REVAMP OF LIAOHE'S AMMONIA PLANT WITH KRES TECHNOLOGY TO REDUCE NATURAL GAS USAGE

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Abstract

Shenzhen Liaohe Tongda Chemicals Co. Ltd. (Liaohe) has been operating a conventional KBR technology based 1000 MTPD ammonia plant since 1978 at Panjin City in Liaoning province China. The plant has been facing a natural gas supply curtailment leading to very low capacity utilization and reduced production.

In 2001 Liaohe awarded KBR a contract to supply technology and basic engineering for a project to revamp this plant to reduce natural gas consumption from 9.15 to 6.47(expected) Gcal/MT by replacing the existing fired primary reformer with KRES (KBR Reforming Exchanger System) and maintain capacity of 1070 mtpd ammonia. An offsite coal fired package boiler was provided to maintain steam balance. Beside increased capacity utilization of ammonia plant and saving on the overall fuel bill, Liaohe also expected increased production of CO_2 by 13% and consequent higher urea production.

Liaohe's KRES unit is based on a significantly improved version of the original design used for Methanex's 350 mtpd ammonia plant at Kitimat, British Columbia, Canada. Several optimized and enhanced features have been incorporated in its design. The commissioning and operating experience at Liaohe has re-confirmed all the outstanding attributes of the KRES at Kitimat. All the technology enhancements, including scalability, have performed per design. The unit is very operator friendly, flexible and it adapts well to varying throughput requirements. The Liaohe revamp project has met all its expected goals. KRES offers new generation of proven technology alternative to the conventional reformer furnace.

The purposes of this paper are to overview the KRES technology and provide project execution, design, commissioning and operating experience on the Liaohe's KRES unit at Panjin

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INTRODUCTION

Shenzhen Liaohe Tongda Chemicals Co. Ltd. has been operating a conventional KBR technology based 1000 MTPD ammonia monia plant since 1978 at Panjin city in Liaoning province China. The plant actually produced up to 1070 MTPD ammonia. However it has been facing natural gas supply curtailments which typically become severe with weather. Supply curtailment goes up during winter and is less severe during the summer when natural gas supply is freed from other priority users. Curtailment is more in nights compared to the day time when the ambient gets warmer freeing some of the gas from the priority users.

KBR studied various technology options to revamp the Liaohe ammonia plant to improve the overall capacity utilization by significantly reducing its natural gas requirement. Unlike natural gas, coal is available in Panjin in abundance at comparatively lower price. KRES technology based revamp was found to be the best solution. In 2001 Liaohe awarded KBR a contract to supply technology and basic engineering package for a project to revamp this plant to reduce its dependence on natural gas.

The **K**BR **R**eforming **E**xchanger **S**ystem - KRES and Autothermal Reforming - ATR, a simple heat exchanger based steam reforming process is used for generation of ammonia synthesis gas. The KRES unit in Panjin is based on a significantly improved version of the original design used for the 1st time in October 1994, at Methanex's ammonia plant at Kitimat, British Columbia, Canada. It utilizes all the experience gained from the KRES unit at Kitimat plus it has several optimized and enhanced features incorporated. The revamped ammonia plant was successfully commissioned in December 2003 in just twelve days after restarting feed and has been performing very well since then reaching its design capacity.

REVAMP OBJECTIVE

The principle objective of the project was to reduce the natural gas usage. The application of KRES technology enabled Liaohe to reduce the use of natural gas fuel and increase the use of alternative cheaper source of energy, coal which is available in abundance. KRES technology eliminated the primary reformer and the auxiliary boiler, both of which used natural gas fuel. The production of steam from the ammonia plant is reduced – consequently the high pressure steam is drawn from the offsite coal fired high pressure package boiler to maintain the steam balance.

The stated goals of the project were:

- Ammonia production of 1070 MTPD (unchanged)
- KRES installation to reduce the natural gas usage
- Maintain the high reliability of Liaohe's Ammonia Plant

With improved energy efficiency and by reducing natural gas usage up to 29%, Liaohe expected to realize step boost in the plant capacity utilization and boost annual ammonia production. Beside increased capacity utilization of ammonia plant, Liaohe also expected increased production of CO_2 by 13% and an increased urea production which was earlier limited by CO_2 availability. Note- KRES technology increases production of CO_2 from ammonia plant by 13% which is attractive for the manufacturers interested in maximizing conversion of ammonia to urea.

REVAMP SCHEME

The Ammonia plant revamp for Liaohe consists of replacing the existing Primary Reformer and Secondary Reformer with a new proprietary KBR designed KRES system consisting of KRES Exchanger, Autothermal Reformer and Process Heater. The natural gas feed is preheated in the Process Heater, desulfurized and is split into two streams with about 70% of the flow going to the Autothermal Reformer and the balance to the KRES. Process steam is then added to the each feed gas stream to facilitate steam methane reforming in both the KRES and ATR.

KRES unit replaces the complex primary reformer furnace through use of a unique process configuration and relatively simple heat exchanger design. A diagram of the KRES process is presented in Figure 1.

Compressed enriched air is introduced, along with the mixed feed, to a specially designed mixing combustion chamber at the inlet of the ATR. Enriched air provides the N_2 requirement for ammonia synthesis and O_2 required for the combustion of the natural gas. Inside this chamber, some of the hydrocarbon is partially oxidized, releasing the heat necessary for the endothermic reforming of the remaining hydrocarbon with steam using conventional catalyst. The reformed gas leaves ATR at about $1000^{O}C$ and 32.0 kg/cm^2(a). The operating pressure is selected such that the existing process air compressor can be used without modifications. Effluents from the ATR flow to the reforming exchanger shell inlet.

The remaining hydrocarbon and steam feed enters the tube side of the reforming exchanger. As the mixture flows down the tubes, it contacts a conventional steam reforming catalyst. The heat required for the endothermic reforming reactions is provided from the shell side gas, which is the mixture of the ATR effluent and the reforming exchanger tube side effluent. The cooled shell side gas exits KRES for further waste heat recovery and processing including high pressure steam raising and superheating.

As seen in Figure 1, the Reforming Exchanger in the KRES unit uses an open tube design. The catalyst filled filled tubes are suspended from a single tube sheet located at the cold end of the exchanger. With the open tube configuration, each tube is free to expand individually without restriction to its growth. Pressure differential between the inside and the outside of the tube is minimized being limited to the unit pressure drop. The KRES unit utilizes heat from the ATR, thus lowering the ing the waste heat available to the plant steam system.

The enriched air for ATR is produced by mixing ambient air with gaseous O_2 supplied from an offsite oxygen package plant. Oxygen requirement to provide enriched air containing 31.5% O_2 to ATR is only 218 MTPD. The enriched air is compressed by the existing turbine driven Air Compressor and is preheated in the Process Heater after adding some steam.

The reformed gas after heat recovery exit KRES is processed through the existing High Temperature Shift (HTS) Converter, Low Temperature Shift (LTS) Converter, Benfield CO_2 removal and Methanator, which are all unchanged.

Compared to a conventional ammonia process using primary and secondary reformers, KRES technology produces reformed gas with 13% higher CO_2 content. Duty of the carbon dioxide removal section has increased correspondingly. Benfield system for the CO_2 removal needs to change the activator from DEA to ACT-1. This modification to the CO_2 removal system has been established in collaboration with UOP, the licensor of the Benfield process. No other modification was necessary.

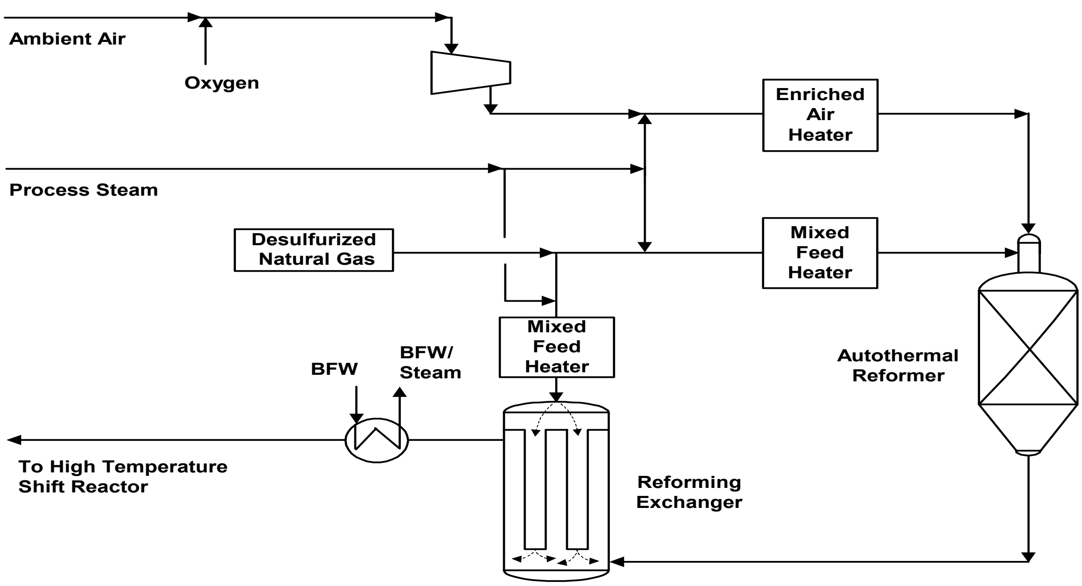

Figure 1

A new off-site coal fired high pressure (HP) steam boiler was provided to maintain ammonia plant's steam balance. The high pressure superheated steam generated in the ammonia plant is mixed with the steam imported from coal fired boiler and fed to the HP steam header. Fundamentally, heat recovery equipment exit KRES and

and associated steam drum from the existing plant need not be changed as the existing equipment are sized for larger duty, but Liaohe decided to replace them and utilize the existing ones in another plant.

The purge gas hydrogen recovery unit was originally designed with six membrane modules (three for high pressure stage and three for low pressure stage) which needed to be maintained for the retrofit case.

KRES BACKGROUND

KBR's Reforming Exchanger System – KRES is a simple heat exchanger based steam reforming process used for generation of synthesis gas for the manufacture of ammonia, methanol, hydrogen or gas to liquid application. KRES went into commercial operation in Methanex's (formerly PAI) ammonia plant in Canada in October 1994 where KRES produces synthesis gas that is converted into 350 MTPD of ammonia. Design features of KRES have been indicated in various papers published by KBR[1,5].

The KRES unit at Liaohe is significantly improved version of the original design used at Kitimat. It utilizes the experience gained from Kitimat plus it has several optimized and enhanced features to improve cost competitiveness. KBR has undertaken extensive development work and improved the KRES design [1], key improvements are:

Optimized Process Parameters: Hot-end temperature approach and feed preheat temperatures have been optimized.

Increased Operating Pressure: Operating pressure is increased to save syngas compression power. KRES exit pressure at PAI was 19 kg/cm^2, at Liaohe is 32 kg/cm^2. KRES can be designed to higher pressure up to 50 kg/cm^2.

Reduced Tube Size: The size of the reforming exchanger is normally heat transfer limited. KBR investigated optimum tube size and determined 1" tube size to be optimum.

Catalyst Shape & Size: Extensive work was undertaken to find optimum shape and size of catalyst. Heat transfer coefficient enhancement by 20-40% was achieved leading to improved thermal performance.

Tubesheet Design: KBR proprietary refractory protected tubesheet design facilitated the use of ordinary stainless steel metallurgy.

The above improvements achieved reduction in KRES size by 40-60% which facilitated use of a smaller diameter shell with easy scalability.

WHY KRES TECHNOLOGY

To overcome the loss of ammonia production due to shortage of natural gas supply, Liaohe selected KRES technology for their revamp project due to the following reasons.

KRES technology is inherently more energy efficient than a conventional ammonia process using primary and secondary reformers since it uses optimum combination of steam methane reforming duty between the ATR and the reforming exchanger. Reformed gas exit a conventional secondary reformer is at very high temperature (950–1000 ^{0}C) carrying high grade waste heat. In conventional ammonia technology, this waste heat is involuntarily recovered by raising steam in a waste heat boiler. Raising steam at 310-328 ^{0}C from this high grade waste heat is thermodynamically not a sound practice since waste heat at such high temperatures is recovered in the form of a lower grade energy in steam.

The waste heat grade of the secondary reformed gas is adequate to support steam reforming instead of raising steam. KRES technology utilizes this high grade waste heat with in the reformer system (in reforming exchanger) for raising additional reformed gas. It totally eliminates the radiant section of fired primary reformer and its associated stack heat losses. The heat previously used to generate high pressure steam is now used to heat heat the reforming exchanger. The lost steam production in case of Liaohe is made up by generating steam in a coal fired package boiler located offsite.

Table 1: Comparison of Feed & Fuel Gcal/MT for Liaohe Plant

*Expected	Before Revamp	After Revamp*
Feed	5.41	6.18
Fuel	3.74	0.29
Total Natural Gas	9.15	6.47
Coal Fired Boiler & Other Credits (net)	0.00	2.10
Total (ex ASU)	9.15	8.57

Table 1 indicates the benefit of KRES based revamp project to Liaohe in this type of application. Natural gas consumption is reduced from 9.15 Gcal/MT to 6.47 Gcal/MT. Coal fired boiler provides additional energy, which is much more cost effective than using expensive natural gas as source of energy. In this way KRES revamp helps Liaohe to:

- **Boost Ammonia Production:** Liaohe ammonia plant had very low capacity utilization due to severe curtailment in supply of natural gas during most of the year. Severity of natural gas supply curtailment is more during colder weather. Liaohe can now improve their capacity utilization by up to 29% during the periods when natural gas supply curtailment is severe. This significantly boosts annual ammonia production for Liaohe.
- **Save on the Total Energy Bill:** Since the natural gas consumption is reduced up to 29% and cost of the coal is significantly lower than that of natural gas, a saving is realized on the total energy bill.
- **KRES Revamp Provides 13% Higher CO_2 Production** from the ammonia plant.
- **Flexible and Robust Operation with High Reliability:** A revamp using KRES technology, eliminated the primary reformer furnace, thereby improved reliability. Revamped plant offered valuable flexibility enabling plant ramp-up and ramp-down on short notice.
- **Mechanically Simple Construction:** The KRES equipment was fabricated locally in China with assistance from KBR.
- **Highly Successful Proven Technology:** KRES technology has already been used by Methanex in Canada since 1994. Liaohe operation has confirmed all the successful features of KRES from Methanex including performance, reliability, flexibility and robust operability.

PROJECT EXECUTION

Split of Work:

KBR provided technology license and a Basic Engineering Design, and played an advisory role in all of the EPC activities, including procurement, critical equipment inspection, construction, start-up and commissioning. Liaohe contracted with HQCEC, a Chinese Design Institute based in Beijing, to perform the detailed engineering, and with the Ninth Construction Company to perform the revamp construction work. Liaohe managed the procurement of materials and other EPC project activities.

The following sections describe the major steps in the Liaohe KRES Revamp Project.

Feasibility Study (KRES Revamp Study)

The revamp for Liaohe began in 2000 with a feasibility study. The feasibility phase included a site survey and development of a base case process model and verification of operation of existing plant. During the study it was determined that the supply of natural gas to the plant was reduced during the winter months.

Recommendations from the study indicated the use of KRES would reduce energy consumption and improve plant production even in period of natural gas curtailment. With the selection of the KRES system, the existing Primary Reformer and Auxiliary Boiler could be eliminated. The study recommended coal, a cheaper and more abundant energy source, to generate high pressure steam. From the study it was determined that the KRES system footprint was small enough to allow the entire KRES system to be built adjacent to the operating Primary Reformer.

Pre-work Agreement

In order to get a head start on long lead equipment items, Liaohe and KBR entered into a pre-work agreement that focused on engineering tasks related to long lead equipment items. This allowed the preparation of inquiry requisition packages, for the long lead equipment items.

Near the end of the pre-work agreement period, most of the major long lead equipment items had been designed and inquired, and purchase orders were ready to be placed by Liaohe. During the feasibility study it was proposed to reuse the existing secondary reformer, waste heat boilers, and steam drum. However, when the re-use of the existing Secondary reformer was studied, Liaohe ied, Liaohe concluded that buying a new ATR compared favorably to the scope of revamping and relocating the existing Secondary reformer. So a new ATR was specified.

Basic Engineering Design

KBR developed the Basic Engineering Design Package (BED) and issued it to Liaohe for review January 2002. A review meeting was hosted by KBR and held in Houston, Texas. Included in the review were representative from Liaohe, HQCEC's design team and the Ninth Construction Company. Before attending the review, HQCEC's team started the detailed Engineering work to better assure the transfer of engineering design intent of KBR's BED requirements into the detailed design effort. A three dimensional (3-D) conceptual model of the design was made by KBR and reviewed as part of the delivery of the BED, shown in Figure 1.

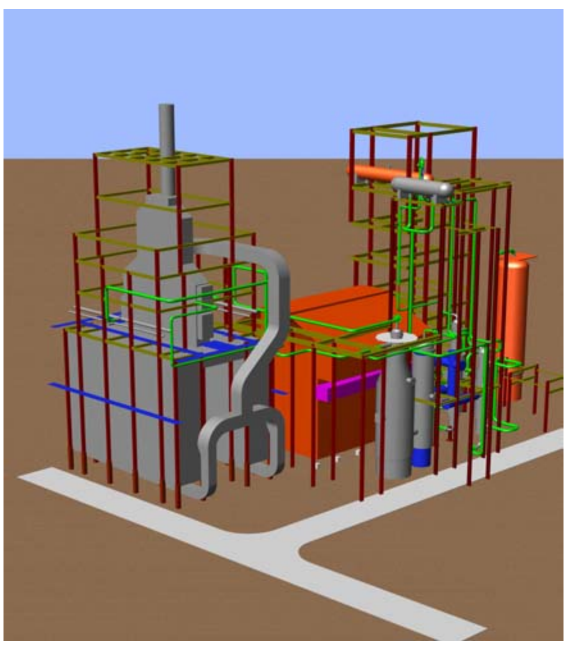

Figure 1 - 3D Conceptual Design for KRES

In **Figure 1**, the 3-D conceptual design shows the new system to scale with the existing primary reformer in the foreground (orange). The KRES system footprint fit within the available space adjacent to the existing primary reformer.

During the BED review meeting, constructability reviews were held with the construction contractor. Liaohe decided as a result of the constructability considerations to purchase new waste heat boiler and steam drum, in lieu of using and relocating the existing equipment, resulting in saving weeks in the planned shutdown duration.

Detailed Engineering Design

The Chinese Design Institute completed the detailed design engineering in 2002. A delegation of KBR specialists attended the review of the detailed design with Liaohe and the Ninth Construction Company in Beijing, during January 2003. With the detailed design completed the construction would begin, and purchasing of remaining materials was finalized. Chinese suppliers attended to meet with KBR, and complete fabrication plans of the critical equipment items. Soon after the detailed design review meeting, Liaohe purchased all of the remaining materials; most were purchased domestically and some from outside China. The KRES exchanger was purchased in China.

Procurement – QA/QC (Shop Inspections)

The performance of the key system components was considered critical, and shop inspection and quality assurance were requirements for successful technology delivery. During the equipment fabrication, stringent shop inspections were held to assure high quality fabrication of the equipment and report deviations from the KBR engineering specifications. A full time KBR inspector was resident in the exchanger fabrication shop where the KRES exchanger was built and in the vessel manufacturer's shop. Although both fabrication shops were in China, they were not close enough to allow for the KBR inspector to travel between the shops. A third party inspection agency was employed to inspect at the vessel shop.

Figure 2 KRES Exchanger during Fabrication in Chinese Supplier

Pre-shutdown Performance Audit

A process audit to measure the production performance of the plant was completed by KBR prior to the planned shut-down. The audit performed in October 2003, measured the parameters selected to record the performance of the ammonia plant.

Construction

Pre-shutdown construction above ground work began in the summer of 2003. KBR provided construction advisor service on site and provided resources for construction matters. The erection of the new system continued while the ammonia plant continued to operate, until Liaohe's planned shutdown. Shutdown began in late November 2003, and continued until the work was completed in December, when the plant commissioning commenced.

Figure 3 Liaohe's KRES -ATR

Commissioning

After completing all the pre-commissioning activities in early December, natural gas was introduced to ammonia plant on 22nd December following a systematic start-up sequence. Ammonia production was initiated during the course of synthesis catalyst reduction on 31st December 2003. Reduction was completed on 3rd January 2004 with ammonia production achieved at 70% of the design capacity within just 12 days of introducing natural gas to the plant.

The procedure for start-up of KRES is fundamentally not different from that of the conventional plant. The catalyst in KRES/ATR is preheated using circulating nitrogen to a temperature above the steam dew point. This is followed by charging steam, continued heating, charging desulfurized feed gas and then charging enriched air in the end. ATR gets combustion flame by auto-ignition of its feed mixture. KRES commissioning and ammonia production was achieved very smoothly. User friendly nature of KRES technology was once again confirmed by successful start-up of the Liaohe's plant by their very high skilled operations staff.

Soon after feeding enriched air to the ATR and trimming the parameters, being in the middle of winter, impact of severely curtailed natural gas supply started to become

become obvious. Natural gas availability typically changed with changing climate, it often reduced in night or with colder spells. Liaohe would like to utilize all the available natural gas at any time and convert it to ammonia. Due to this reason, plant through-put required ramping up and down all the time. This requirement was met very easily with KRES based front-end compared to the conventional plant with furnace type primary reformer. With fewer operating parameters to watch and check during ramping and due to faster response of the compact equipment system in KRES technology, through-put changes were made conveniently. Plant was never shutdown due to shortage of natural gas and higher ammonia production was made possible in the revamped plant.

Plant throughput has been typically 60-80% during the first quarter of 2004 restricted due to natural gas supply curtailments. This production was substantially higher than first quarter of prior years. With improved availability of natural gas, during summer months the plant has operated at or above the design capacity of 1070 MTPD. As such, no bottleneck to design production rate was found and plant performance has been satisfactory.

OTHER APPLICATIONS OF KRES

KRES can be used in following other applications:

- KRES for increasing capacity of the front-end of existing ammonia, hydrogen or methanol plants. These applications have been in described in detail in the papers published by KBR[4,6].

- KRES-Purifier process for ammonia plant. This is described in detail in the papers published by KBR[4]. KRES and Purifier are a natural fit and compliment each other. KRES requires enriched or excess air over and above the stoichiometric requirement of nitrogen for ammonia synthesis. Purifier requires excess air for cryogenic purification. Thus excess air provides a natural fit for use in KRES and this also avoids importing oxygen or installing an air separation plant.

- KAAP*plus*™ for ammonia process which incorporates KBR's KRES, Purifier and KAAP technologies in a single flow sheet. This is described in detail in the papers published by KBR[2,3].

SUMMARY

- A KRES unit is in operation at Methanex's 350 MTPD ammonia plant at Kitimat, Canada since October 1994. In about nine plus years of operation, the reforming exchanger has been 100% available.

- In December 2003, Liaohe commissioned a large KRES unit for 1070 MTPD revamped ammonia plant at Panjin city in Liaoning province China.

- In the Liaohe's ammonia plant KRES technology has reduced natural gas consumption by 29% and replaced the energy with steam produced by a coal fired boiler. Liaohe has also achieved higher ammonia production during feed gas curtailment in winter months.

- KRES unit of Liaohe is significantly improved version of the unit at Kitimat. It utilizes experience gained at Kitimat and incorporates several optimized and enhanced features to improve cost competitiveness.

- KRES technology can also be used to increase the capacity of front-end of the existing ammonia, methanol or hydrogen plants. It can be combined with Purifier and/or KAAP technologies of KBR to reduce energy consumption and capital cost.

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