CFCL-2 Ammonia Plant Operating Experience of a KBR True Cold Wall Add-on Converter

Chambal Fertilizers and Chemicals Limited (CFCL) currently operate two ammonia plants in Kota; Rajasthan, India and a third plant is in construction. The new plant is based on KBR purifier technology. To increase the plant capacity and improve energy efficiency, the existing plants have considered installation of add-on ammonia converters for increasing per pass conversion. The ammonia concentration from the add-on converter is in the range of 20 – 23 mole %. At CFCL-2 the new reactor was successfully commissioned during a short turn around in April 2017 and has achieved all capacity and energy targets. This paper presents the analytical design, installation and operating experience at CFCL-2.

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Introduction

Chambal Fertilizer & Chemicals Limited (CFCL) is located in Kota, Rajasthan, India. This fertilizer complex has two ammonia plants and a third plant is in execution. This new plant is based on KBR Purifier® Technology with expected start in 1st quarter of 2019.

The first ammonia plant has a design capacity of 1,500 MTPD (1650 STPD) and is based on Hal-dor Topsoe technology. KBR revamped this plant in April 2009 and increased the capacity to 1,900 MTPD (2,090 STPD). Major features of the revamp were installation of KBR Reforming Exchanger System (KRES), a new secondary reformer and a new add-on converter.

The second ammonia plant, CFCL-2, was originally commissioned in mid-1999 with a design capacity of 1,500 MTPD (1,650 STPD). This plant is based on KBR’s conventional technology. CFCL-2 was also revamped by KBR in April, 2009 with a revamped capacity of 1,780 MTPD (1,960 STPD).

CFCL decided to enhance the capacity further by carrying out a retrofit in 2017. To limit shutdown time for capacity expansion, CFCL opted to add a new cold wall add-on converter downstream of the existing converter. KBR’s true cold wall converter was commissioned at CFCL-2 in April – May 2017.

Add-on converters are more often considered for revamping the existing ammonia plants to boost per pass ammonia conversion to increase plant capacity and also to enhance process energy efficiency.

When feed gas to the add-on converter is hot, technology providers face challenges in using it with cold wall pressure vessels. Typically, hot wall add-on converters have been used in the industry for such service which is known to be unreliable due to cracks experienced in the weld seams, particularly on the hotter end of the converter due to hydrogen-induced cracking and nitriding in the presence of hydrogen and ammonia. All components in the synthesis loop are in some way affected by the combination of nitriding and high temperature hydrogen attack.
Both mono wall and multi wall vessel designs have experienced such failures. There are numerous examples of premature failures of the hot wall converters worldwide.\textsuperscript{[1]}\textsuperscript{[2]},\textsuperscript{[3]}

This is unlike the cold wall main ammonia converter shells, which face no issues even after decades of being in service. Keeping in view this fact and utilizing KBR’s classic “Slim-Jim” (a tall and skinny vessel, which was the early version of a standard 1,000 STPD ammonia plant converter) features, true cold wall design based add-on converter has been incorporated in CFCL ammonia plant-1 (2016) and plant-2 (2017). These plants were successfully commissioned after installing the add-on converter during a short turnaround.

The effluent gas from the main ammonia converter is passed through a loop boiler used for generating HP steam. Then the gas is sent to a new single-bed add-on ammonia converter, where its ammonia concentration is increased further by about 3 mol\%. Refer to Table 2 for add-on converter in out composition. The bed inlet temperature is controlled using the loop boiler bypass at a temperature in the range of 350°C to 380°C (662°F to 716°F). There is no feed/effluent exchanger in these converters. To keep the converter shell cool using the cold-wall concept, a sweep gas arrangement is provided. Cold syngas from the synthesis loop is passed through the converter shell annulus space to keep the shell cool. In this case, the cold syngas is taken downstream of feed/effluent exchangers in both the CFCL plants. The sweep gas temperature is in range of 65°C to 75°C (149°F to 167°F).

CFCL-2 Add-on Converter

The CFCL-2 add-on converter was commissioned in May 2017. The synthesis loop of CFCL-2 is designed for 1,940 MTPD (2,140 STPD), but all the capacity upgrade features have not been implemented. So, the current capacity is close to 1,800 MTPD (1,980 STPD). Table 1 below shows the operating parameters of CFCL-2 Add-on Converter, 1105-D.

<table>
<thead>
<tr>
<th>Parameter (July 8th, 2017)</th>
<th>1105-D (CFCL-2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet Pressure (Kg/cm(^2) G) / psig</td>
<td>160.4 / 2282</td>
</tr>
<tr>
<td>Outlet Pressure (Kg/cm(^2) G) / psig</td>
<td>160.3 / 2280</td>
</tr>
<tr>
<td>Pressure Drop (Kg/cm(^3)) / psi</td>
<td>0.14 / 2</td>
</tr>
<tr>
<td>Inlet Temperature (°C) / (°F)</td>
<td>350 / 662</td>
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<tr>
<td>Outlet Temperature (°C) / (°F)</td>
<td>398 / 748</td>
</tr>
<tr>
<td>Sweep Gas Inlet Flow Rate (T/Hr) / ST/Hr</td>
<td>92.6 / 102.0</td>
</tr>
<tr>
<td>Sweep Gas Inlet Temp (°C) / (°F)</td>
<td>75 / 167</td>
</tr>
<tr>
<td>Sweep Gas Outlet Temp (°C) / (°F)</td>
<td>81 / 178</td>
</tr>
<tr>
<td>Gas-Gas Exchanger Outlet Temp (°C) / (°F)</td>
<td>75 / 167</td>
</tr>
</tbody>
</table>

Table 1 - 1105-D Operating parameters

Increase in ammonia concentration is 3 mole % as indicated in the Table 2.

<table>
<thead>
<tr>
<th>Component</th>
<th>H(_2)</th>
<th>N(_2)</th>
<th>CH(_4)</th>
<th>Ar</th>
<th>NH(_3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1105-D Inlet</td>
<td>53.47</td>
<td>18.93</td>
<td>8.28</td>
<td>2.58</td>
<td>16.74</td>
</tr>
<tr>
<td>1105-D Outlet</td>
<td>50.64</td>
<td>18.22</td>
<td>8.71</td>
<td>2.71</td>
<td>19.72</td>
</tr>
</tbody>
</table>

Table 2 - 1105-D In / Out Molar Composition

Sweep Gas

The temperature rise in the sweep gas is approximately 6.0°C (10.8°F). Nearly 30% of the total circulation is the sweep gas flow. This flow keeps the converter shell cool.

Converter Shell Temperature

The converter shell is at a uniform temperature of 75°C (167°F). This shows that sweep gas flow is sufficient and the arrangement is efficient for keeping the shell cool. The pressure drop in the annulus space for sweep gas flow is 0.1 kg/cm\(^2\) (1.4 psi).
KBR’s True Cold Wall Add-on Ammonia Converter Concept

The synthesis gas entering the add-on converter is at a high temperature 350ºC to 430ºC (662ºF to 806ºF). However, it gives significant advantage from an equipment design perspective if the wall of the add-on converter is not exposed to this high temperature gas and the pressure shell temperatures are maintained low. It is well known that the cold walled main ammonia converters operate reliably without any issues even after decades of being in service.

Cold wall design for the add-on ammonia converter is achieved by passing a relatively cold “sweep gas” through the annulus between the shell and the basket. A slip-stream of cool converter effluent gas taken from downstream of the existing feed-effluent exchanger is used for the sweep gas, similar to KBR’s classic “Slim-Jim” quench converter circuit design. The sweep gas, having a temperature of approximately 70ºC (158ºF), remains isolated from the main process gas and is returned to the existing circuit upstream of the cooling water exchanger.

A sketch depicting the cold wall design of the add-on converter is shown in Figure 1. The process gas enters the equipment through a nozzle at the top and directly enters the catalyst filled basket without making contact with the pressure shell of the converter. The basket in turn is insulated on the outside thus preventing any heat transfer between the high temperature process gas inside the basket and the sweep gas that flows through the annular space between the basket and the pressure shell - thus keeping the pressure shell at a lower temperature.

Although the sweep gas temperature which is in contact with the pressure shell is low, KBR has selected a low alloy steel material for the pressure shell. Low alloy steel provides a conservative design considering the exposure to high pressure synthesis gas containing hydrogen.

Figure 1 - KBR’s Proprietary True Cold Wall Configuration for Add-on Ammonia Converter

The Flow Scheme

Figure 2 shows the process flow scheme. The compressor discharge is pre-heated in the Feed / Effluent Exchanger, 121-C before the synthesis gas is sent to the Horizontal Converter, 105-D. The main converter (105-D) effluent is cooled in the new HP Steam Generator 1123-C. The gas exit the steam generator is sent to the Add-on Converter, 1105-D.
Equipment Configuration

The add-on converter in CFCL-2 is configured vertically and is supported on a skirt resting on a concrete foundation. It is installed in the vicinity of the existing ammonia converter.

**Pressure Shell: Add-on Ammonia Converter**

The external pressure shell is provided with a full diameter girth flange which enables a removable top head assembly that provides full access for lowering an insulated catalyst basket into the pressure shell. The basket rests securely on a ledge which is integral with the shell girth flange thus enabling free expansion of the basket shell in the downward direction. This top hung basket arrangement is a unique feature of KBR’s designed add-on ammonia converters.

The girth flange of the pressure shell is sealed by a highly reliable double conical gasket which is a special gasket for high pressure equipment such as the ammonia converter.

Being high pressure equipment, KBR has chosen ASME Section VIII Division 2 code for achieving optimum wall thickness for the pressure components.

The gas inlet and outlet connections between the basket and the converter are located on the top dished head, and these pipes are provided with expansion bellows. This is to take care of the differential thermal expansion between the basket and the pressure shell.

A manway located on the top head allows access to the top side of the basket for catalyst loading/unloading and other maintenance activities. The pressure shell is made of 1.25 Cr – 0.5 Mo low alloy steel material.
Internal Catalyst Basket

The basket is made of stainless steel grade 304 with 3” thick insulation on the outside. The catalyst is contained by outer and inner screens made from state of the art Profile V wire (see Figure 4) construction which is robust and reliable even when subjected to the start-up and shutdown cycles. These screens also have less friction with the catalyst particles thus allowing longer life for the catalyst and lower mechanical loads on the screens.

As shown in Figure 5, the basket is supplied in a specially designed and fabricated transportation container to protect it during dispatch to the site and during erection prior to insertion in the pressure shell in the field.

Field Installation and Catalyst Loading

In the field, the pressure shell is first erected on the foundation, and the top head assembly is disassembled. Thereafter, the transportation container with the basket inside is made vertical next to the pressure shell. The basket is then extracted vertically from the container and inserted into the pressure shell (Figure 6).

Once the basket is lowered, the top head is reassembled, and the internal piping connections, including the expansion bellows, between the basket and the process nozzles are welded. The basket is now ready for catalyst loading.
Catalyst loading is performed through the manhole in the top head assembly and through another manhole in the basket head right below the outer manhole. After completion of catalyst loading, the basket manhole is seal welded and dye penetrant examined prior to boxing up of the outer manhole on the top dished head. This ensures that the process gas circuit is isolated from the sweep gas circuit. At CFCL-2, this activity was completed in April 2017 and the plant was commissioned between April and May 2017.

Once the plant is commissioned, after installation and catalyst loading, the sweep gas, at about 70°C (158°F), flows through the annulus between basket and shell. The sweep gas keeps the pressure shell at a very low temperature. The catalyst basket which is insulated on the outside retains the heat generated through the exothermic catalytic reaction. The sweep gas stream and the process gas stream are isolated from one another thus achieving true cold wall design.

True pressure vessel cold wall technology provides unmatched flexibility in operations. The catalyst bed can be operated at optimum hotter temperatures to maximize conversion, as temperature of the pressure vessel remains totally independent of the synthesis gas being processed through catalyst bed. Feed and product synthesis gas can have hotter temperatures as required over life cycle of catalyst to maximize conversion.

Conclusions

1) Hot wall ammonia converters have had a history of failures. Many articles have been published which records these failures.[1] [2] [3] All components in the synthesis loop are affected by the combination of nitriding and HTHA.[2] The most critical common denominator is the presence of hydrogen-induced micro-cracks in the weld.[3]

2) The cold walled ammonia converter shell, which has shell cooling flow, has had no issues even after decades of being in service. Prime examples of this are KBR’s classic “Slim-Jim” converters which are still in operation after over forty years of service.

3) KBR’s true cold wall converters implemented at CFCL 2 plant has shown successful process performance. The sweep gas is about 30% of the total circulation. The converter shell remains at around 75°C (167°F).

Acknowledgement

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References


(4) Johnson Screens® (A Weatherford Company) catalog