Ammonia Plant Safety Vol. 40 2000 33-42 00614

Experience of Ammonia Converter with Catalyst Leakage and Repairs

The operating experience is discussed concerning an ammonia synthesis converter of an expansion unit in which catalyst leakage appeared about three years after plant commissioning. The plant operation with catalyst slippage was successfully managed for two to three years until the problem was rectified. The problems encountered, ways to sustain plant operation, problem analysis, planning for repairs, and actual repairs undertaken with results achieved are discussed.

Muhammad Aleem Khan
Fauji Fertilizer Co., Ltd., Goth Machhi, Pakistan

Jørgen Juul Rasmussen
Haldor Topsøe, Lyngby, Denmark

Introduction

Fauji Fertilizer Company Ltd. (FFC) is the leading urea manufacturer in Pakistan. FFC is operating two ammonia and urea plants with common facilities of utilities, situated in Goth Machhi, Sadikabad.

The base unit (first plant) was commissioned in April 1982 with a design capacity of 1,000 MTPD ammonia and 1,725 MTPD urea. The expansion unit (second plant) was commissioned in March 1993 with a nameplate capacity of 1,100 MTPD ammonia and 1,925 MTPD urea. The base unit was successfully revamped to 122% of the design capacity in 1992.

Both the units employ Haldor Topsøe technology in the design of ammonia plants and both urea plants are designed by Snamprogetti. The ammonia plant of the base unit is based on late 1970s technology, while that of the expansion unit is based on the low energy process technology. The synthesis loop of the expansion unit ammonia plant is typically designed on the basis of Haldor Topsøe's latest technology, which was available in the late 1980s, that is, the low synthesis loop pressure with addition of purge gas recovery units, and so on.

This article deals with the operating experience of the ammonia synthesis converter of the expansion unit in which catalyst leakage appeared about three years after plant commissioning. The plant operation with catalyst slippage was successfully managed for two to three years until the problem was rectified. The problems encountered, ways to sustain plant operation, problem analysis, planning for repairs and actual repairs undertaken with results achieved are also discussed.

Background

Catalyst leakage from the synthesis converter was suspected for the first time when the 1,500 Kg catalyst was removed during draining of the ammonia separator during the 1996 turnaround. A synthesis converter catalyst was loaded in June 1992 and the ammonia plant was commissioned in February 1993. In the beginning, the catalyst accumulated in the ammonia separator was removed during plant shutdowns. Later, a high-pressure filter was installed on the ammonia separator drain line for catalyst removal during normal plant operation.

Total 4.2 m^3 catalyst was removed from the separator drain before repairs were undertaken during the 1998 turnaround.

Description of Synthesis Loop and Ammonia Converter

Ammonia synthesis loop

The Ammonia synthesis loop of the expansion unit is designed for 1,100 MTPD of 99.9% liquid ammonia. The synthesis unit is designed for a maximum pressure of 158 Kg/cm^{2}g, and the normal operating pressure is in the range of 141–145 Kg/cm^{2}g. The reaction temperature in the catalyst bed is 370–490°C.

The synthesis loop in addition to the converter includes a recirculating compressor integrated with a synthesis gas compressor, a waste heat boiler, a boiler feed water preheater, and a water cooler for synthesis gas cooling and condensation of ammonia. The final separation of ammonia takes place in the ammonia separator V-4501 after cooling in cold gas-gas exchangers and chillers, up to 5°C temperature.

The condensed ammonia is then transferred to a let-down vessel at 25 Kg/cm^{2}g under level control of V-4501 by two control valves (See Figure 1).

Ammonia Converter

Process description

The ammonia synthesis converter R-4501 is a radial flow type converter with Haldor Topsøe design S-200 basket. The process principle in the basket is shown in Figure 2.

The main gas flow to the converter is introduced from the bottom. The inlet gas passes up through the annular space between the pressure shell and the basket. From the annular space, the gas is transferred to

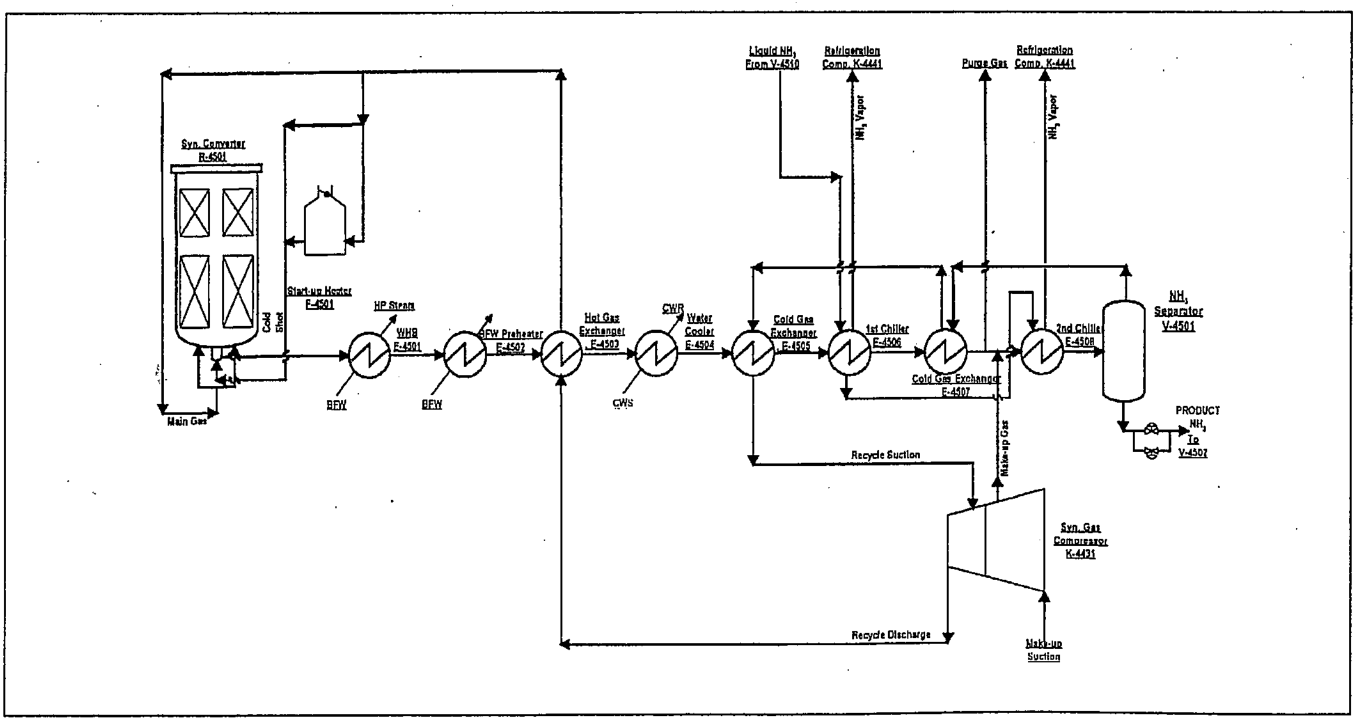

Figure 1. Ammonia synthesis loop process (expansion unit).

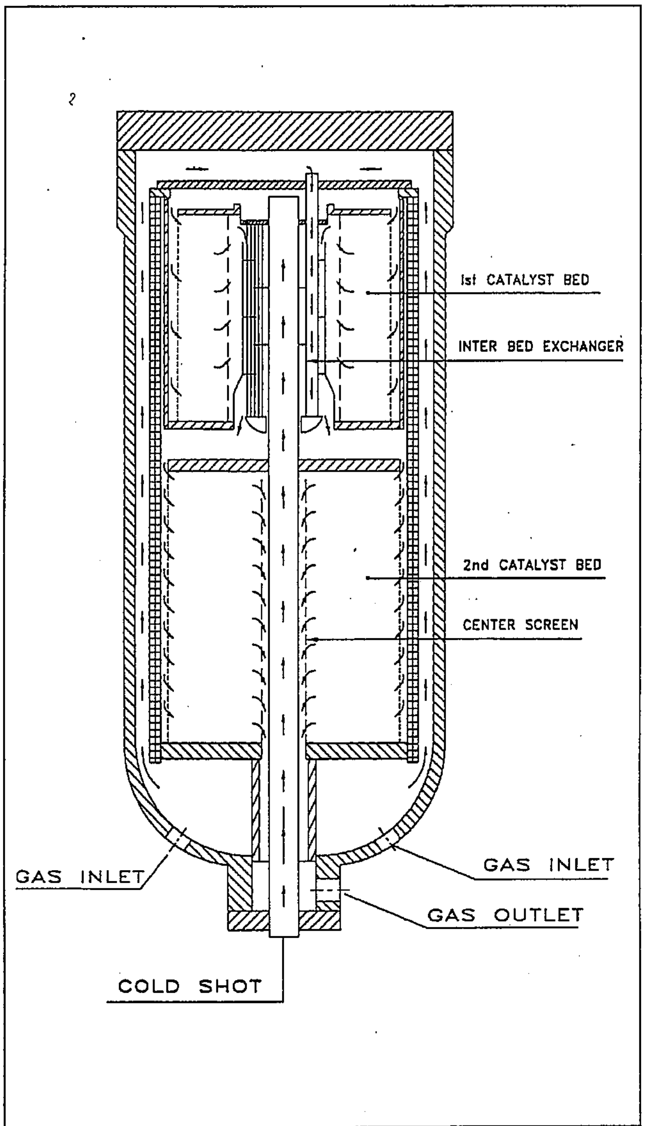

Figure 2. Ammonia converter (expansion unit).

the inlet chamber of the tube side of the interbed heat exchanger through two transfer pipes. The heated gas from the tube side of the exchanger is mixed with the cold shot by a mixing device. The mixed gas under temperature control enters the first catalyst bed through the annulus of screen panels around the catalyst bed. The heat of reaction gained in the first bed is removed when gas passes through the shell side of the interbed heat exchanger. The outlet gas enters the second catalyst bed through the perforated inner walls of the panels. Gas from the second catalyst bed containing 16–17% ammonia leaves the converter.

Mechanical Description

The S-200 basket installed in the synthesis converter R-4501 consists of two catalyst beds with an interbed heat exchanger located in the center of the upper catalyst bed. The basket is designed in such a way that it can be installed as single piece into the converter. The base of basket rest on the converter bottom ring.

The first bed has to be removed from the basket before the loading of catalyst. The bed can be removed either with or without the interbed heat exchanger. The first bed in the basket is hanging down such that the upper flange rests on the basket top flange. This arrangement allows free movement of the bed due to thermal expansion.

For proper distribution of gas in the radial direction, Johnson screen panels (Scallops) supported by the bed shell are provided for the inlet gas to the catalyst beds, while outlet screens provided for both the beds are of the same type along with a stuffing box as described in a later section.

The basket shell also serves as the outer wall of second bed and the gas inlet screen panels (Scallops) are supported with the same shell. Both the beds have the full opening from the top, which is closed by flanged cover. The cold shot pipe passes concentrically through the center screen of second bed and the interbed heat exchanger. The cold shot pipe is provided in two portions such that the bottom pipe can thermally expand into the upper portion flanged housing. The expansion bellow is also provided on the top of second bed center screen, and the same is welded in-between the cold shot pipe and center screen.

Operating Experience of Converter with Catalyst Leakage

Monitoring of catalyst leakage

Catalyst leakage from the converter was confirmed, but in order to ascertain the extent and severity of the problem, the following information was required to finalize the action plan:

- Catalyst leakage rate.

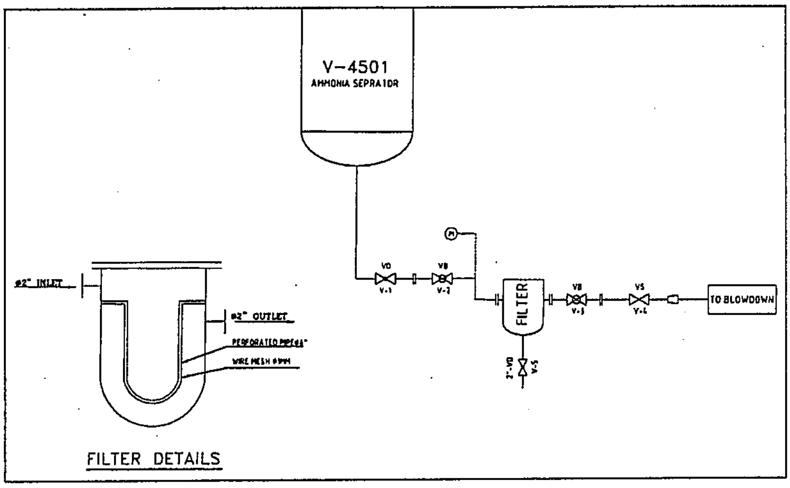

Figure 3. Provision of filter on V-4501 drain.

- Factors which could aggravate the problem.
- Effect of catalyst slippage on synthesis conversion.
- Location of damage.
- Limitations to execute repair job.
- Condition of the first bed.

In order to answer most of the questions listed above, a high-pressure catalyst separator (filter) was installed on the drain line of the ammonia separator V-4501 with an arrangement to remove the catalyst during normal plant operation (see Figure 3). After installation of the filter, the catalyst leakage rate from the converter is generally found to be 4–5 Kg/day. However, the problem was observed to aggravate after plant shutdown (see Figure 4).

It was suspected that if the damage to the center screen is located in the upper portion of the screen, then the catalyst slippage may stop after some time, and replacement and repair jobs could, accordingly, be deferred. However, the catalyst slippage continued. In spite of that, the catalyst replacement and repair jobs, initially planned for the 1997 turnaround, were successfully deferred until October 1998 due to quantitative detection of the catalyst leakage rates.

Synthesis loop pressure drop measurement

In order to analyze the problem and to evaluate the accumulation of catalyst in the downstream equipment of the synthesis loop, pressure drop monitoring across the synthesis converter and the loop exchangers was started in October 1996. No significant change was observed in any of the equipment. The pressure drop measurement across the converter revealed that the first bed is in healthy condition.

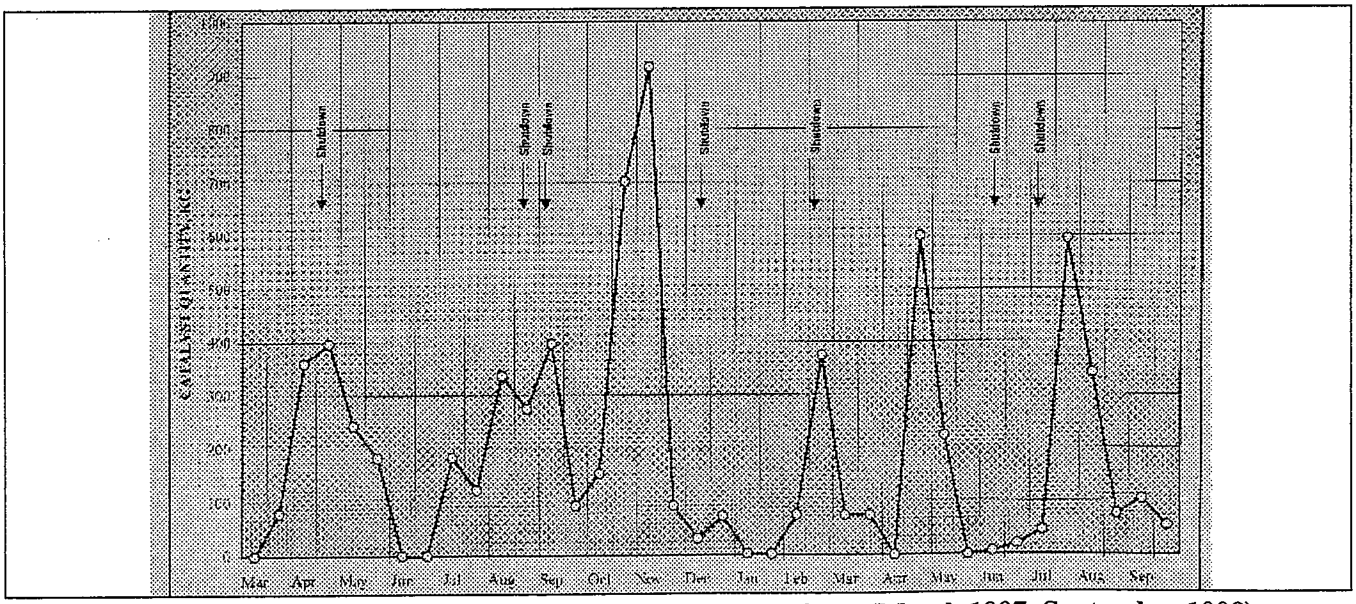

Figure 4. Ammonia converter catalyst removed through filter (March 1997–September 1998).

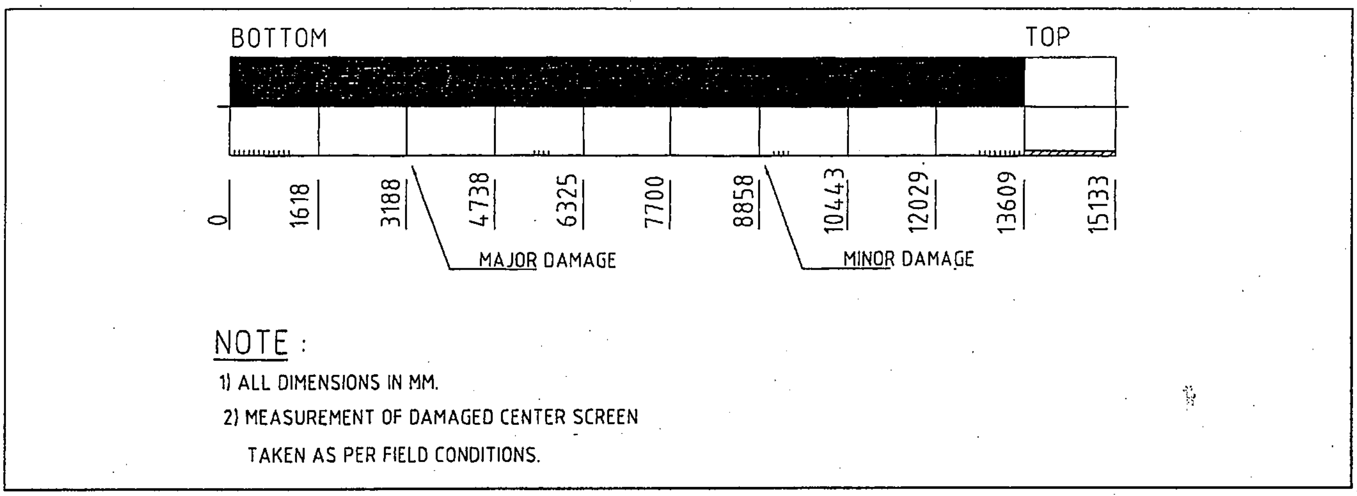

Figure 5. Ammonia converter second bed center screen.

Synthesis converter low performance

In the synthesis converter, the gas enters the catalyst beds, as shown in Figure 2. The top portion of the center screen in the second bed is unperforated and the gas passage is virtually blinded through this area. It was suspected that bypassing of gas would start after removal of catalyst from the unperforated area resulting in low performance of synthesis converter.

The converter low performance problem was observed in July 1998, as expected, with the overall decrease in the converter ΔT by 2°C. When the second

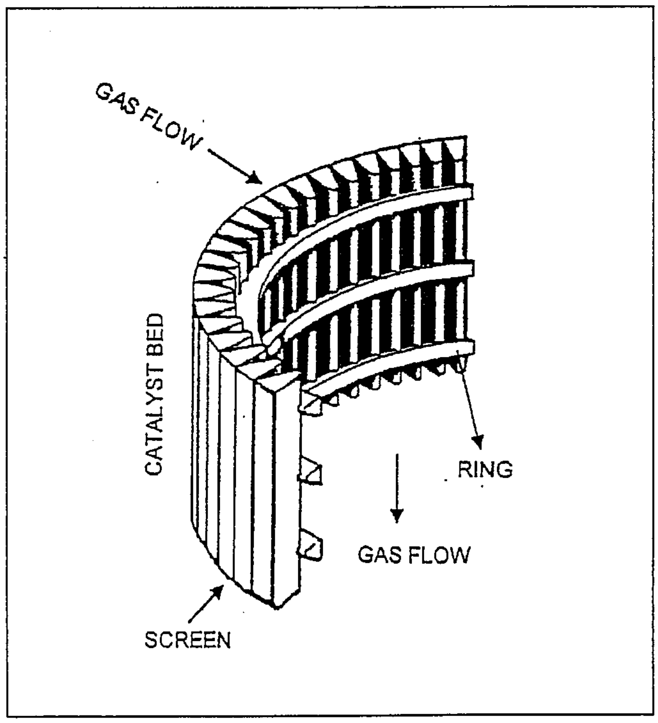

Figure 6. Second bed center screen: existing design.

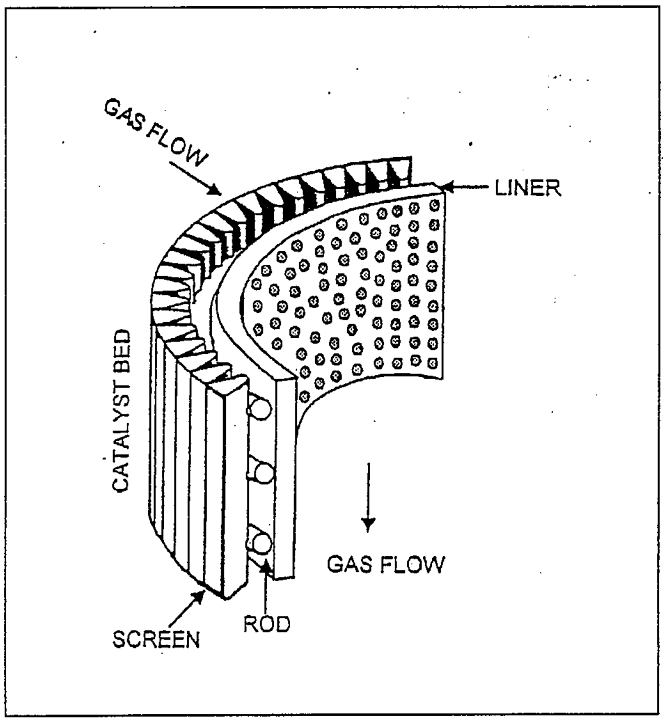

Figure 7. Second bed center screen: modified design.

bed cover was removed for catalyst unloading activity, a crater of ~2 m was observed, and the catalyst was far below the unperforated portion of center screen all around the one-half of the bed circumference (as seen in Photo 1). The catalyst on the other side of the crater was ~ 0.4 m below the top cover plate of the bed.

HP ammonia pumps seal flush filter problem

The fine catalyst particles with product ammonia entered the HP ammonia pump's seal flush filter at the urea plant, causing its frequent choking problem. This also resulted in high frequency of pump process seal damage. The presence of catalyst particles in the liquid ammonia was suspected as one of the contributing factors to the frequent seal failure.

Ammonia separator level control problem

A problem in level control of the ammonia separator was observed due to the accumulation of catalyst in the bottom of the vessel. Both the valves had to be fully opened due to the blockage of the line with the catalyst particles, especially during startup. The level control valve's stem was damaged twice, while its plug was de-shaped four times, along with the observation of abnormal mechanical noise from the valve. Finally, the size of the orifice provided downstream of the control valves was slightly increased (2 mm) to reduce opening of the control valves.

Action Taken to Sustain Plant Operation

After detection of catalyst leakage from the ammonia converter in July 1996, plant operation was continued for more than two years until the center screen repair job was undertaken during a plant turnaround in October 1998.

With the advent of catalyst leakage, some operational problems were observed due to the accumulation of catalyst in the ammonia separator. These problems were not only a threat to the smooth operation of the plant – its reliability was also at stake. In order to resolve these problems, some actions were taken, not only to continue plant operation without jeopardizing its reliability and safety, but also to cope with any unwanted situation.

The following actions are worth mentioning:

- Installation of high-pressure catalyst filter on the V-4501 drain line facilitated on-line removal of catalyst particles in addition to evaluating the severity of the problem.
- Operating procedures of the synthesis loop were revised to decrease heating and depressurization rates lower than the recommended maximum values (30°C/h and 2 Kg/cm^2/min, respectively).
- Ammonia filters were installed at the ammonia plant battery limit to avoid slippage of catalyst to the urea plant.
- The size of the orifice downstream of the V-4501 level control valves was increased by 2 mm to avoid full opening of control valves.
- Immediate ordering of synthesis converter catalyst charge.
- HTAS was contacted to review design of the center screen.
- Ordering of new center screen.
- Catalyst technology, England, was awarded a contract for catalyst loading/unloading job on short notice.

As the catalyst leakage could be successfully managed for some time, an immediate plant outage for repairs was uneconomical, mainly due to extensive downtime required for the repair job. In the meantime, all the necessary preparations as mentioned above were made.

Center Screen Failure Analysis

Construction of old center screen

The old second bed center screen designed by Haldor Topsøe was fabricated by Johnson. Johnson center screens are fabricated by welding "V" shaped longitudinal wires to support rods as will be shown in Figure 6, and the entire length is obtained by welding a number of sections together, as shown in Figure 5.

Installation of old center screen

The center screen is welded to the base plate of the second bed at the bottom, while the upper solid portion of the screen is installed in a manner which allows

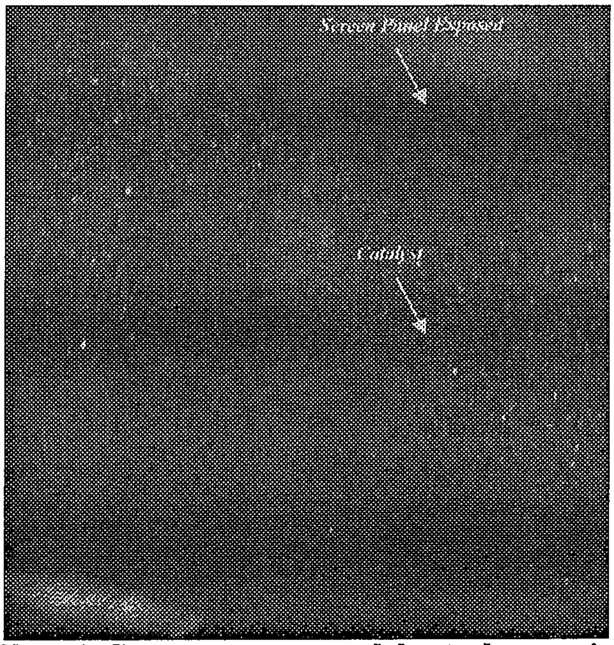

Photo 1. Center screen exposed due to decrease in catalyst level in second bed.

movement in an upward direction due to thermal expansion. A stuffing box is provided at the top, and the upper portion of the center screen is machined to provide proper sealing of the gas. Expansion bellows are welded between the cold shot pipe and the center tube upper flange to allow the relative movement, especially during a hot startup when the gas from the cold shot pipe passes at elevated temperatures.

Findings on the center screen

Inspection of the center screen was carried out after removal of all the catalyst. The screen was found damaged at two locations (see Figure 5). It was severely damaged at about 3.2 m from the bottom (at the third circumferential joint). The screen wires were found twisted and a few wires were also torn apart allowing passage for catalyst leakage (see Photo 2).

The second damage was found at about 8.8 m from the bottom (at the seventh circumferential joint). At this location, the two sections of the screen were torn apart from circumferential weld, while the wires were intact and straight (see Photo 3). All other joints were OK, and no denting or bulging was observed on the screen.

The old expansion bellows was removed from the center screen and some cracks were also observed (see Photo 4).

Causes of failure

The damage to the center screen at the bottom, as shown in Photo 2, indicates that the screen wires exhibited excessive compression stresses due to the fact that the upper section of the center screen was restricted in expanding thermally. These stresses resulted in high axial load causing failure of either the weakest circumferential joint or failure in the lower portion of the screen. At the second location, the screen was sheared off circumferentially due to axial tension, as shown in Photo 3.

The possible causes of center screen failure due to high axial load may be due to any one, or the combination of more than one, factors given below:

- Excessive friction between catalyst and center screen due to compaction in the catalyst bed leading to excessive compression stresses.
- Restriction in the center tube expansion due to rigidity in the stuffing box.
- Load from the expansion bellows.
- Weak circumferential joint between the two sections of the center screen.
- High temperature in the second catalyst bed resulted in higher than design axial load.

It is important to mention that, during the plant operation, neither the temperature of the catalyst beds has exceeded the design condition, nor any sudden jerk in pressure or any upset occurred in the synthesis loop.

Modification in the center screen

The new modified center screen of the second bed, with higher strength against the axial load, is also designed by Haldor Topsøe (see Figure 7). A perforated liner of Inconel 600 was welded to the inner side along the entire length of the center screen. There are holes provided on the liner for the passage of gas without posing additional differential pressure. In order to provide radial (collapse) strength, the screen wires were welded to the circumferential rings at each point. These rings are provided in-between the liner and

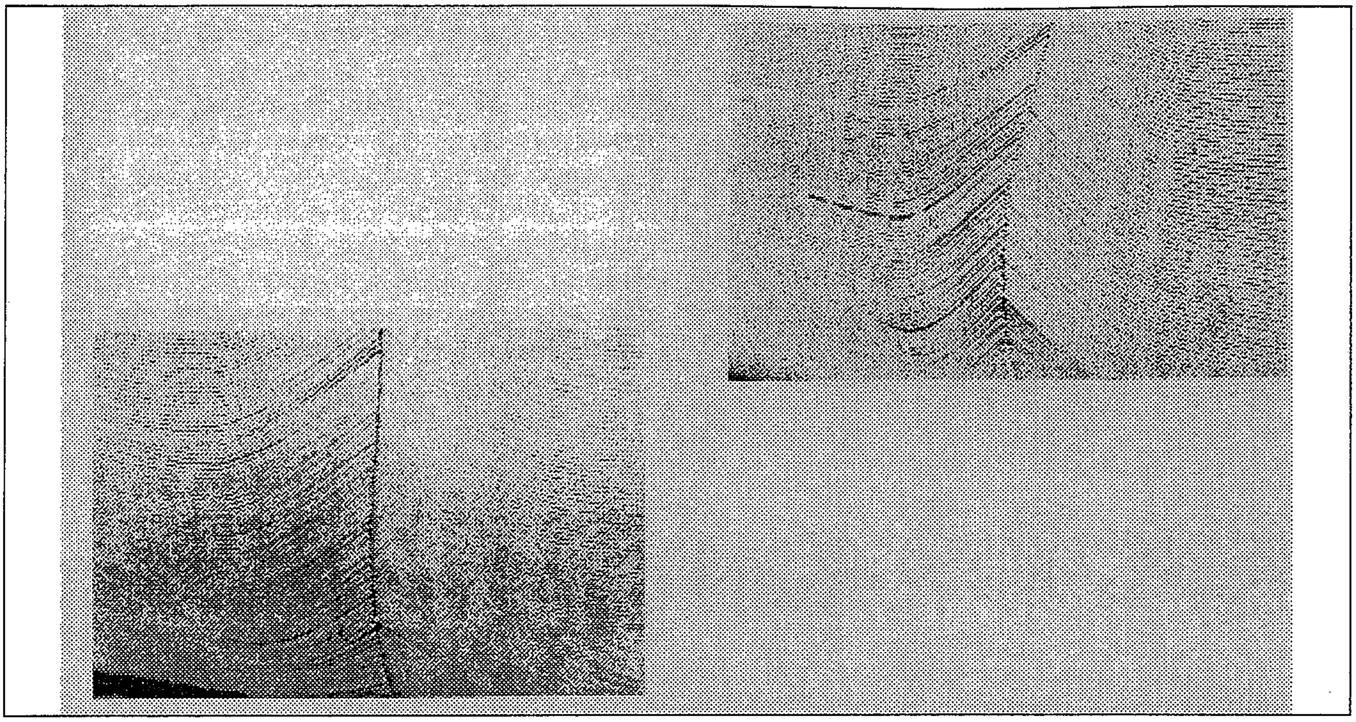

Photo 2. Damaged center screen at 3.2 m from the bottom.

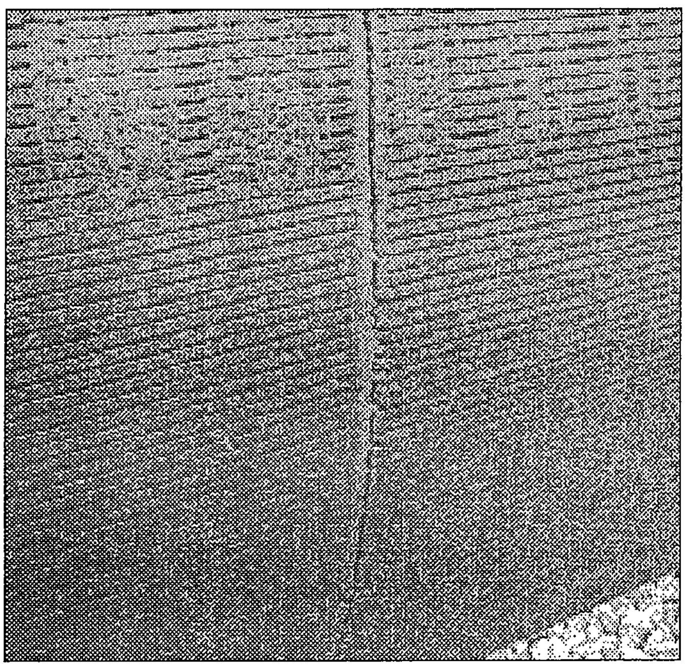

Photo 3. Damaged center screen at 8.8 m from the bottom.

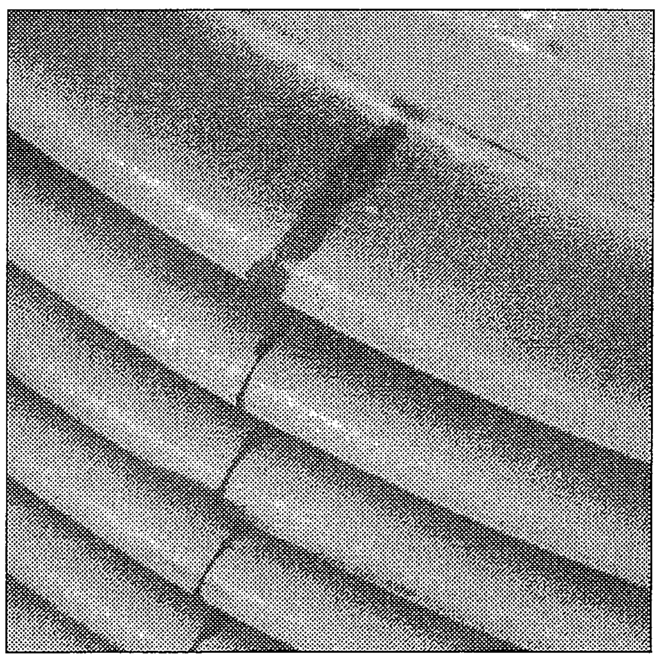

Photo 4. Damaged expansion bellow.

screen wires along the entire length of the screen. These rings are also welded to the perforated liner at four points on the circumference. With these modifications, the allowable axial load has been increased to more than twice the original design load.

The total length of the screen and center tube is decreased by 60 mm and 50 mm, respectively. The material of the upper blank portion of the center tube was changed from SS-304 to SS-321 due to the change of material presently being used in the ammonia synthesis converter (as shown in Photo 5 of the new center screen).

Maintenance Job on Center Screen

Removal of damaged center screen

After removal of catalyst from the second bed, scaffolding was raised up to the height of the center screen. At the location of damage, plates were tack-welded to provide support during the screen lifting. The joints between the expansion bellow and the cold shot pipe were grinded after removal of the center ring and, then, the screen was slightly lifted (supported) by crane. The screen was then cut at a 30 mm height from the base ring and lifted out from the bed. Photo 6 shows the old screen lying after removal from the bed. (Photo 7 shows catalyst level decreasing in the first bed.)

Repair/welding of new center screen

The new center screen was provided in two sections; therefore, the same was welded circumferentially from the inner and outer sides by the welder from Johnson's filtration system (France). The new expansion bellows were welded to the upper flange of the center screen before installation. Prior to this, a dye check of all the welding joints of the screen was carried out and some defects were observed at four locations on the circumferential weld joints. The same was repaired by grinding and welding before installation.

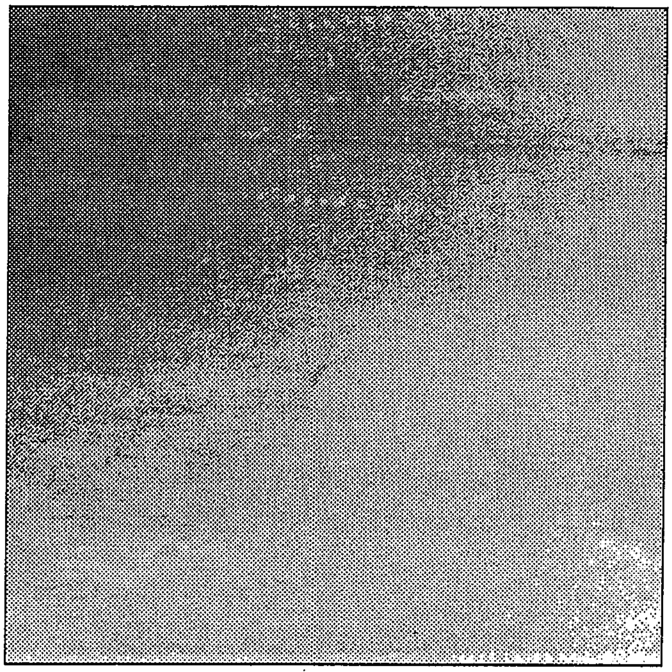

Photo 5. Inside view of new center screen.

Installation of new center screen

Before installation of the new center screen, the remaining 30 mm portion of the base ring was grinded flat (angle of beveling O°). Nitrided layers were removed by grinding from the inner and outer sides. The tips of 12 support plates welded to the cold shot pipe were cut by 10 mm at a 30° angle to provide additional space required by a new screen with a liner. The new center screen bottom was provided with the backing strip.

The welder from the Johnson filtration system welded bottom of the center screen after providing the guide ring.

Synthesis converter catalyst replacement and repair activity

In order to carry out the second bed center screen replacement job, it was required to unload all the catalyst from the basket. The reduced catalyst is pyrophoric, and, therefore, its unloading was carried out under

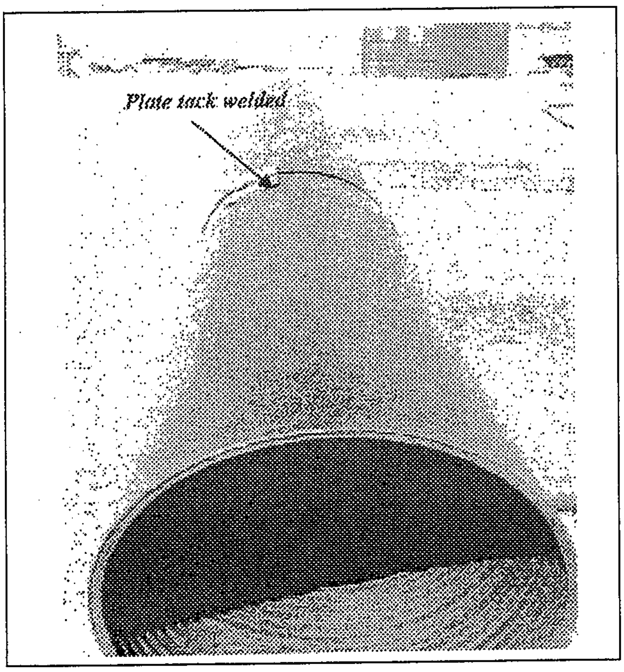

Photo 6. Old center screen.

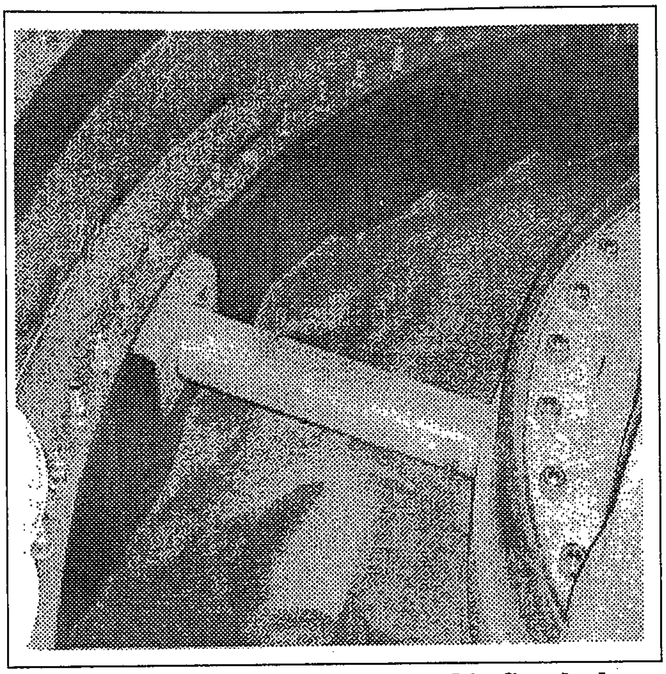

Photo 7. Catalyst level decreased in first bed.

Table 1. Sequence of Activities

Activities and Duration

(1) Ammonia plant backend shutdown, cooling and purging of the reactor (17 h)
(2) Purging of reactor and synthesis loop/HP cover de-bolting (27 h)
(3) Removal of shell/basket and first bed cover (24 h)
(4) Removal of the catalyst from the first bed (37 h).
(5) Removal of first bed.(10 h)
(6) Removal of catalyst from 2nd bed (93)
(7) Replacement and Inspection of center screen/internals.(71 h)
(8) Catalyst loading in second bed.(31 h)
(9) Installation of first bed.(13 h)
(10) Catalyst loading in first bed (10 h)
(11) Box up (12)
(12) Activation of the catalyst (48 h)

Total: 393 h

N_2 atmosphere. The working under immediately dangerous to health and life (IDHL) atmosphere is a special job; therefore, the whole catalyst change-out activity was contracted out to CATALYST TECHNOLOGY, U.K.

Sequence of activities

The whole activity for the Synthesis Reactor R-4501 catalyst/center screen replacement was carried out in the sequence shown in Table 1.

Conclusion

The failure of the S-200 basket's second bed center screen was due to the higher axial load in the second bed of the basket. The main reason for the problem is suspected to be the weaker design of the center screen to bear the actual compression stresses caused by the combined action of thermal expansion of the screen and the opposite forces which might be exerted by friction of the catalyst and/or expansion bellows. The subsequent modifications carried out in the center screen are also in line with the above conclusions.

QUESTIONS

(1)Were erosion marks observed in the high velocity zones of synthesis loop pipeline and tube sheets of heat exchangers?

Muhammad Aleem Khan, *Fauji Fertilizer Co., Ltd.*: Thickness monitoring of the synthesis loop piping, especially on the elbows, have shown no thickness reduction.

(2a) What is the estimated rate of the catalyst leakage?

Khan: The catalyst leakage rate during normal plant operation was found to be 2 to 4 Kg/day. However, after plant shutdown the rate was generally found to have been much higher.

(2b) Do you agree with me that running the plant for two to three years with all the difficulties you mention is an unsafe approach?

Khan: There was no safety concern in operating the plant under the mentioned conditions. Only plant operational reliability was of concern, and, as the immediate plant outage was not economically feasible, all preparations for the repair were kept in-hand within a minimum possible time.

(3) Were there any pitting marks on HP NH_3 pump impeller due to catalyst particles?

Khan: No pitting marks were observed on HP Ammonia pump impeller.