KBR PURIFIER™ Technology and Project Execution Options for Ammonia Plants

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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 dryers 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>
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<th>Expected Gcal/MT</th>
</tr>
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<tbody>
<tr>
<td>Natural Gas Feed</td>
<td>6.06</td>
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<tr>
<td>Fuel</td>
<td>1.72</td>
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<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>Total Energy</td>
<td>6.53</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:
• 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 Licensor’s 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:
Option C – Competitive EPC Bidding Based on Licensor’s BED

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 Cost Plus or Reimbursable</th>
<th>Option B Convertible LSTK or Open Book</th>
<th>Option C LSTK</th>
<th>Option D LSTK</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIC</td>
<td>Lowest</td>
<td>Medium</td>
<td>Medium (-)</td>
<td>Highest</td>
</tr>
<tr>
<td>Schedule</td>
<td>Shortest 30~32 months</td>
<td>Medium 32~34 months</td>
<td>Medium (+)</td>
<td>Longest +48 months</td>
</tr>
<tr>
<td>Quality of Equipment, Material &amp; Construction</td>
<td>Highest</td>
<td>Highest (-)</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Owners Risk</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


