stages evaporators under vacuum. The concentrated urea melt is pumped to the Prilling bucket, on the top of the Prilling tower.

The solidified Prills are transferred to the Bulk storage or loading station via Fluid bed Cooler. The overall Urea process is illustrated in block diagram as shown in Figure 1 below:
III. Urea Reactor Process Description

The reactor is provided with trays and has sufficient volume to accommodate the residence time of the relatively slow endothermic reaction involving carbamate conversion to urea product.

\[ \text{NH}_2\text{COONH}_4 \rightarrow \text{NH}_2\text{CONH}_2 \ (\text{Urea}) + \text{H}_2\text{O} \ (\text{Water}) \]

The function of the trays is to ensure proper mixing of the reactants consistent with the specified vessel volume - residence time requirement of the reactor. The fluid mixture leaving the reactor at a temperature of 183 °C contains urea, water, carbamate and excess ammonia. This reaction mixture is proceeding in the high pressure stripper for further separation. Reactor outline is shown below in Figure 2:
IV. Reactor Level Measurement Mechanisms

In Urea process industry, level measurements and controls are vital for tracking the inventory in either storage or process vessels. This enables accurate Material stock identification, Prevention of vessel overflow, Prevention of overload or underload to the agitators, Batch filling & emptying control, Operation at optimum level etc.

Al-Bayroni experienced with both Radioactive as well as Radar Technologies in its Urea reactor level measurement.

A. Radioactive Level Measurement

1. Measurement Methodology, Concept and Design

The gamma radiation is measured in scintillation rod detectors using crystals. A photo multiplier converter converts the light generated by the radiation in the scintillator into pulses. Pulses sent from scintillation counter from the field to control room level monitoring system and DCS.

A scintillation counter measures ionizing radiation. The sensor, called a scintillator, consists of a transparent crystal that fluoresces when struck by ionizing radiation. A sensitive photomultiplier tube (PMT) measures the light from the crystal.

These PMTs multiply the current produced by incident light by as much as 100 million times. The PMT is attached to an electronic amplifier and other electronic equipment to count and possibly quantify the amplitude of the signals produced by the photomultiplier. The scintillation counter was invented in 1944 by Sir Samuel Curren.

Typical radioactive type level measurement technology is represented in the below figures 3, 4 & 5:
2. Health and Safety Concerns

Nuclear radiation exposure is certainly dangerous to the human health and environment. Hence, handling of nuclear materials is a high potential concern.
3. Operational Concerns

The tedious maintenance of the radioactive system leads to certain operational concerns namely the following:

i. Loss of indication due to transmitter failure  
ii. Source Flange leak  
iii. Detector high temperature and no adequate cooling system provided during commissioning  
iv. Calibration difficulties due to water filling and draining requirement  
v. Reverse flow due to wrong level reading  
vi. Inconsistent reading due to foaming

B. Radar level Measurement

1. Measurement Methodology, Concept and Design

RADAR stands for “Radio Detection and Ranging”

Radar-based devices beam microwaves at the process material's surface. A portion of that energy is reflected back and detected by the sensor. Time for the signal's return determines the reactor level. Radar provides a non-contact sensor that is virtually unaffected by changes in process temperature, pressure, vapor and foaming.

In the year 2008, Urea Reactor Radioactive Level measurement was substituted with Radar type technology.

Guided-wave technology sends the radar pulse down a probe that extends into the reactor liquid contents. It has 6.3 GHz frequency for better accuracy and repeatability. It is mounted from the reactor top hanging down. The pulse hits the urea solution surface and is reflected back up the probe to the sensor, where the transit time is translated into a distance. The instrument is spanned according to the distance the 100% and 0% points within the reactor are from its reference point. This radar gives a very precise continuous reading, is energy efficient (a consideration for potential battery-powered wireless connectivity), and it operates in such difficult corrosive urea reactor environment.
Below figure 6 shows the typical guided wave radar installation in a urea reactor:

![Figure 6](image)

## 2. Advantages of Radar Level Measurement over Radioactive Level Measurement

<table>
<thead>
<tr>
<th></th>
<th>Radar</th>
<th>Radioactive</th>
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<td>Health &amp; Safety</td>
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<td>Proven</td>
<td>➢ 10 Application</td>
<td>➢ 100 application</td>
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<tr>
<td>De-Installation</td>
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<td>Complicated</td>
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<td>Dependence on Process Condition</td>
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<td>Trouble shooting</td>
<td>Easy</td>
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<tr>
<td>Calibration</td>
<td>Easy configuration</td>
<td>Tedious (Water filling, draining)</td>
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<tr>
<td>Disposal</td>
<td>None</td>
<td>Stringent Legal compliance</td>
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V. Installation and Operational Challenges of Radar Level Control

In the year 2008, Urea Reactor Radioactive Level measurement was substituted with Horn type Radar type technology, as depicted in below figure 7:

Horn antenna radar sensor had certain difficulties as outlined below:

A. Installation Challenges

1. Effective Placement of Radar Transmitter:

For the transition to the Radar technology, the first challenge was in deciding the effective place for installing the Radar in the reactor. The proposal to place the Radar on the hemispherical head would lead to enormous change in the reactor design. Hence, the proposal was overlooked and rejected. Thus decided to install the radar in the existing top manhole dome cover. Below figure 8 shows the effective and successful placement of the Radar Transmitter:
2. Proper Gasket Sealing

There identified a deficiency in the gasket metallurgy to provide the desired sealing, hence resulting in leakage. Safurex serrated ring with PTFER layers provided for the gaskets for achieving the best sealing.

3. Consistent Level Measurement

The horn antenna indicated inconsistent level readings due to the interference of the fumes and gases within the vessel, especially when the reactor level reached 70%. To overcome the problems it was decided to replace the measurement technique with an improved design of the radar. The horn antenna was replaced by guided wave radar having a standpipe in the year 2010.

The figure 9, 10 & 11 depicts the stand pipe construction of the improved radar design:

B. Operational Challenges

Operating Urea plant with inconsistent Reactor level display:

Between year 2008 and 2010 until the mounted Radar type transmitter made modifications, Operations continuously monitoring the Urea process parameters for ensuring Reliability and Integrity of the Urea plant which are described below.

Since the reactor level was not indicated consistently, the synthesis loop was operated by monitoring the HP Scrubber top vent temperature, bottom solution temperature, reactor top temperature, loop pressure, HPCC bottom temperature, HP Carbamate stripper delta T as well as steam pressure, flow of stripper steam and HPCC generated steam, which
were ensured to maintain the ranges as provided in the Standard Operating Procedures (SOP).
The installation of stand pipe type Radar in year 2010 overcome all the inconsistent level measurement issues and Operations & Control of Urea Process became smooth as indicated in the figures 12 & 13

VI. Conclusion:

SABIC, a Global Company is committed towards Responsible Care. To accomplish the objective Al-Bayroni, a SABIC affiliate, successfully phased out Radioactive Source Level Measurement in Urea Reactor with that of Radar type.

During design, installation of Radar and subsequent operating period certain imperative challenges faced were successfully mitigated.

The experience derived might be of high value to other Urea plants in case of implementing similar initiatives.
GPIC Initiative to obtain Responsible Care® Certification as full member of GPCA

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GPIC Initiative for Responsible Care

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“We are committed and looking forward enthusiastically to further enhancing our safety, security, health and environmental performance by implementing the principles and ethics of responsible care management system at our facilities.”

Abdulrahman Jawahery – President, GPIC
Introduction

Gulf Petrochemical Industries Company (GPIC) was established in 1979 as a nucleus of cooperation among Gulf Cooperation Council Countries for the manufacture of fertilizers and petrochemicals. The joint venture is equally owned by the Government of the Kingdom of Bahrain, Saudi Basic Industries Corporation (SABIC) Kingdom of Saudi Arabia and Petrochemical Industries Company, Kuwait.

GPIC uses natural gas as a feedstock for its petrochemical complex. Built on a 60 hectare reclaimed area at Sitra Island, the project initially consisted of two production plants: Ammonia and Methanol together with their Utilities. The plants were commissioned in May 1985, each with a capacity of 1,000 tonnes per day (330,000 tonnes per annum).

In 1989, their capacities were further increased to 1,200 tonnes per day (400,000 tonnes per annum).

The success of these two plants in production and marketing impelled the management to explore other feasible downstream projects. GPIC decided to expand its operations and build a 1,700 tonnes per day (600,000 tonnes per annum) Urea Plant that was commissioned in 1998. Urea plant included its own utilities and comprehensive marine export facilities to export the finest quality granulated Urea, Worldwide.

The drive for the Urea Plant was to safeguard the environment, create further employment opportunities, improve the company’s financial position by both asset and revenue growth, as well as contribute to the fertilizer industries efforts to provide food to the nations of the world.

By 2009, in order to cut down greenhouse gas emission and improve overall efficiency of the resources by generating additional methanol and urea products, GPIC is also constructed a Carbon Dioxide Recovery Project that utilize flue gas from the Methanol reformer for the recovery of 450 tonnes per day (39,600 tonnes per annum) and Urea production by 80 tonnes per day (26,000 tonnes per annum).
**GPIC’s initiative for Responsible Care**

Responsible Care is both an ethic and a commitment that seeks to build confidence and trust in an industry that is essential to improving living standards and the quality of life.

GPIC have been living Responsible Care throughout its existing and now it had confirmed that by obtaining the RC 1400 certification in the 21 June 2010.

GPIC’s achievements are numerous and the company is proud to have won many significant awards. At the local level in 2002 GPIC won H.H. the Prime Minister’s Award for Excellence in Major industries. At regional level, in 2003 GPIC won H.H. Sheikh Mohammed bin Rashid Al Maktoom Award for Outstanding Arab Enterprise and at international level, in 2005 GPIC won the prestigious Sir George Earle Trophy from Royal Society for the prevention of Accidents (ROSPA) UK, which is awarded for the highest performance of Occupational Safety & Health Worldwide. GPIC had become the first organization outside Europe and North America to be awarded with this prestigious trophy. In 2008 GPIC won the Robert W.Campell Award for Excellence in Safety, Health and Environment Management from the National Safety Council, USA.


In the field of Environment and Environmental Project, GPIC is considered a role model in the protection of the Environment as we are the first regional industrial company to use practical demonstration projects to verify the eco-friendliness of its operations. A fish farm, a bird sanctuary and palm tree plantations have already been established in this regard at the GPIC complex.

The company has achieved another first in the kingdom of Bahrain with the introduction of environmental research grants to secondary schools.

It is the dedication and teamwork of both the executive management and employees of GPIC that must be singled out as major forces that have brought about these achievements. These unique qualities of the GPIC’s workforce are the pillars on which the future of the company can be built. There is no doubt that the employees of GPIC form the golden key to the company’s future success and achievements.
GPIC loss prevention related management systems, and associated expenditure. In comparison with fertilizer companies worldwide had shown that GPIC’s operations to be world class in a number of operational performance areas.

The Management Systems ensuring loss prevention practices are carried out constantly. quality accreditation includes ISO 9001, ISO 14001 and ISO 27001. Safety and Health utilizes the OSHAS 18001 management systems approach.

Keeping in mind the vintage of the original plant, equipment integrity remains at a very high standard reflecting continuing investment, preventive and predictive maintenance routines with regular complex turnarounds every 2 years.

An effective inspection activity including Risk Based Inspection (RBI), resourced by qualified personnel, ensures repairs, vessel replacement or metallurgy upgrading is exercised continuously.

Safety has a high profile and has been regularly recognized by organizations such as ROSPA, British Safety Council and the National Safety Council culminating in GPIC being awarded the Sir George Earle Trophy in 2005 and the R.W.Campell award in 2008. A Behaviour Based Safety program was started in 2007 and is being further strengthened and reinforced to ensure enhanced performance and control of accidents. Proactive safety measures such as reporting of ‘’Near misses’’ are used to achieve the company’s objectives of Zero Harm.

Fire protection and emergency response facilities are rated well above average by reinsures. There are a well-equipped full time on-site fire brigade, with a mutual aid agreement in place with the neighboring companies. Fire training has been an expanding and developing more and more in recent past years.

We have fire proofing features. Retrofit fireproofing has been applied in a number of different areas all over the plant .

There have been improvements in fire and gas detection and alarm systems in recent years.

Mechanical integrity is addressed via shutdowns, inspection and by recommended replacement of equipment. there are similar programs for process control and protective instrumentation systems, fire detection and alarm.

The GPIC Risk Management system is intended to add value to the company by contributing to the demonstrable achievement of objectives and improvement of, for example, efficiency in operations, environmental protection, health and safety, product quality, legal and regulatory compliance.
Within GPIC, risk management is an integral part of the company’s processes. To this end, risk management is part of the responsibilities of management; it is not a stand-alone activity but part of the main activities and processes of the company.

The risk Management system process at GPIC is an interactive process and involves risk identification, risk analysis, risk evaluation and risk treatment. The process risk management strategy addresses fundamental safety, health and environment issues in petrochemical plants.

Process Hazard Assessment (PHA) is applied to modifications/ new construction proposals, capital projects and existing process units to identify and analyze the significance of any potential hazard and or operational constraints that may be involved in the proposed modification, new construction, capital projects etc.

**Work Practices, Procedures and Regular training:**

At GPIC we have effective procedures related to safe work practices and emergency response. All maintenance jobs are carried out as per an approved permit to work system to ensure safety and controlled work.

Further, we have a comprehensive emergency response procedures to provide all employees with the required information for a swift, effective and fast response to any emergency situation

Additionally, different books/ handbooks being issued such as a chemical handbook has been prepared to provide relevant information on the hazards related to the chemicals used in the complex. these three manual s in booklets form have been provided to all GPIC employees.

Regular emergency response based exercises are carried out internally and with the mutual aid neighboring companies.

‘’GPIC is an example of a perfect balance between industry, environment and caring for human resources”’

*Dr.J.Tickel  best seller Australian Author*
Social Responsibility and Enhancing Safety and Health

At the forefront of our social responsibility comes the safety of GPIC employees and that of the citizens of the Kingdom of Bahrain.

GPIC has recognized early on, that the only way to compete with the giant petrochemical and fertilizer companies was to create an institution that not just competes but exceeds all standards on quality, safety , reliability and social responsibility.

The continuation of GPIC’s social responsibility initiatives along with the company’s commitment to ensure the welfare of its employees and their families including hosting social programs was acknowledged when the company won the prestigious award for the ARAB CORPORATE SOCIAL RESPONSIBILITY (CSR) from the United Arab Emirates.

Care for the environment

Equal and parallel to safety, health and social responsibility is GPIC’s attention to environmental Care.

GPIC’s process plants were designed to the most exacting environmental standards, enabling all our emissions to meet the strictest international standards even today.

GPIC consider itself a role model in the protection of the environment and was the first industrial company to use practical demonstration projects to verify the environmental credentials of its operations. The company’s continuous effort’s to enhance the environmental protection has enabled it to win the Saudi Arabia Environmental Management Award for the second consecutive year in 2008

Environmental Responsibility

Since its establishment, GPIC has felt the need for maintain an environmental balance. The project’s environmental impact was thoroughly examined and studied. All the necessary measures and steps were then taken to maintain such a balance. Although more than 24 years have passed since the plants went on stream, all the plants are still operating accordingly to the strictest local and international environmental standards. Gas emissions, waste water releases and
liquid and solid effluents resulting from various processes have been minimized and are constantly monitored and controlled.

All minor and major projects as well as engineering modification undergo an environmental review at the design stage and prior to actual commissioning. the company received certification to the international environmental management system ISO –14001 in December 1999.

**Waste Reduction and Treatment:**

The company policy for waste management hinges on the 3Rs: Reduce, Re-use and Recycle.

The company mainly seeks to reduce waste to the minimum through the use of materials and processes that do not have any adverse effect on the environment. As for the remaining waste, it is disposed of according to the environmental standards and rules in force in the Kingdom of Bahrain. Systems and procedures ensure that the safety of any new chemical material is checked before it is used.

**Gas Emission Control:**

GPIC has installed Sulphur and Nitrogen oxide emissions monitoring equipment on stacks in the complex. The emission levels from the process plants are much lower than the environmentally permitted levels in the Kingdom of Bahrain and internationally. The company has also decided to discontinue the use of Halon gas used in fire extinguishers because of its impact on the ozone layer. Additionally, the company has invested heavily in the replacement of the cooling and refrigeration system that use Freon gas to utilize more environmentally friendly gas.

**Environmental Awareness:**

The Environmental Awareness program for schools:

GPIC also believes that carrying for environmental does not end at its doorstep. In 1998, GPIC started its environmental awareness lectures to schools. To date, 185 schools have been visited benefiting 13,800 students.

Environmental Awareness program for schools is part of GPICs initiative towards environment and society.
GPIC recognizes this initiative as part of its social responsibility, a pillar of its sustainable development policy. These lectures aim at enhancing the awareness of the school students about the major local, regional and global environmental issues.

Bahrain. Graduate engineers From GPIC visit public and private schools preaching the important environmental message to future generations,

Program Objectives:

- To promote environmental awareness amongst young generation
- To serve the community by minimizing the pollution and protecting the environment
- To assist students to take part in saving the environment
- To encourage other industries to take positive role in protecting our environment
- To enhance the presentation skills of the graduate engineers as part of their development program
The environment is the essence of nature and the basis of life for all living things. Since its inception, GPIC has chosen to consider the environment in its operations and plants designs and to apply the strictest environmental specifications, despite the high cost of such choice. Our experience has proved that it was the right choice; the benefits are enormous.

*Princess Sabeeka Aromatic Garden*
Socially Responsible

The company has been able to increase its contributions to the local community, a policy trend that is strongly supported by the UN, which urges all concerned worldwide to comply with it under ‘’Corporate Responsibility’’

In the past eight years alone, GPIC contribution to the community amounted to US$ 4.62 million. most of these financial contribution went to local charities, sport funds, education, health and environmental protection. the charities were for helping the poor, handicapped, orphans, childhood care and women organizations.

In addition to financial contributions GPIC regularly donates items such as wheelchairs, laptops and schoolbags, etc. more than 2,000Kg of dates produced in the charity Garden are donated annually to the needy.

Hundreds of school bags are distributed to students in need at the beginning of every academic year. In all , GPIC had donated more than 30,000 school bags by the end of 2008.

In 1996, the company established its fish farm and expanded it in 2001 to produce more than 30,000 fish annually. part of this yield is donated to the needy.

Community involvement:

Community involvement is embedded in the fabric of GPICs business. most importantly, GPIC’s active participation in various institution. GPIC is represented on the board of directors for University of Bahrain, Bahrain Training Institute, National Committee for safety and many professional bodies.

Supporting the Welfare of the community is also realized through generous contributions to organization such as sport clubs and associations, libraries and professional bodies. in the past 9 years , GPIC trained 640 school and university graduates and provided material support to organizations caring for the young.

GPIC has taken upon itself the task of developing the environment and not just preserving it. With this in mind , the company has implemented a number of unique environmental projects
that have added new concepts to environmental care. Since its inception in 1985, GPIC has made substantial investments in developing its environmental systems and its own projects and initiatives to improve the local environment around its complex, such as:

The Charity Garden:

In March 1992, GPIC launched its first initiative to improve the local environment around and inside its complex. The charity vegetable farm was able to supply more than 16 tons of green produce and dates to the needy.

![Charity Garden](image1)

This was a seed planted by the company to enhance the employees love for nature and greenery and was the foundation for many other environmental projects.

The Fish Farm:

As one of the most important projects in the preservation of marine life, the fish farm was opened on November 20th 1996, with a fish capacity of 10,000. In order to improve the conditions of local fisherman and marine life, the company has expanded the farm twice; it now holds 60,000 fish, adding more than 360 thousand sea-breams to the country’s fish stock by the end of February 2011.

![Fish Farm](image2)

The Bird Sanctuary:

The bird sanctuary was set up in June, 1999, west of GPIC complex. It has provided a safe haven, a natural and convenient habitat for flamingoes.
and other migrant birds that stay for much of the year in shallow coastal areas and feed on crustaceans available at the site. The sanctuary covers two small islands (3,800 square meters) as part of this facility to offer shelter and feeding grounds for the birds. 75 species that have visited the sanctuary have been captured on film and were recorded in a booklet titled ‘birds from GPIC’

Green Oasis:

GPIC provided an area of 16,000 square meters for the Green Oasis project, with the employees donating more than 80% of the planted trees, while VIPs and visiting delegations provided the remaining trees. the oasis is now a beautiful green place full of palm and fruit trees.

The Medical Herbs Garden:

On the 9th of May 2005, GPIC launched a plants and medical herbal garden at the company’s complex, under the patronage of HH Shaikh Abdulla bin Hamad Al Khalifa, Chairman of the General Authority for the Protection of Marine Resources, Environment and Wildlife. The Herb Garden allows the growth of 20 varieties of such herbs in addition to numerous fruit trees such as Banana, Palm, Pomegranate and Olive trees. The aim is to preserve the herbs used by our ancestors to treat various ailments; the garden also provides a very good site for researchers in this field.

Princess Sabeeka Garden for Aromatic Plants:

The Company was honored on March 5th 2009 by a visit from of HRH Princess Sabeeka bint Ibrahim Al Khalifa, wife of HM King and Chairwoman of the Supreme Council for Women. Her Highness opened the Aromatic plants Garden which bears the name of HRH.

The garden contains 45 different types of medical herbs and aromatic plants collected from various Gulf countries in order to maintain and provide an appropriate environment for scientific research. Now the company boasts a total of some 5900 trees all cultivated at the GPIC complex.

As proof of assuming its responsibilities in developing and maintaining the environment, the company was able to plant olive trees forming a green Oasis that is now contains more than 600 olive trees. The Oasis was established according to the direction of HRH Princess Sabeeka bint Ibrahim Al Khalifa.
Different Technologies and Monitoring methods implemented by GPIC in the environmental protection / control

Carbon Recovery Unit (CDR)

It is the first project in the middle east, of its type. Recovers 450MT/day of CO2 gas and hence protecting the environment by minimizing the emission of greenhouse gases. Increased Urea production by ~ 26,400 MT per annum and Methanol production by ~ 39,600 MT per annum.

The CDR unit recovers CO2 from the flue gas of the Methanol reformer. The CO2 recovery unit had been designed to recover 450 metric/ton/day of CO2 as a design capacity from the flue gas of existing Methanol plant reformer. The recovered CO2 gas is used as a raw material in the existing Urea Plant. The flue gas is extracted from the stack and brought to the CO2 recovery plant by flue gas blower through flue gas quencher.

The CO2 produced in Ammonia plant process, is sent directly to Urea Plant. As CO2 is required in the production of Urea. Thus, with the commissioning of CDR unit in Methanol plant, GPIC had reduced its CO2 emission to very low level and thus contributing in the environmental protection as CO2 is considered as greenhouse gas and chief contributor in Global warming.
Monitoring:

- Environmental report is prepared quarterly, by which it covers all the air emissions and water effluents to the sea, including all the waste produced in the complex. This report is documented and a copy is sent to the environmental directorate of Bahrain.
- A online monitoring system is also installed in all the stacks located in the plant. This online monitoring is directly connected with the environmental directorate of Bahrain also.
- To demonstrate GPIC adherence to Bahrain environmental legislation, a Mobile Air Quality monitoring unit has been procured and located near Shaikha Sabika Aromatic Garden at the south west of GPIC complex. The unit is installed on a trailer so it can be moved to other locations when required. The unit is provided with gas analysers to measure the gaseous pollutants concentration at the proximity of the unit in addition to the pollutants source direction (e.g. East, West, etc.).
- In addition, the unit can measure wind direction, wind speed, Air temperature and relative humidity.
- All the effluent water, which is sent to the sea water outfall is first undergo a complete treatment before introducing it back to the sea.
**Responsible Care Certification:**

The company has sought to adopt regulations and systems that ensure environmentally friendly operations. GPIC received the ISO 14001 for the environmental management system in 1999, the first company in either Bahrain or the Arab world to receive such international recognition. GPIC is also audited internally by the company’s qualified inspectors and externally by internationally recognized establishments. According to the company’s point of view, those regulations are on obligation more than anything else. And as with the continuous development and enhancement of the Company, Responsible Care support was declared by the President of GPIC on the 19th of January 2010, and by the July of the same year, GPIC received RC 14001 certification.

- **19 Jan 2010:** Support Responsible Care
- **third party certification for RCMS**
  - Assigns DNV.
- **20th to 23rd May 2010:** Pre-assessment and gap analysis for RCMS
- **final audit was conducted in June 2010.**
- **GPIC received RC 14001 certification in July 2010.**

Responsible Care is the chemical industry’s global initiative to drive continuous improvement in health, safety, security and environmental performance.

Being a responsible care company means sharing information with communities and others about performance and ways to improve. it means addressing concerns about health, safety and security, the environment and products. and it means doing more than what is required by the regulations.
A responsible care management system offers an integrated, structured approach to drive results in seven key areas:

- community
- distribution
- employee health awareness and emergency response
- security
- and safety
- pollution prevention
- process safety
- product stewardship
GPIC’s complies with the Responsible Care of Codes of Practice:

7 Responsible Care codes of Practice:

1. Community Awareness and Emergency Code: Being open to the community and respond to the public’s questions and concerns about health and safety and environment. GPIC has a comprehensive emergency response procedures and plans to protect employees and communities by responding rapidly and effectively to any emergency.

2. Security Code: A comprehensive security plan has been set by the GPIC management to protect people, property, products, processes, information and information systems to enhance security, including security against potential terrorist attack.

3. Process safety Code: The plants are designed according to sound engineering practices, built, operated and maintained properly and periodically reviewed for conformance. Dynamic systems established in place to protect from harmful effects stemming from operation, through a comprehensive risk assessment and by reducing and controlling risks through continues emission monitoring, safe operating procedures, training and of our employees, and continuously and systemically audit operation and activities. (PSM)

4. Employee Health and Safety Code: in addition to the compliance of OHSAS 18001 and ISO 14001, the company commits to continually improve work site health and safety, by adapting practices that provides a multidisciplinary means to identify and assess hazards, prevent unsafe acts and conditions, maintain and improve employee health, and foster communication on health and safety issues. this will enable us to protects and promote the health and safety of employees, contractors and the public and protect the environment.

5. Distribution Code: standards, procedures and training for the storage and handling of chemical products are followed to ensure the safe distribution of our product. we are currently working with our partners SABIC & PIC to further improve this aspect.

6. Pollution Code: In addition to adhering to the government emission regulation, the company is continually seeking the best engineering practices to reduce the amount of all contaminants and pollutants released to the air, water, land and wastes generated from company facilities. These reductions are intended to respond to public concerns with the existence of such releases, and to further increase the margin of safety for public health and the environment. Our system in terms of pollution control is governed by ISO 14001.
7. Products Stewardship:
Health, safety and environmental protection is an integral part of designing, manufacturing, marketing, distributing, using, recycling and disposing of our products.
Composite fertilizers including Urea+ and NPK production in High Speed Drum Granulator

Danil Safonov
International Affairs Manager,
R&D Institute of Urea (NIIK)
Russia
PRODUCTION OF NP, NPK AND COMPOUND UREA BASED FERTILIZERS (UREA+ FERTILIZERS) IN HIGH SPEED DRUM GRANULATOR

By the present moment the demand and supply of compound fertilizers has been showing tremendous growth and it’s expected to steadily increase in the future outrunning the average demand for other types of fertilizers. Market success of compound NP and NPK fertilizers which production exceeded the level of 65 million tons in 2010 is explained by following reasons:

- they contain higher concentration of nutrients, decreasing production, handling and transportation costs and cost for soil application;
- compound fertilizers have better physical, chemical and mechanical properties compared to regular fertilizers;
- compound fertilizers offer a wider variety of options and can be adjusted to satisfy demand in accordance with particular soil composition.

Increased demand in NPK puts fertilizer producers to a challenge where they need to find the most cost effective solution to diversify the range of products with a possibility to adjust to changing market trends and requirements of their customers. They would also want to be the first to give their customers more choices before they are left behind while the competitors are accumulating additional profits on more added value products.

The ideal solution would be a single multifunctional unit with low CAPEX and OPEX indices, moderate energy consumption, occupying a small footprint area so that it can be installed at existing plant and – most importantly – providing the flexibility to produce different types of fertilizers depending on market requirements.

R&D Institute of Urea developed a unit that satisfies the aforementioned requirements. It’s called High Speed Drum Granulator (HSDG). It’s a unit designed to granulate urea, Urea+ and compound fertilizers. Depending on the fertilizer type either fertilizer melt is sprayed over the crystals or granules of nutrient compound (for example urea melt over ammonium sulfate) or nutrient compound is melted and sprayed over the fertilizer granules or crystals (for example, sulfur melt over urea granules). The HSDG has been successfully tested to produce granulated urea, ammonium nitrate, urea based fertilizers (Urea+ fertilizers), compound and NP and NPK fertilizers.
Outer surface of HSDG is an outer barrel (drum) inside of which an internal drum with blades and classifying screen are installed. Between them there is a reverse crew for internal product recycle. From both ends of the drum fixed loading and discharging chambers are. On the loading chamber’s wall there’s a loading tube and inlet nozzle.

During the operation the granules or crystals of product used as seeds are introduced into the main drum. While the drum rotates the product inside the drum creates “a curtain” in its cross-section and fertilizer or compound solution is sprayed over “the curtain” through the spraying nozzle. The blades on inner surface of the drum serve several purposes: they lift the granules or crystals and maintain the uniformity of the “curtain” and they move the product through the granulator.

As a result the product in the drum undergoes multilayer fattening – the same granule is being sprayed over for many times until it reaches the designed characteristics; after the spraying chamber the product moves to a classifying screen inside the drum. Fine particles fall through the screen and are returned into the beginning of the drum by a reverse screw. The product of the desired size passes the screening and is discharged to storage or for handling,

Fine fraction returned into the main drum undergoes the same process – it is transported by the blades inside the drum as a part of the “curtain” and sprayed over with the solution again and again – until it has the required size and it can pass through the screen.
inside the drum. Product undergoes this cycle for many times. To remove the heat from the process and cool the product atmospheric air is introduced into the drum and outer surface is cooled with water. To remove surplus water from the solution the air introduced into the drum can be heated, heated air can be also directed to the nozzle.

Main features of HSDG are:
1. “Curtain” across inner section of the drum;
2. Internal screening and recycle of the product;
3. Compact size and intensification of production (compared to conventional drum granulation) due to increased speed of drum rotation.
4. Diversity of product range and possibility to expand it by installing additional nozzles.

Laboratory HSDG unit located in R&D Institute of Urea is used for experiments, process optimization for production of particular type of fertilizer. Initially all samples are produced on it. In cooperation with one of Russian urea manufacturers R&D Institute of Urea installed an industrial pilot unit to further improve the process of fertilizer granulation in HSDG in real plant conditions.

Using the units R&D Institute of Urea specialists enhanced the capacity of the equipment and upgraded its design so that now it can be used for a large spectrum of fertilizers with macro- and micronutrients. Most recently we produced trial batches of urea with phosphogypsum, MAP with sulfur, NP and NPK of different composition.
For better explanation of the production process I’d like to give several examples of compound fertilizers that have already been produced in HSDG.

Urea with sulfur

Sulfur is essential due to its agricultural properties, it improves plants growth, its combinations are highly demanded for sustainable plant development. Research conducted by Institute of Sulfur concluded that more than 48 countries suffer from soil sulfur deficiency.

HSDG has been used to produce urea with sulfur and ammonium nitrate with sulfur. Installation of such a unit at existing plant will require low capital investment, little space and newly additional equipment and can be performed at a very short period after equipment manufacturing.

Production process very similar for all compound fertilizers. We use granules, prills or crystals as seeds and spray them with nutrient containing solution, melt or slurry.

Sulfur for urea+sulfur fertilizer can be obtained by using regular sulfur or ammonium sulfate that is commonly found in most plants and has very low cost. Pictures show urea covered with sulfur (left) and urea covered with ammonium sulfate (right).
Urea with micronutrients: zinc, copper, iron
Zinc, copper and iron are valuable nutrient essential for both human and plants.
To produce urea with zinc we sprayed urea prills with copper sulfate pentahydrate, for urea with iron – with iron sulfate heptahydrate.

Urea with phosphogypsum
Urea with phosphogypsum is a brilliant solution for utilization of phosphogypsum and maintaining the profit level for urea. Urea with phosphogypsum has a positive impact on soil structuring it, deoxygenating it and bringing additional nutrients to it.

Ammonium nitrate and ammonium sulfate
The product combines features of the most affordable fertilizers and adds a safety of ammonium sulfate to ammonium nitrate, making it much safer to handle, store and transport. Considering that regulations against usage of ammonium nitrate are spreading further, an easy switch to production of ammonium nitrate combined with ammonium sulfate can help the producers to get ahead of their competitors who have a problem adjusting to new market requirements.

NPK fertilizers
HSDG can replace conventional drum granulators and dryers for production of ammoniated superphosphate or MAP. Also, HSDG can be used for combining several nutrients to create a compound fertilizer with set balance of nutrients.
HSDG has been tested for production of ammoniated superphosphate (NP-fertilizer) and NPK that consists of urea, MAP and potassium chloride.

Urea particles used as seeds can be easily substituted with AN seeds in all aforementioned cases.

At the present moment majority of plants offering NPv and NPK fertilizers use drum granulator and dryer that occupies vast area, gulps energy resources and is considered to be outdated technology.

HSDG when compared to conventional technologies for NP and NPK production has the following advantages:
- smaller footprint area at the same capacity due to intensification of the process.
- easy to install at existing plant with limited space;
- low capital and operational costs;
- cutting edge technology for the top producers to be ahead of their competitors;
- flexibility.

Depending on market requirements the producer can define what fertilizer is best suited to satisfy the demand and has a higher added cost value. HSDG can be used as an additional unit to diversify the range of offered products. R&D Institute of Urea is open for suggestions from fertilizer plants owners to try production of particular product in our laboratory unit,

Most recent references for HSDG are:
HSDG for ammonium nitrate production in Kazkhstan plant;
HSDG for calcium nitrate and magnesium nitrate in Perm, Russia;
HSDG for urea+sulfur, urea+ammonium sulfate and composite product that contains potassium nitrate, magnesium nitrate and urea in Novomoskovsk, Russia;
HSDG for urea granulation in Kemerovo, Russia.

HSDG is a flexible, ecological, cutting edge technology to satisfy the need of both its customers and farmers for various tailor made fertilizers. R&D Institute of Urea provides engineering services, equipment procurement and full range of services for urea plants, enhancing their reliability, decreasing consumption and assuring their sustainable operation.

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Delegates List
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<td>Khaled EL SAYED</td>
<td>3rd-Ev.2012-Ord-1085-1310</td>
<td>Production Director</td>
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<td>Mohamed Yousry MANSOUR</td>
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<td>Mohammed AL-SOGAIH</td>
<td>3rd-Ev.2012-Ord-1542-1010</td>
<td>Board Chairman &amp; Managing Director / Company - SINCO</td>
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<td>+965 23263678</td>
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<td>Lebanon</td>
<td>Elias NAOUM</td>
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## List of Delegates

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<td>Marcel HAGE</td>
<td>3rd-Ev.2012-Oth-1965-2220</td>
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<td>Lebanon</td>
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<td>Monte Carlo</td>
<td>Gian Pietro TESTA</td>
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<td>Business Development Manager&lt;br&gt;&lt;br&gt;K &amp; T</td>
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<td><a href="mailto:gianpietro.testa@gmail.com">gianpietro.testa@gmail.com</a></td>
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| 129  | Oman             | RASHID NASSER AL Farsi        | 3rd-Ev.2012-Ord-1141-320  | Mechanical Engineer OMIFCO                    |            |                               |
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<td>Fawaz Habis AL-HARBI</td>
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