Radial Flow Ammonia Converter

With the radial flow reactor it is possible to use very fine catalyst particles and still obtain converter pressure drop appreciably smaller than is typical of older reactor.

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When the demand arose for large single-train ammonia plants, Haldor Topsoe considered a number of alternative designs for this new family of plants based on the use of centrifugal compressors. Considerations pivoted on a number of factors some of which were: reactor pressure drop, catalyst volume as related to catalyst particle size, gas distribution, and easy access for catalyst change or emergency repair. We finally decided upon the radial flow reactor constructed with full opening closure on the pressure vessel. With radial flow it is possible to use very fine catalyst particles and still obtain converter pressure drop appreciably smaller than is typical of older reactors designs.

Figure 1 shows concentration profiles of ammonia, nitrogen, hydrogen, and temperature radially through a 5.7 mm. ammonia catalyst particle in contact with gas at a pressure of 214 atm., a temperature of 450°C, 12% inerts and, as shown, approximately 3% ammonia in the bulk fluid, a condition which corresponds to inlet to the catalyst. By observing the conditions at the center of the particle, one can see that the ammonia concentration is close to 20% and, as a consequence, the particles are very poorly utilized. Figures 2 and 3 show the ammonia concentration in the bulk gas and at a 0.5 relative radial distance. An effectiveness factor is shown on the right side of Figure 2 for a 5.7 mm. particle, and on Figure 3 for a 1.5 mm. particle. Notice that while the overall effectiveness factor of the larger particle size is roughly 0.6, the small particle size has an overall effectiveness factor of at least 0.9. As a result, the catalyst volume could be appreciably decreased, and catalyst volume for a 1,000 short on-day reactor is in the order of 1,000 cu. ft.

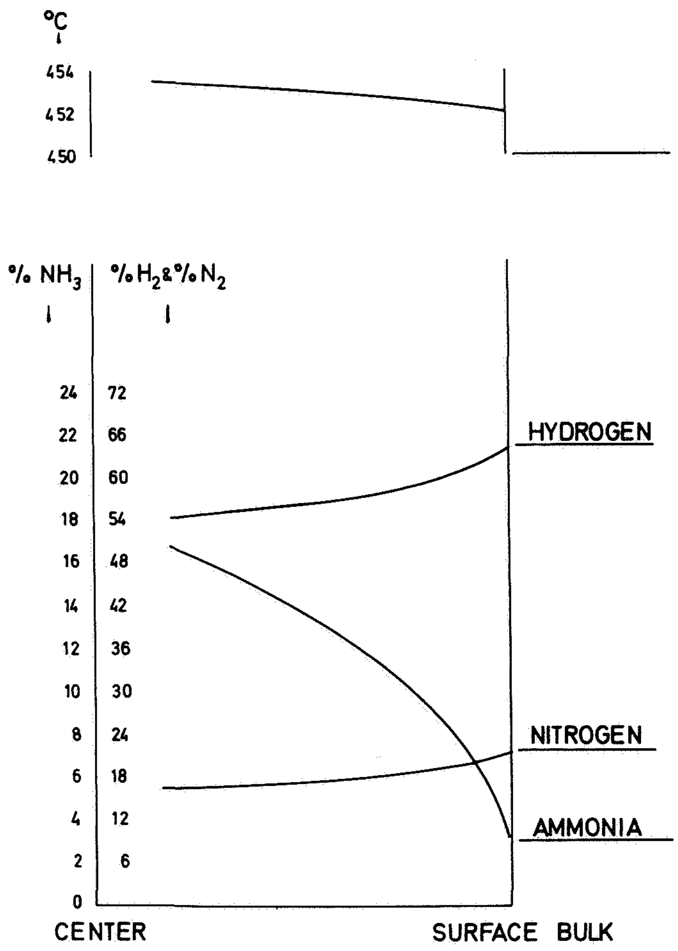


Figure 1. Concentration profiles shown radially through a 5.7 mm. catalyst particle: pressure, 214 atm.; temperature, 450°C; inerts, 12%. Inlet to bed.

figure courtesey La Chimica e l'Industria, 51, 1,056 (1969).

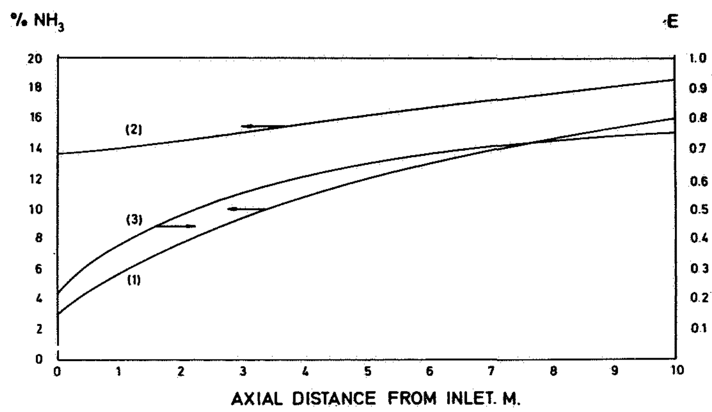


Figure 2. Per cent NH_3 in bulk (1); Per cent NH_3 at relative radial distance of 0.5 (2); and effectiveness factor (3). Pressure, 214 atm.; temperature, 450°C; inerts, 12%. S.V. = 15,000 V/V/h. Particle diameter, 5.7 mm.

figure courtsey La Chimica e l'Industria, 51, 1,056 (1969).

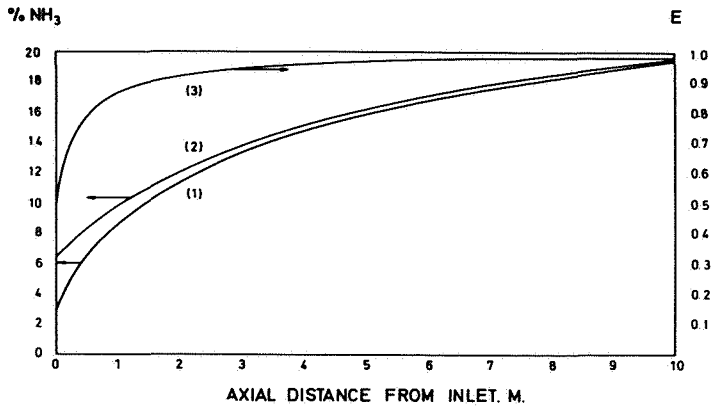


Figure 3. Per cent NH_3 in bulk (1); Per cent NH_3 at relative radial distance of 0.5 (2); and effectiveness factor (3). Pressure 214 atm.; temperature 450°C; inerts, 12%. S.V. = 15,000 V6V/h. Particle diameter 1.5 mm.

figure courtsey La Chimica e l'Industria, 51, 1057 (1969).

Operation

The radial flow ammonia synthesis converter consists of a pressure shell, and an internals or catalyst basket. The startup heater is normally placed outside the pressure shell. Figure 4 shows a general arrangement of the reactor. We shall now follow the route of the synthesis gas through the converter. The main feed flow enters through two inlets at the top, from there it passes downwards in the annular space between the externally insulated catalyst basket and the converter shell. At the bottom of the basket the gas enters the lower heat exchanger. In the top of this exchanger the gas is mixed with cold bypass gas to control the inlet temperature to the number one catalyst bed. The gas passes the riser tube to the central tube in the number one bed at top, and from there radially through the number one bed. Having passed the number one bed, the gas is thoroughly mixed with quench in order to obtain the desired inlet temperature to the number two catalyst bed. This mixing takes place in the annular space between the inner and outer basket annulus. The gas then enters the number two catalyst bed and flows inwards towards the center line of the reactor. From this bed, the gas goes through the annular space surrounding the center riser pipe, and passes the lower exchanger through the exchanger tubes, continuing through a collecting box, and leaves the reactor through the bottom part. Proper gas distribution in the catalyst beds is ensured by introducing artificial pressure drops at the inlet and outlet cylinders to the beds. This could readily be afforded since pressure drop on each bed is in the order of only 2 lb./sq. in. A typical pressure drop through a radial reactor is 40 lb./sq. in.

Apart from the use of the radial flow principal and the particular considerations to ensure good flow distribution, to avoid bypass on top of catalyst beds, and to achieve effective mixing of exit gas from the first bed with quench gas, this reactor is in many ways a classicial one. The pressure vessel is equipped with a full opening closure and the converter internals can be lifted out in one piece should mechanical repair be required. For a catalyst change the converter internals are not removed. The procedures for such a change will be discussed later.

Typical operating data for one 1,000 ton/day radial flow

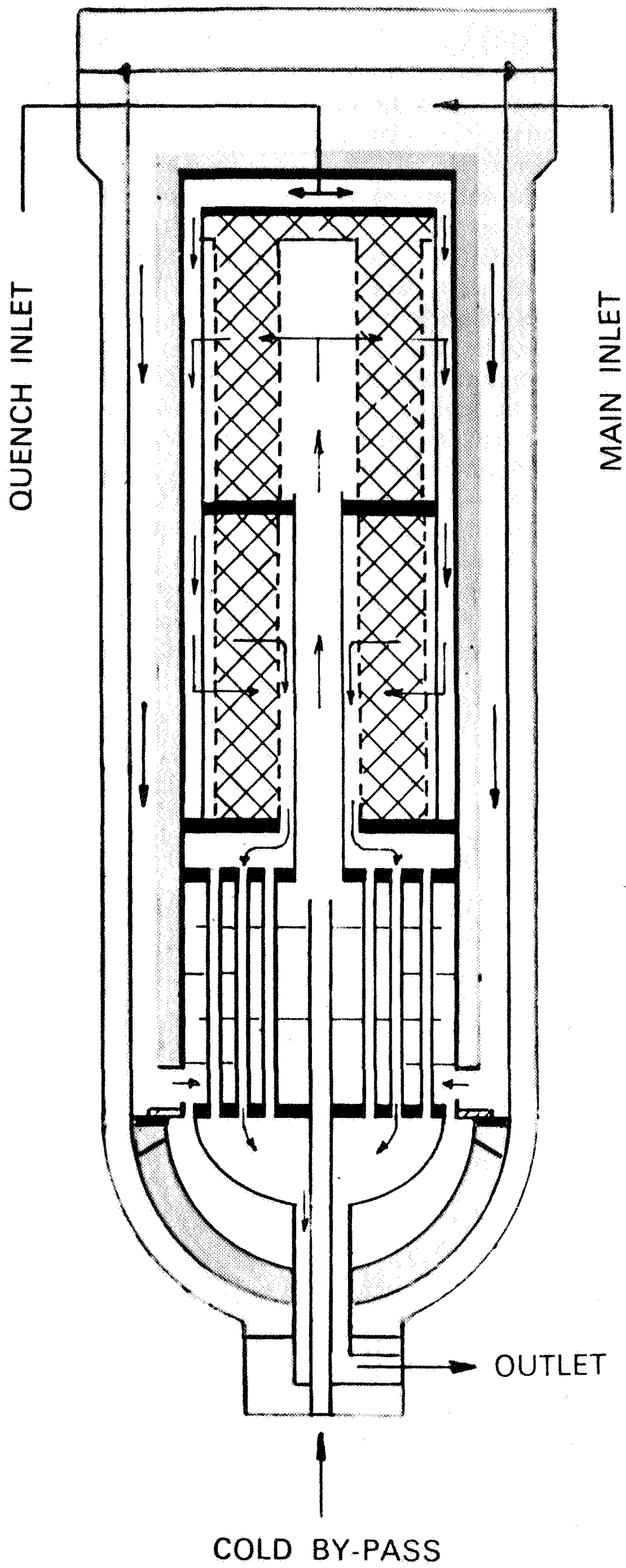


Figure 4. General arrangement of radial flow ammonia converter.

converter and one 1,500 ton/day converter are shown in Table 1. For comparison, the design data are also given here.

Safety

Safety aspects are particularly related to the high pressure shell and to catalyst loading and unloading procedures.

Ammonia converter shell – As mentioned, the main inlet to the reactor is via two lines to the top of the vessel. From the top of the vessel the flow of gas, which is a minimum of 10% of the total converter feed and normaly much much more, passes along the shell to the bottom of the vessel where it enters the shell side of the lower exchanger. The catalyst basket and exchanger are provided with an effective external insulation. Depending on the way in which the heat of reaction of the ammonia synthesis is integrated into the overall heat balance of the ammonia plant, different temperatures are used for the main inlet gas. The material of construction of the reactor shell, of course, depends on the design temperature with particular view to the risk of hydrogen attack. Consideration are given to the situation arising in case of compressor stop to make sure the shell can, if necessary, dissipate the heat transferred from the hot catalyst if no shell cooling gas is

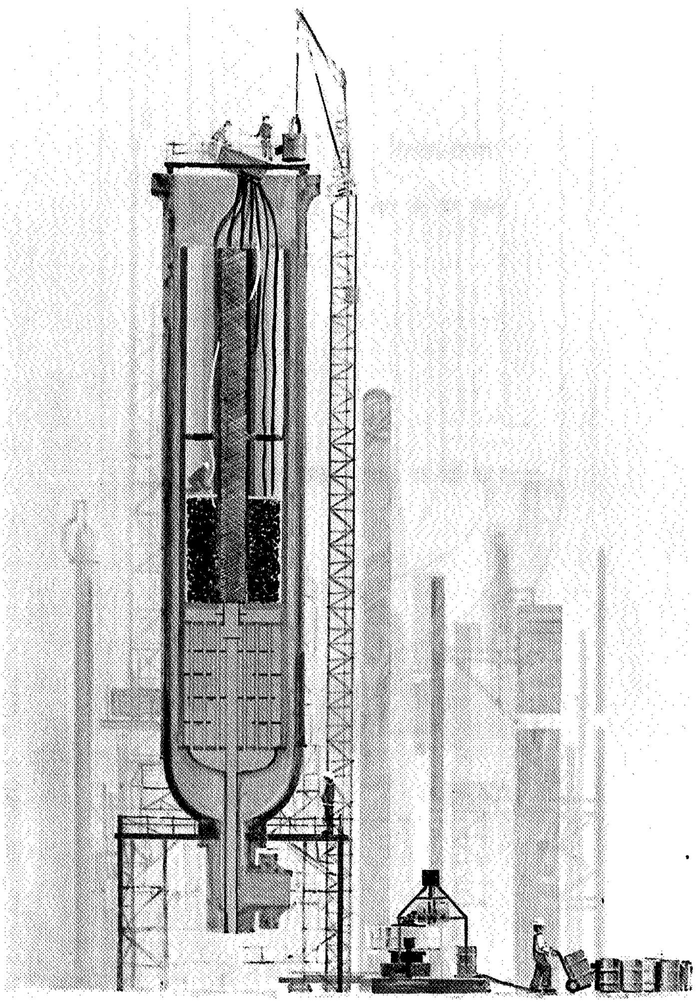


Figure 5. Loading of radial flow ammonia reactor.

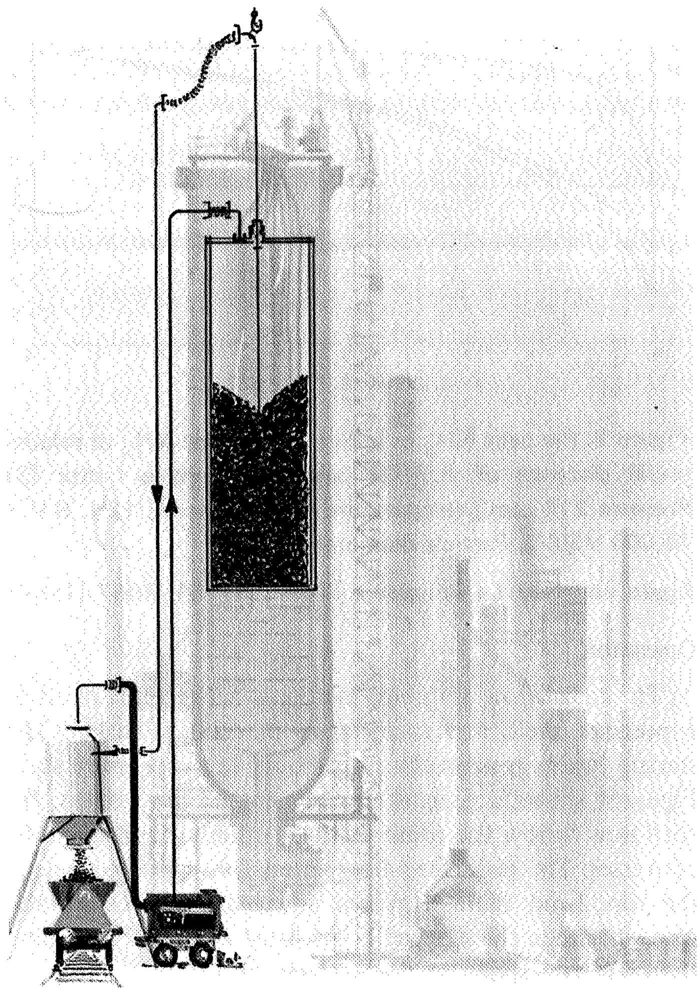


Figure 6. Catalyst removal in nitrogen atmosphere from radial flow ammonia reactor.

available. As to the bottom section of the vessel, particular consideration is given to hydrogen attack and, in some cases, to nitriding of surfaces exposed to a gas of high ammonia content. The temperature of the pressure vessel is indicated by several temperature indicators, and the temperature of the gas leaving the reactor is normally recorded and an alarm for high temperature installed.

All radial flow reactor shell temperatures known to Haldor Topsøe have been very uniform, and we have not come across any problems with hot spots, hydrogen attack, or overheating of any part of the reactor shell or bottom part of the pressure vessel. We believe this is due to the proper selection of materials and because the inner catalyst basket is insulated from the shell by two annular spaces and an effective and rugged insulation layer.

Loading of radial flow ammonia converters – More than 20 radial flow converters have been commissioned or are under construction. In most cases, pre-reduced catalyst or a composite charge of unreduced catalyst in the bottom bed, and pre-reduced catalyst in the top bed have been used. Four of these reactors which have been started up have a design capacity of 1,500 short ton/day. Loading of such a large unit is, of course, and operation which has to be carefully planned and supervised. Loading may take from five to 15 days depending upon whether it is continued around the clock or only carried out during the day shift.

Figure 5 shows an artist's view of a catalyst loading operation. Often a force of ten people are involved. Two men work on the ground handling, opening, and screening catalyst. As shown in Figure 6, the screened catalyst is lifted to the top of the reactor where two men are working. They pour the catalyst into a wooden box of adequate size which serves to distributre the catalyst into about six 2 in. polyethylene filling hoses. These hoses extend down to about 1-1/2 ft. above the bottom of the second bed when loading starts, and are shortened after every round of catalyst pouring. While the lower bed is still being loaded, two men work there, and one man is posted at the bottom of the upper bed for the safety of the two men working below. One rope ladder is suspended from the top to the bottom of the upper bed, and another from hooks in the ceiling in the lower bed to the bottom of this bed. The two men who work in the bed where loading takes place guide the loading hoses during the filling operation. A certain short layer of catalyst is filled in each operation. When the appropriate amount of catalyst has been poured and the surface evened out, a patterned frame is laid down on the surface and the catalyst vibrated with a pneumatic vibrator rod. The two men working in the lower bed normally use air masks, and when catalyst is being poured they climb a few feet up the rope ladder. Alternatively, rubber clothing with fresh air supply is used. The catalyst dust is unpleasant to the skin due to its alkali content. The only time when dust will appear is when catalyst is poured, and this is done a maximum of ten times a shift for approximately 3 min. each time. The loading is carried out with a proper supply of air, which is maintained by a steam or compressor-driven Venturi blower at the top of the converter with its intake through a polyethylene hose that extends close to the bottom of the converter and is shortened as the catalyst bed is filled up. With this set-up dust is easily removed.

Removal of ammonia catalyst – When the synthesis catalyst has to be changed out, the ammonia reactor has to be cooled down to 50°C and a slight nitrogen overpressure established on the converter. Figure 7 shows the principle of such an operation. For simplicity, the two catalyst beds and center pipes etc. have not been shown. When the converter outlet and cold shot pipes have been disconnected, blind connections provided with 2 in. connections each, and nitrogen hoses connected to these two points, an overpressure of a few inches of mercury is established. The lid of the pressure shell can now be taken off. The annulus between the basket and the inside of the pressure shell is blanked off, the two basket lids are taken off, and a temporary lid is installed instead. The thermocouples which had to be withdrawn in order to remove the converter lid are re-installed through the temporary lid so that the catalyst temperatures can be surveyed during the catalyst removal. The catalyst will be removed in its active pyroforic state without any pre-stabilization procedure.

First, the catalyst is sucked out from the top bed. Normally one aluminum tube is used at a time for removal of the catalyst, but pipes of different length are needed for the different sections of the converter. The vacuum system can be seen in Figure 6. Nitrogen introduced to the converter brings the catalyst through the suction pipe. The catalyst is removed in a cyclone and a filter, and the nitrogen is recycled. Make-up nitrogen is introduced through the bottom connections in order to maintain a positive excess pressure at all locations inside the converter.

The catalyst taken out from the circulating nitrogen is directed from a hopper into a car where it may be sprayed with water and disposed of.

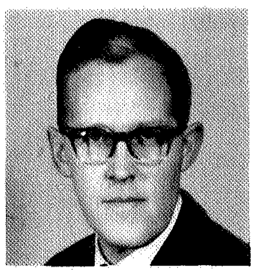
When the catalyst has been vacuumed from the upper bed, mechanics in air suits enter the bed under nitrogen blanket to open the manways in the upper bed support deck. People again leave the reactor and the catalyst is removed from the lower bed by the vacuum system. There has been an actual case of removal of ammonia catalyst from a 1,500 short ton/day. It took 24 hr. to empty the top bed, and about 72 hr. to empty the bottom bed which holds more than twice as much catalyst.

Performance

Some catalyst batches have now been in operation for more than 3 yr., and analysis of data from these reactors shows that the catalyst is holding up very well. In analyzing one reactor we found a catalyst type factor of 2.2 after 12 months of operation, 2.2 after 20 months of operation, and 2.15 after 26 months of operation. For another reactor we found a type factor of 1.6 after a period of 3 yr. The type factor is a measure of the activity of the catalyst. Since the design factors are normally in the order of 1.0, a very long catalyst life may be expected. This confirms our anticipation that, in modern ammonia plants, catalyst will lose its life not by poisoning, but from recrystallization. Thus, there is no penalty involved in the use of a smaller volume of more active catalyst for the same production rate.

Preliminary design of reactors up to 3,000 ton/day has been made, and this reactor principle could, without any appreciable changes, be used for reactors of this capacity. The approximate weight of the pressure shell for a reactor for the manufacture of 3,000 ton/day ammonia would be 400 tons, and thus well in line with vessels now being handled for refinery use. #

NIELSEN A.



DISCUSSION

Q. Does your design restrict you to a two-bed converter, can you go to more beds than two?

NIELSEN: The somewhat more than 20 radial flow reactors designed have been two-bed reactors except for one one-bed reactor for a special situation. We have developed designs so that we can go to 3 beds, however, we have found that the economic incentive of going to 3 beds does not justify the additional complication of the system.

Q. Having radial flow against the catalyst coming in sideways means the catalyst has a habit of shrinking. You can get a bypass across the top. Do you void that area so the gas cannot void?

NIELSEN: This was one of the considerations which we had to consider when we made the design. What we do to avoid any problems is first that we vibrate the catalyst in the basket when it is being filled as mentioned earlier. This reduced the subsequent shrinkage because shrinkage of an ammonia catalyst bed is neither due to a shrinkage of the individual particle during its reduction nor to any shrinkage or significant abrasion during use.

What is observed some times in industry as quite a large shrinkage is essentially due to a re-orientation of the particles because without vibration the catalyst as filled has far from the minimum voids. So by use of vibration we get a minimum bed shrinkage later. Now since we do realize we may have over the life of a catalyst batch a certain shrinkage, we have a catalyst volume on top of each of the two beds which is not serviced by draw-off and inlet perforated areas so that for a certain calculated amount of shrinkage, there will still be no by-passing on top of the beds.

Q. How wide are your beds? A man has to get in there.

NIELSEN: No, he has not. The space available, of course, will vary a little with converter capacity and other operating conditions which define the size of the unit. Typically for a 1500 STPD unit the ID of the pressure vessel is 84 in. Now the most narrow space is at the deck between the top and bottom beds. You have manways there, say in a given reactor manways or manholes which are kind of a elliptic with a minimum diameter of about 18 in. and a maximum diameter of about 20 in.

Q. Do you offer your converter design for modernizing or debottlenecking of an existing plant? If so, how do you offer the design, procurement, and inspection services involved?

NIELSEN: The first answer is that we do in fact offer converters for modernisation or debottlenecking of an existing plant.

For one thing we make the detailed shop drawings of the ammonia converter designs whereever in the world they are to be manufactured. We offer these designs to a client or if the client wants a contractor to do a certain job we offer the reactors through one of the contractors with whom we have established relationships. We also offer shop inspection services.

Q. Does the exchanger have to be pulled in order to be inspected?

NIELSEN: Yes, you cannot inspect the heat exchanger unless you pull the basket out of the reactor.

Q. But you do have a full opening closure?

NIELSEN: We do have a full opening closure, Yes.

Q. What type of insulation do you use—just a generalized type or do you try to limit the chlorides in the insulation?

NIELSEN: We look most critically on the chemical analysis of the insulation material both with respect to chloride and also with respect to sulfur as a possible source of poisoning for the catalyst. Now the general type of insulation we use I do not know, but maybe my colleague Erik Vohtz can help. At the time of the meeting Kaowool was mentioned; this is corrected in proof reading to Cerafelt which is the material actually used for insulation of the radial converter baskets.

Q. In your experience of removing the catalyst under nitrogen pressure, do you or your customers feel it's somewhat hazardous of going down in to open the hatches on the bottom bed?

NIELSEN: This is not my impression. We do not feel that our clients consider it somewhat hazardous, and we do not feel that way. At the moment the converter is entered you have the bottom bed all in a nitrogen atmosphere and you have a nitrogen bleed coming up through the bottom of the reactor. The man who enters goes into a nitrogen-filled space with his air supply. And remember the man is in the top bed where he is in good communication with people above at the top of the converter.