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HTS CONVERTER REVAMPING AT AGRIUM BORGER AMMONIA PLANT, A CASE HISTORY.

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ABSTRACT

The Agrium ammonia plant at Borger is of Kellogg standard design, with an original capacity of 1000 STD. Prior to this HTS revamp the plant was running at approximately 1500 - 1520 STD (cold weather days) thanks to several upgrade projects performed in recent years.

In 1997 Agrium was interested in further improving the performance of this unit and, among other possibilities, revamping of the high temperature shift converter was considered, as its catalyst was close to the end of run. The goal of the revamping was to reduce the plant energy consumption and to allow for further future capacity increases by reducing the pressure drop across the HTS. The shift converters revamping technology was available from Ammonia Casale, who had already performed the same revamping work in two similar Kellogg plants in China for both HTS and LTS. The revamping was then studied carefully and the contract signed in the summer of 1997.

Because of mechanical problems at the Agrium Borger plant, the HTS revamping was postponed to 1998. It was successfully implemented in October 1998 with the desired goals reached.

This paper describes the technical feature of this revamp, the reason for Agrium to choose it, the project implementation and the operating performances achieved.

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PART 1

THE TECHNOLOGY

1. FOREWORD

In the last decade great efforts have been devoted by all engineering Companies in order to improve the performances of ammonia plants, either by reducing the energy requirements or by increasing the throughput.

In order to accomplish the above task, every single step of the ammonia process was thoroughly scrutinized with the aim of exploiting any possibility of improvement, thus leading to the wide variety of new schemes that are presently available.

However, the CO shift stage, where the converter design still reflects old concepts, has not yet profited from the above trend.

AMMONIA CASALE, based on its long term and successful experience in the field of highly efficient ammonia converters, has recently completely redesigned the shift converter achieving, in industrial applications, significant improvements.
The new technology is suitable for the revamping of existing converters as well as for new converters, and this paper describes its first installation in North America.

2. THE PRESENT TECHNOLOGY

The CO contained in the gas leaving either the reforming or the gasification section, is converted into more valuable H_2 via the so-called water gas shift reaction:

$$CO + H_2O \bullet CO_2 + H_2$$

Owing to its exothermic nature, the equilibrium reaction is carried out at the lowest temperature possible. For kinetic reasons it has to be split in two stages, each working at different temperatures, the so-called High Temperature Shift (HTS) and Low Temperature Shift (LTS).

In each stage a solid catalyst, in the form of small cylindrical pellets, has to be used.
One single, adiabatic bed is normally necessary for both HTS and LTS whilst the reaction heat is recovered in external heat exchangers.

The relatively mild operating temperatures, respectively about 400°C for HTS, 220°C for LTS, and pressure (35 bar) allows the use of pressure vessel made of carbon or low alloy steel with the catalyst directly in contact with the wall of the converter.

With the present technology the gas flows in an axial direction, from top to bottom, with the consequent limitations due to the inherently high pressure drop relative to radial design.

3. THE AXIAL-RADIAL SHIFT CONVERTERS

There are many advantages of the axial-radial technology over the axial one, both when revamping plants for capacity increase and for energy savings. They can be summarized as follows:

3.1 Revamping for Capacity Increase

* Lower pressure drop due to lower differential pressure with the axial-radial technology;
* Lower catalyst volume required, due to the use of a more active, smaller sized catalyst;
* longer operation at equilibrium with higher product purity (H_2 plants) or higher production rates (NH_3 plants);
* longer operation at equilibrium leading to higher plant capacity;
* longer catalyst life due to higher catalyst activity and poison resistance;
* protection of catalyst from water droplets thus extending the catalyst lifetime.

3.2 Revamping, Same Capacity

* energy saving thanks to the lower pressure drop;
* reduced catalyst volume (30-50%) for the same catalyst life;
* same catalyst volume with longer life.

3.3 General

There are no drawbacks with the axial-radial design compared to the axial converters, in fact:

* the converter operation is equal to that of an axial bed converter;

* the catalyst loading / unloading is equal to that of an axial bed converter;
* catalyst life monitoring is equal to that of an axial bed converter.

A further advantage present in all cases is that there are virtually **no possibilities of channeling** in the catalyst bed thanks to the very low velocity of the gas in the catalyst bed.

The main features of CASALE patented design for both HTS and LTS converters, that lead to the above advantages, are:

* an axial-radial flow path of the gas crossing the catalyst resulting in a low pressure drop;
* use of small-size, more active catalyst having a higher resistance to poisons;
* protection of catalyst from water droplets carried over from secondary reformer heat recovery train or others;
* possibility to load different volumes of catalyst;
* easy operation.

a) Low Pressure Drop

The low pressure drop characteristic of the axial-radial flow pattern is due to the very low gas velocities through the catalyst, about five to ten times lower then for an axial bed.
The low pressure drop of the catalyst bed allows the use of a smaller size, more active catalyst, and also achieves a power saving in the make-up compressors due to the increase in the corresponding suction pressure.

As an alternative, when the output is limited by the capacity of the Process Air, reducing the shift section pressure drop and maintaining the same pressure at syngas compressor suction will allow higher plant throughput thanks to the corresponding reduction in air compressor discharge pressure.

Furthermore, when planning a plant capacity increase, the shift converter revamping will eliminate any pressure drop limitation in the shift converter section.

b) Use of Small -Size Catalyst

As mentioned above, the low pressure drop inherent to the axial-radial beds allows the usage of smaller size catalyst.

It is well known that in any pore-diffusion limited reaction, such as the CO-shift conversion, the apparent catalyst activity is inversely proportional to pellets dimensions since only the outer portion of the pellet tends to be used.

The smaller size catalyst is more active then the large size one, thanks to its higher geometric surface per unit of volume, and this higher activity allows the reduction of the catalyst volume necessary, or, in alternative, a longer catalyst life for the same volume.

The longer operating life thanks to the better resistance to poisoning is particularly significant for the L.T.S. section where chemical equilibrium is reached and the catalyst is deactivated due to the presence of poisons in the feed gas. The poisoning, which occurs at the surface of the catalyst, causes the final CO concentration to increases regularly, up to the point when replacing the charge becomes necessary.

If small-size pellets are used, then, owing to their higher specific surface, the operating life of the catalyst can be increased by 30 to 50%, according to catalyst Vendor’s information.

A further advantage, peculiar for ammonia plants, is related to the lower average CO concentration over the whole operating life of one charge, achieved with more active catalyst.

In fact, since the CO is eventually converted to methane before the ammonia synthesis, then also the average inerts concentration in the synthesis loop is maintained at lower levels. This enables, for instance, in a typical 1000 MTPD ammonia plant without hydrogen recovery, to increase the final ammonia output by about 10 MTPD each 0.1% of CO decrease.

As for the first option, shortloading the converter is becoming quite common and using smaller catalyst will allow to do it more often than now, with no performance penalization. Moreover, we emphasize that operators can offset the cost of the new internals against the smaller amount of catalyst to be used.

c) ***Protection of Catalyst from Water Droplets***

It is a well known fact that in many plants the pressure drop of industrial axial HTS converters builds up during the operating life owing to water droplets carried over by the incoming gas, which tend to form a caked layer at the top of the bed.

When the pressure drop exceeds the maximum admissible value, the top layer of catalyst is skimmed off or, in the worst case, the catalyst charge has to be replaced.

AMMONIA CASALE has developed, for the axial-radial bed, a patented fluid dynamic design which allows the water droplets contained in the gas feed to concentrate on the top layer of catalyst (axial part of the axial-radial bed).
The caked layer which may eventually form will simply shift the incoming gas toward the radial inlet distributor, thus minimizing the effect on the total pressure drop.

Therefore, even in the event of a severe leakage of water from an upstream boiler, the HTS catalyst and internals will be saved from any damage, with a much safer behavior then the standard axial configuration.

In case of total flooding of the HTS converter with water, then the situation will be identical for an axial-radial bed as well as for an axial bed, as in this case only the resistance of the catalyst will be important to limit the damages.

Therefore, with axial-radial internals the bed pressure drop remains constant over time, because the catalyst pressure drop is and remains negligible. The entire the pressure drop is concentrated in the nozzles and in the perforated wall, that do not change their characteristics with time.

With reference to figure 1 below, it is evident that a low and constant pressure drop, as achieved with axial-radial internals, can increase the operating life of the catalyst, with respect to axial internals when affected by water impingement.

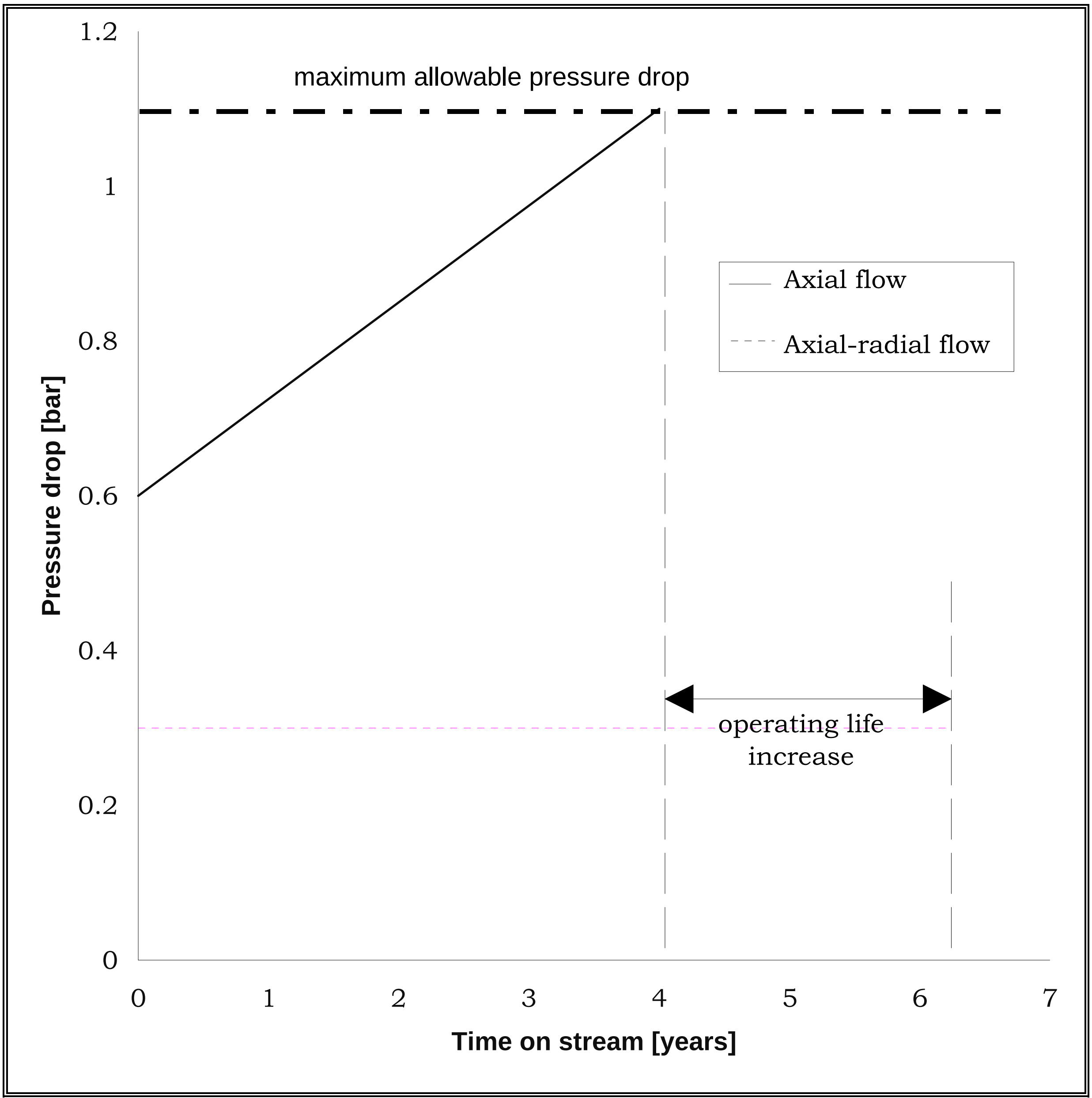
1.2
maximum allowable pressure drop
1
Axial flow
Axial-radial flow
0.8
0.6
Pressure drop [bar]
0.4
operating life
increase
0.2
0
0 1 2 3 4 5 6 7
Time on stream [years]

Figure 1

4. OPERATION OF AN AXIAL-RADIAL SHIFT CONVERTER

The operation of an axial-radial shift converter is in all respects very similar to the traditional axial converter.

- **the catalyst loading** is to be done in the same way as an axial bed, thanks to the fact that, unlike a pure radial bed, the top of the bed is open *(see figure 2)* and completely accessible without restrictions from the top manhole, so the traditional technique of sock loading, or the more modern dense loader for HTS, can be used without special precautions.

- **the catalyst unloading** is done using the drop out pipes that are normally present in the shell, or otherwise by vacuuming the catalyst out from the top manhole. In this last case, again, the operation is simplified by the fact the bed has no top cover, so it is easily accessible.

- **the catalyst reduction** is done according to the same procedure as for an axial converter.
  The temperature profile evolution along the catalyst depth can be checked thanks to the fact that the thermocouples are inserted in an inclined thermowell, *(see figure 3)* measuring the value of temperatures in the radial part at different depths of the catalyst layer in the horizontal direction, and therefore, not only at the inlet and at the outlet, but also in an intermediate position.

- **the normal operation** is also done in the same way as for an axial bed, controlling the same parameters, with all the advantages of the axial-radial configuration, i.e. lower inlet temperatures, lower and constant pressure drop, longer catalyst life, fewer problems in case of plant upset such as water leakage.

  The catalyst aging can be checked in the usual way by following the temperature profile evolution at different points of the catalyst depth, thanks to the inclined thermowell *(see figure 3).*

5. INDUSTRIAL EXPERIENCE

Before the Agrium plant, AMMONIA CASALE had revamped two shift converters trains, respectively in the Spring of 1995 and 1996, each made by one HTS and one LTS, in two Kellogg ammonia plants in the P.R. of China.

Herebelow, we summarize the performances obtained during the test run of one the two trains:

TABLE 1	PRESSURE DROP (bar)		
	HTS	LTS	TOTAL
Before revamping	0.55	0.55	1.10
After revamping	0.25	0.22	0.47
Decrement	0.30	0.33	0.63

The test-run CO leakage from the LTS was 0.11%, whereas before revamping it was 0.25%, thus realizing a decrement of 0.14%. In both cases the revamping was carried out within a normal turnaround.

Please note that thanks to the higher catalyst activity the inlet temperatures after revamping were lower then before, lowering the CO leakage due to the more favorable equilibrium concentrations at low temperature.

6. DESCRIPTION OF THE CASALE AXIAL-RADIAL SHIFT CONVERTER

In an axial-radial catalyst bed the gas distribution is such that most (about 90%) of the gas passes through the catalyst bed in a radial direction, resulting in a much lower pressure drop when compared with the axial flow.

The balance passes down through a top layer of catalyst in an axial direction, thus eliminating the need for a top cover of the catalyst beds, *(see figure 2).*
This feature is an essential factor for an easy and simple construction of any type of converter internals and for an effective elimination of the catalyst caking problem.

The gas flow through the catalyst is controlled by perforated walls at the inlet and at the outlet, where most of the bed pressure drop is concentrated.

In this way it is possible to use all the catalyst in the bed, even the top part, while the pressure drop at the bed outlet wall is able to compensate possible catalyst packing inside the bed due to poor loading or other reasons.

Therefore, the axial-radial bed is superior to the pure radial one due to its ability of using the catalyst completely, even the top part, and is superior to the axial beds for the lower pressure drop, but also because the gas flow is controlled by the perforated walls, and not by the catalyst, compensating in this way possible catalyst density problems.

A typical shift converter, either HTS or LTS, with axial-radial internals is shown in *figure 4.*

The CASALE axial-radial beds mainly consist of:

a. Two cylindrical walls, one close to the pressure vessel wall, and the other installed in the center of the reactor. The walls provide the means of containing the catalyst. Each wall is made of a special plate, embossed and perforated, and a wire mesh.

   The perforations are calculated to give the optimum distribution of gas within the catalyst while the embossment provides the support for the wire mesh and creates an interspace between the perforated plate and the wire mesh. This airspace between the perforated walls and the mesh favors an even distribution of the gas. The void external spaces outside the cylindrical perforated walls are used to, respectively, distribute the incoming gas and to collect the reacted one before being sent to outlet nozzle.

   When present, a heat exchanger is placed inside the central collector; the exchanger in most of cases is a gas-gas exchanger or a waste heat boiler.

b. A top catalyst hold down grid.

c. Two thermocouples bundles in order to monitor the temperature respectively at bed inlet and outlet and in the bed.

d. The materials of the new internals are:

   - bed walls : AISI 304
   - retaining wire meshes : AISI 304
   - thermowell pipes : ASTM A 335 Gr. P1

e. A newly designed inlet distributor, to be fixed to the existing inlet nozzle, to address the water droplets.

The modification of the converters mainly consists in the transformation of the existing axial bed into an axial-radial one by inserting two concentric cylindrical walls.

The access to the bed is, of course, possible only through a manhole. The internals are, therefore, all prefabricated in pieces in order to be easily introduced through the manhole and then assembled inside the vessel using the same procedures and techniques already successfully used for revamping bottle-shaped ammonia converters.

It is important to underline that no welding will be done on the existing vessel, so all risks of metallurgical nature are avoided.

PART 2

THE ACTUAL IMPLEMENTATION

1. INTRODUCTION

The Agrium Ammonia Plant at Borger is of Kellogg standard design. The original plant production capacity was 1000 STD. Subsequently, plant upgrades in 1989 and 1994, the plant name plate capacity was upgraded to 1230 and 1450 tons/day respectively. At the time of this revamping, the plant was operating at about 1480-1490 STPD.

1.2. The HTS Converter Revamping

In 1997 Agrium became interested in further improving the performance of the plant and, among other possibilities, the revamping of the high temperature shift converter was considered. As HTS catalyst was close to the end of run after being in service for 6 years, it was giving a high pressure drop of 14-16 PSIG. At that time, CO slip was ranging between 3.4 - 3,5% with a 715 °F inlet temperature. With the inlet temperature control valve, TRC-10, giving problems, this temperature could not be increase any further. It was then considered to upgrade the HTS converter and revamp the converter's conventional axial flow into an axial/radial flow design .

The goal of the revamping was to reduce the plant energy consumption, including compression energy, by reducing the pressure drop in HTS and to enable further potential capacity increases.

The shift converters revamping technology was available from Ammonia Casale, that had already performed the same revamping work in similar Kellogg plants in China for both HTS and LTS reactors, and had already revamped Agrium's ammonia synthesis converter in 1989. Casale was contacted and presented a technical and commercial proposal to Agrium including all benefits and disadvantages.

United Catalyst Inc. (U.C.I.), a prominent catalyst supplier, was involved from the beginning and provided detailed calculations of the new catalyst performance in the revamped converter. The catalyst in fact was new, with a smaller than usual size, developed purposely for this type of application in axial-radial converters. The catalyst behavior was calculated throughout its expected life, in order to determine the benefit from the anticipated better evolution of the CO concentration.

Casale made a simulation of the plant front end to calculate the saving achievable in the synthesis gas compressor thanks to the lower converter pressure drop and the better performance of the catalyst, i.e. lower CO at the exit due to the lower operating temperatures.

Casale guaranteed that the pressure drop could be cut in half with 2.45 % CO slip. It was also stated that the inlet temperature could be run at 665°F and a further saving of approximately 0.05 MM BTU / ST at the higher capacity was achievable.

2.3. The project execution

The contract was signed in the summer of 1997 to revamp the HTS converter to an axial/radial flow design. Casale supplied the license, the engineering, the revamp materials, including U.C.I. catalyst, and the engineering supervision during installation. Agrium supplied the installation labor and the catalyst handling, since during the same turnaround other work had been scheduled, so it was economical to use the same catalyst handling contractor.

The implementation of the project was originally scheduled for in October 1997 turnaround. Unfortunately, due to unavoidable circumstances in the plant, the implementation of the project was postponed. It was successfully implemented during the Borger plant's maintenance turnaround in October 1998, reaching the desired goals of reducing the pressure drop, reduction in energy consumption per ton and increasing production. The catalyst used was U.C.I. C12-4-1 mini, and the volume was increased from a possible short loading of 1300 cubic feet to 1500 cubic feet. More catalyst than required was loaded in order to sure that catalyst volume was appropriate for possible future ammonia plant upgrades.

The scheduled time for the entire modification was 10 - 11 days. Work was planned for around the clock. Considerable pre-planning, both on-site and with Casale, was done by the installation contractor - Piping Companies. Difficulties and problems were anticipated since all parts and equipment had to enter the vessel through a small nozzle some 20 - 25 meters above ground elevation, so as much planning and discussion as possible was done ahead of the actual work. One unanticipated problem was encountered with the vessel exit nozzle orientation. This nozzle was inexplicably off-center by 3 inches and the entire Casale bottom support system had to be modified to fit the existing vessel bottom arrangement.

Another unexpected problem encountered was winds of 20 - 30 MPH that occurred when sidewall panels were being lifted to the top of the vessel for entry. Because of the large surface area of the individual pieces exposed to the wind and the relatively light weight of the pieces, control during lifting was difficult if not impossible. Several alternate methods of lifting were tried, but in the end this part of the job was delayed for several hours until the wind speed dropped down. Of course, general working conditions and room to move around inside the vessel were difficult, but the pre-planning helped overcome most of these problems.

Start-up of the ammonia plant in mid-October 1998 was normal. Casale and U.C.I. personnel were on-site during the start-up for technical support in bringing the HTS converter to desired operating conditions. Shortly thereafter, a 48 hour performance test was conducted and the HTS met Casale's guaranteed conditions.

Photographs of the new assembled internals are shown in *Figures 5* and *6.*

Unfortunately, in mid-November 1998, the plant began detecting a high pressure drop across the HTS converter Casale was immediately contacted and come to the Borger plant, as did U.C.I. representatives. The pressure drop continued to slowly rise even as production rates of the plant were reduced. Finally, in late November 1998, the ammonia plant was shut down to internally inspect the HTS. All needed materials and personnel were assembled at the plant prior to the shutdown. After cool down, the internal inspection of the HTS revealed excessive quantities of catalyst dust and pieces in the annular space of converter bed. The inner collector screen was also partially plugged with dust. Obviously, this pluggage was causing the high pressure drop and subsequent reduction of plant production rates. Catalyst was removed from the HTS converter and the vessel thoroughly cleaned. No damage to the radial-axial internals resulted. The only damage found was rearing of the top hold down screen and, of course, loss of some catalyst. A new charge of catalyst was installed, but unfortunately only 6x5 mm U.C.I. catalyst was available on this short notice, not the 6x3 mm originally used. Use of the smaller catalyst was desired, but the urgency of the situation prevented waiting for its availability. The top hold down screen system was also modified slightly. Casale and U.C.I. personnel provided quick and invaluable assistance and support in analyzing this problem. Close cooperation by Casale and U.C.I. with Agrium plant personnel enabled this problem to be resolved quickly and the HTS converter put back into operating conditions.

Again the plant start up without incident. A 24 hour performance test was conducted in early December and all Casale guarantees met. No similar pressure drop problems in the HTS have occurred since.

2.5 The Results Achieved

Agrium has seen desirable changes in the ammonia plant operation. There is an increase of 8 PSIG in the suction pressure of the Syngas compressor and consequently there is a production increase. Using the generally accepted rule of thumb, that each 1 PSI reduction in suction pressure will give an equivalent to 3 STPD of ammonia, then Agrium has also seen the production increase benefits, as the production is now in the range of 1540-1560 STPD (cold weather days). The HTS is being operated at a cooler inlet temp of 665 °F with approx. 128 °F temperature rise and CO slip down to 2.63 %. These are the numbers that are being seen with the present axial/radial flow design. It is possible to lower the CO slip further by increasing inlet temperature, but Agrium does not want very aggressive operation, as there is a new LTS guard bed downstream that can pick up some more load.

Agrium feels the HTS revamping project was successful and beneficial for its Borger TX ammonia plant.

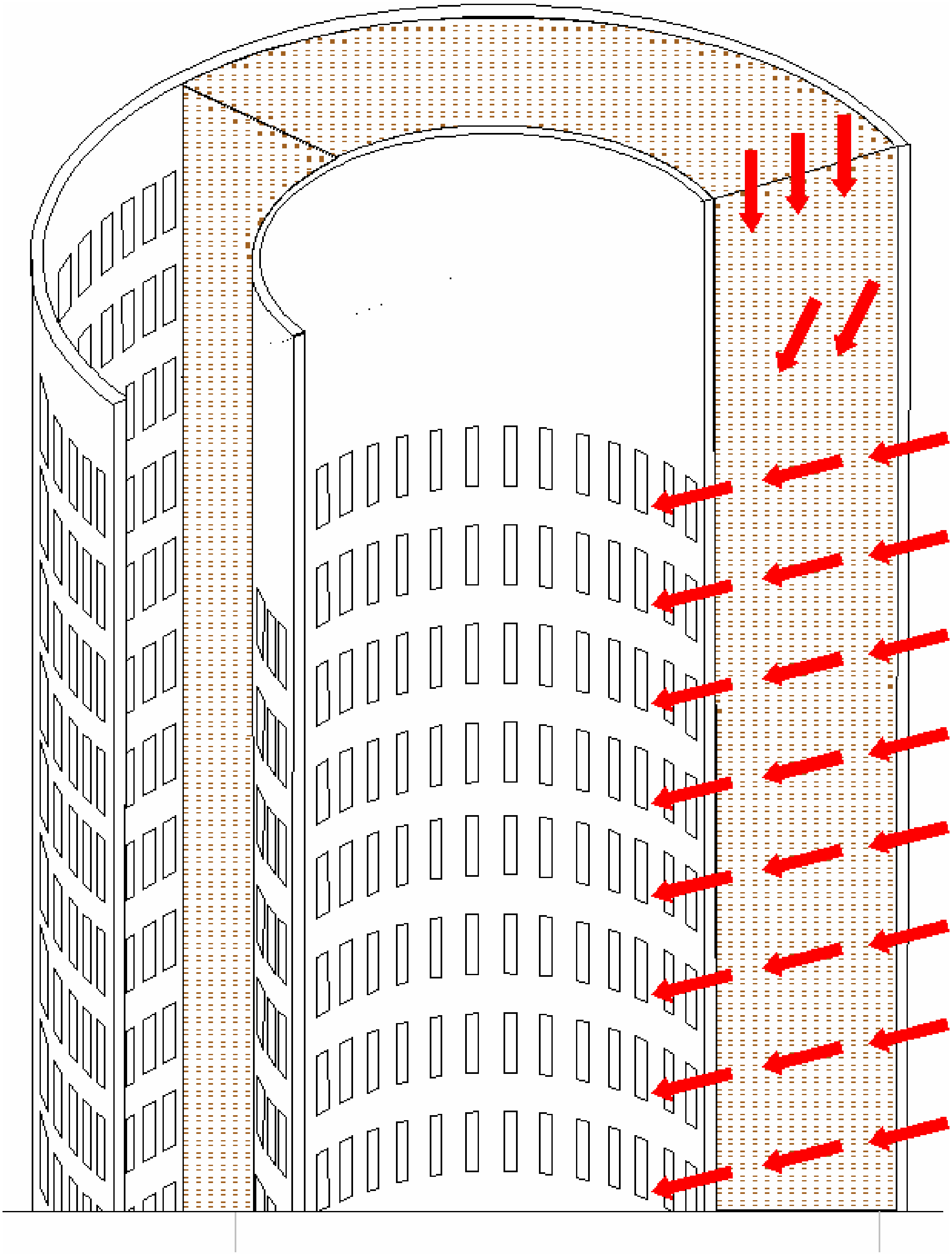

FIGURE 2

AXIAL-RADIAL GAS BED

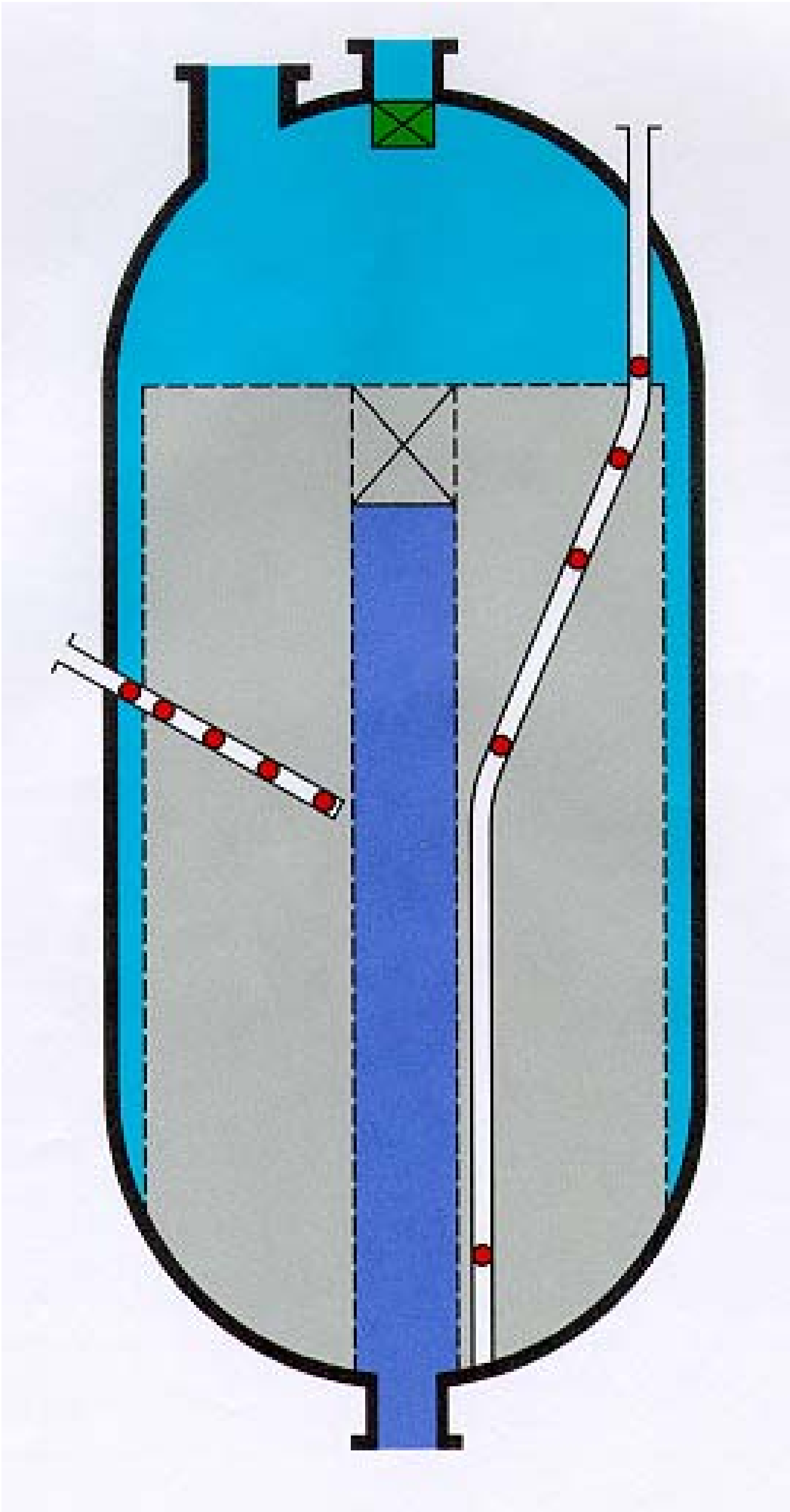

FIGURE 3

THERMOWELL AND THERMOCOUPLE POSITION

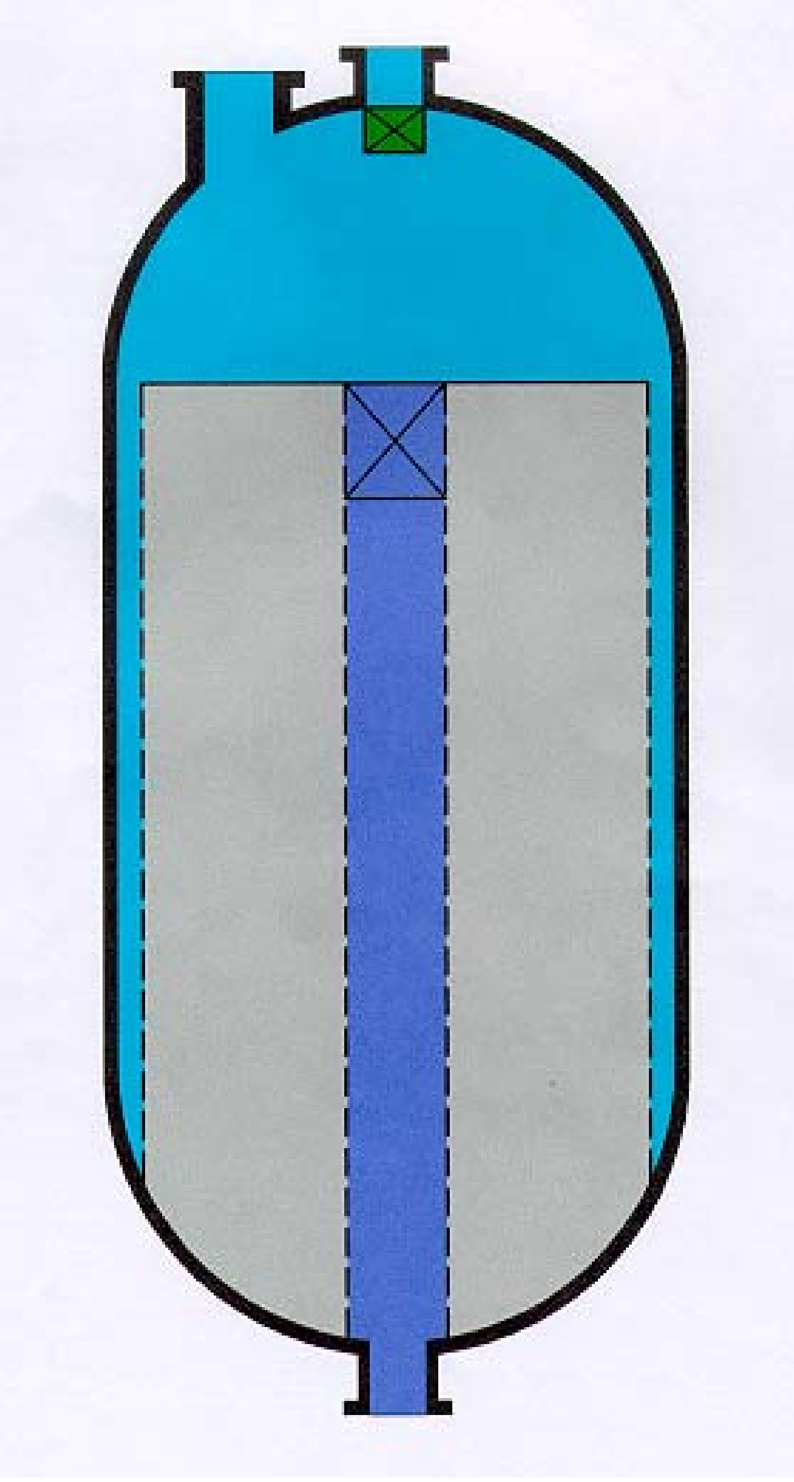

FIGURE 4

AXIAL-RADIAL SHIFT CONVERTER

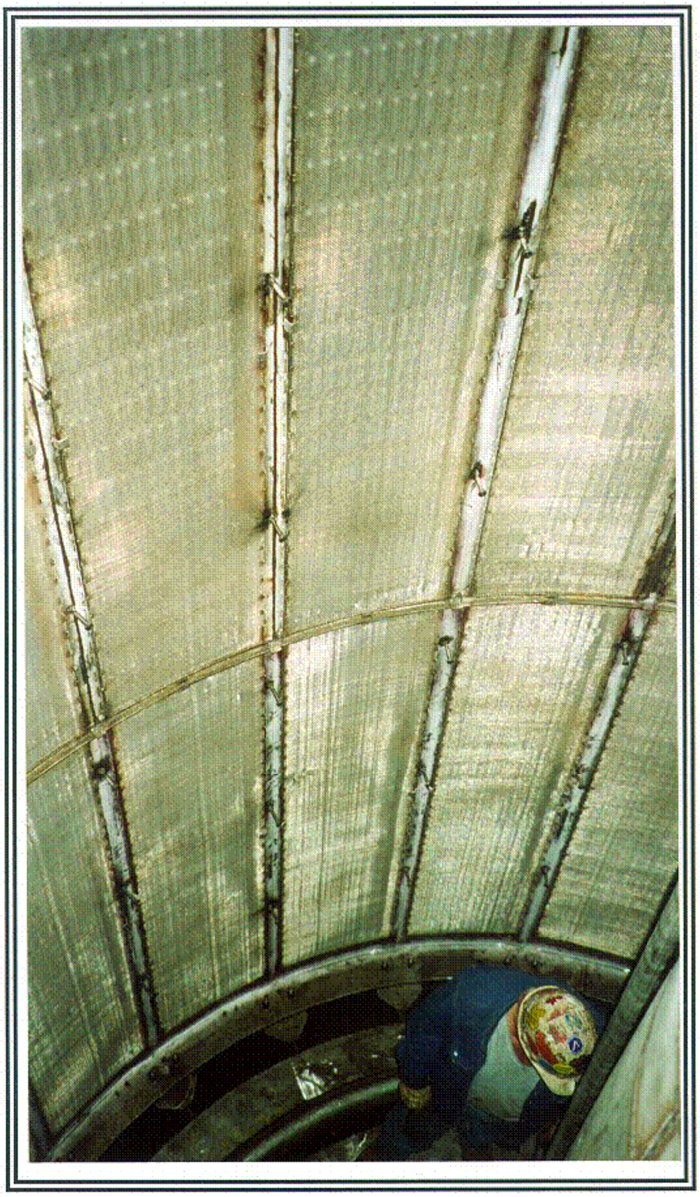

FIGURE 5 - ASSEMBLED INTERNALS

FIGURE 6 - ASSEMBLED INTERNALS