# A New High Capacity Ammonia

**Besides providing good flow distribution and optimum pressure drops, the capacity of this new converter is limited only by the weight of the external pressure vessel, excluding internals and catalyst.**

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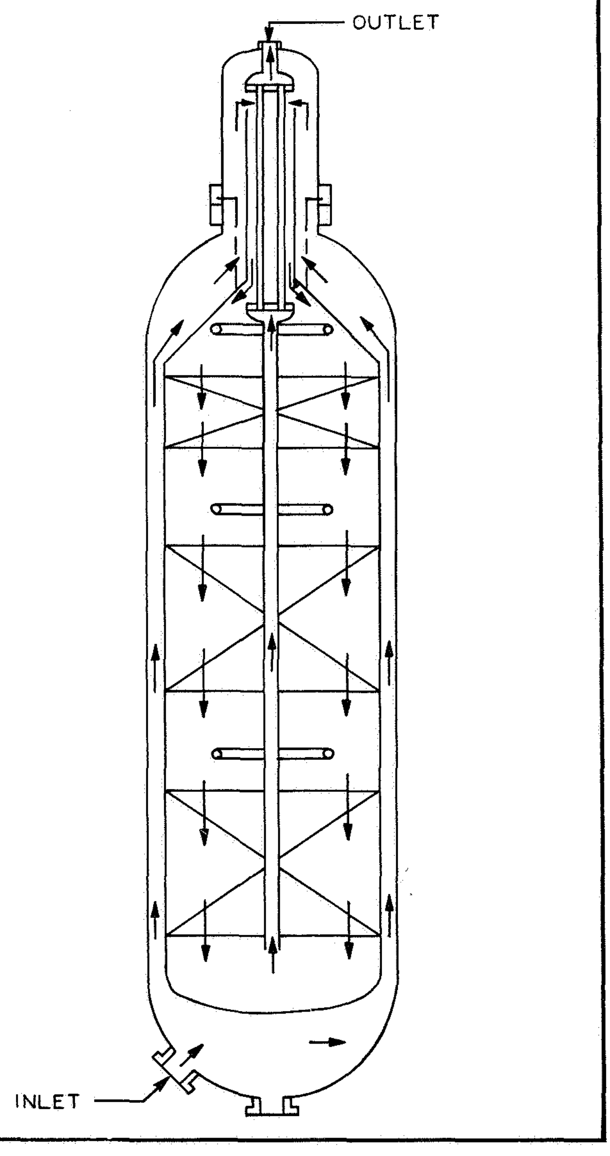



**Figure 1. Vertical quench type converter.**

WITH THE ADVENT OF LARGE CAPACITY AMMONIA plants, new design concepts were developed for single-train process equipment for capacities of 1,000 tons ammonia/day and above. This involved new ammonia converters designs, including the one developed by M. W. Kellogg (*1*). This design has been installed in 40 units, most of them in operation. Plant designers and users are looking into the future, and developing and assessing the feasibility of single-train plants whose capacity would be substantially above those presently in service. For the conventional design, using an axial flow vertical converter, limitations would be reached due to the required vessel diameter, pressure drop, total vessel weight, and inability to take full advantage of the more efficient small size synthesis catalyst.

M. W. Kellogg developed a new large capacity ammonia converter (*2*) whose main features are horizontal installation, and a basic design which can be easily adjusted for a wide range of plant capacities. For plant sizes exceeding 3,000 tons only the weight of the pressure shell would be limiting. The removable basket permits maximum utilization of catalyst and quench features. This article will describe the basic reasons that led to this design, major design features, as well as actual installation and operating experience of one converter which is part of the world's largest ammonia plant.

## History

The conventional arrangement of a single, large capacity (1,000- to 1,500 tons) ammonia converter is shown in Figure 1. It consists of a vertical pressure shell with an internal basket and three or more catalyst beds with quenching between beds to control optimum operating conditions. The specific design shown in Figure 1 was developed by M. W. Kellogg as part of a large, single-train ammonia plant. The size of these converters depend on:

1. Plant capacity
2. Feed composition
3. Synthesis loop pressure (*3*)
4. Catalyst volume as a function of activity and particle size.

To extend this design to plants with total capacity

# Converter

much above 1,500 tons/day would require an increase in diameter which would be limited by fabrication facilities and shipping clearances. With this restriction of the diameter, capacity could only be increased through an increased operating pressure which may not be optimum with respect to machinery selection or through increasing the pressure drop through the catalyst bed which, again, may prove to be uneconomical. The use of smaller particle catalyst would reduce the catalyst volume and depth, but these features would be offset by an increase in pressure drop.

Alternate solutions are available and have been successfully applied. One of these is a radial flow arrangement, as shown in Figure 2, which, for a given vessel diameter and length, permits a shorter flow path and an increased cross sectional flow arrangement. This design is the subject of another paper (*4*). In the authors' opinion, such a catalyst arrangement will not permit maximum use of the catalyst due to the varying velocity and contact time per unit length along the gas flow path, as shown on Figure 2. It also requires careful attention to gas distribution prior to entering the catalyst bed with the bed contributing only little to the distribution since most of the unit pressure drop is at the catalyst bed outlet.

Over the past few years M. W. Kellogg reviewed several other alternates and settled on a horizontal bed arrangement as shown in Figure 3. As can be easily seen from this figure, such an arrangement offers maximum flexibility with respect to bed depth, total catalyst volume, and uniform gas velocity through the catalyst itself. To vary converter capacities, the bed length may be changed while all other design dimensions may be kept unchanged. The flow is directed downward through the catalyst. The overall dimension of such a converter is shown on Figure 4, which represents an actually built unit for a capacity above 1,500 metric tons (1,700 tons) at an operating pressure of approximately 3,000 lb./sq. in. gauge.

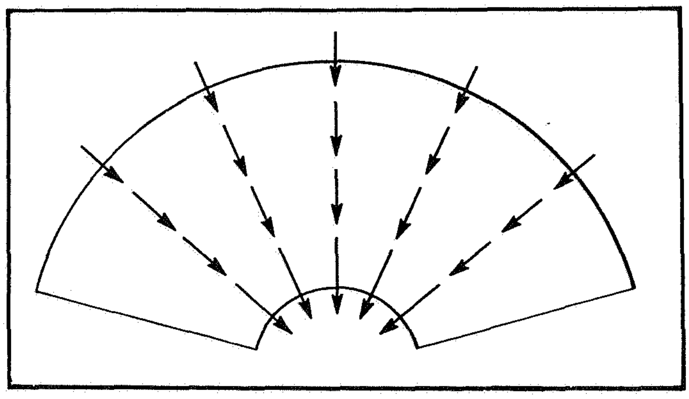


**Figure 2. Radial flow arrangement.**

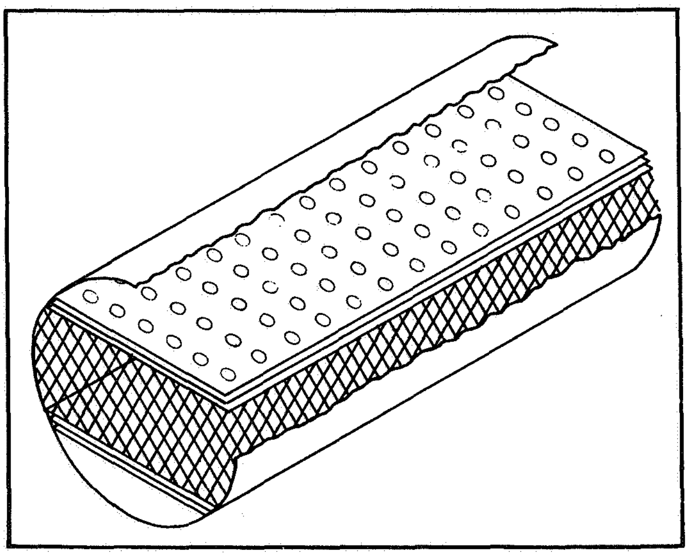


**Figure 3. Horizontal bed arrangement.**

## Description of converter

During operation, the reactants are charged to the converter through the inlet nozzle, Figure 5, and directed toward the interchanger via the annulus formed between the cartridge and pressure shell. This keeps the pressure shell temperature low, permitting the use of conventional pressure vessel steels without the need to consider protection against hydrogen attack or elevated metal temperature. The reactants flow through the interchanger (shell side) and exit via the gas transfer line. At this point

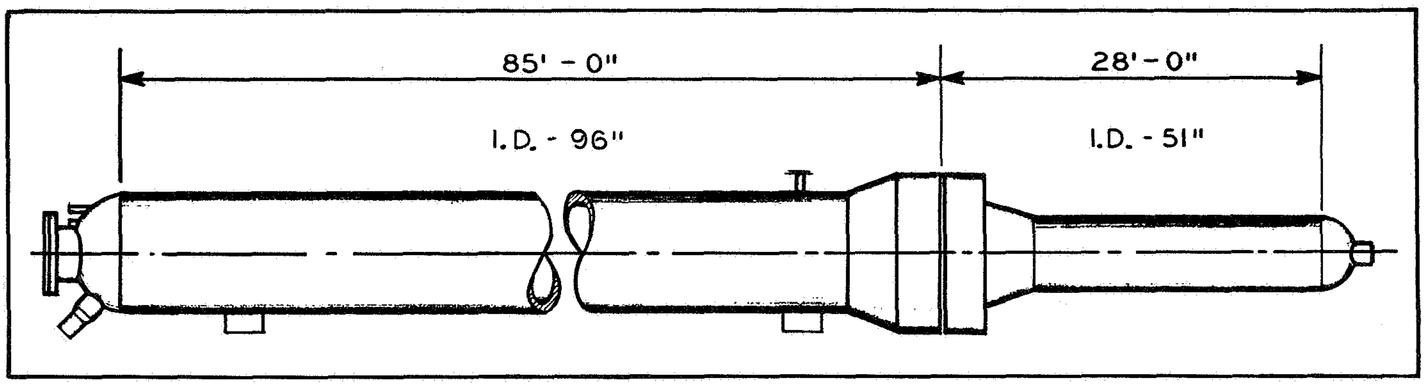



**Figure 4. Converter dimensions.**

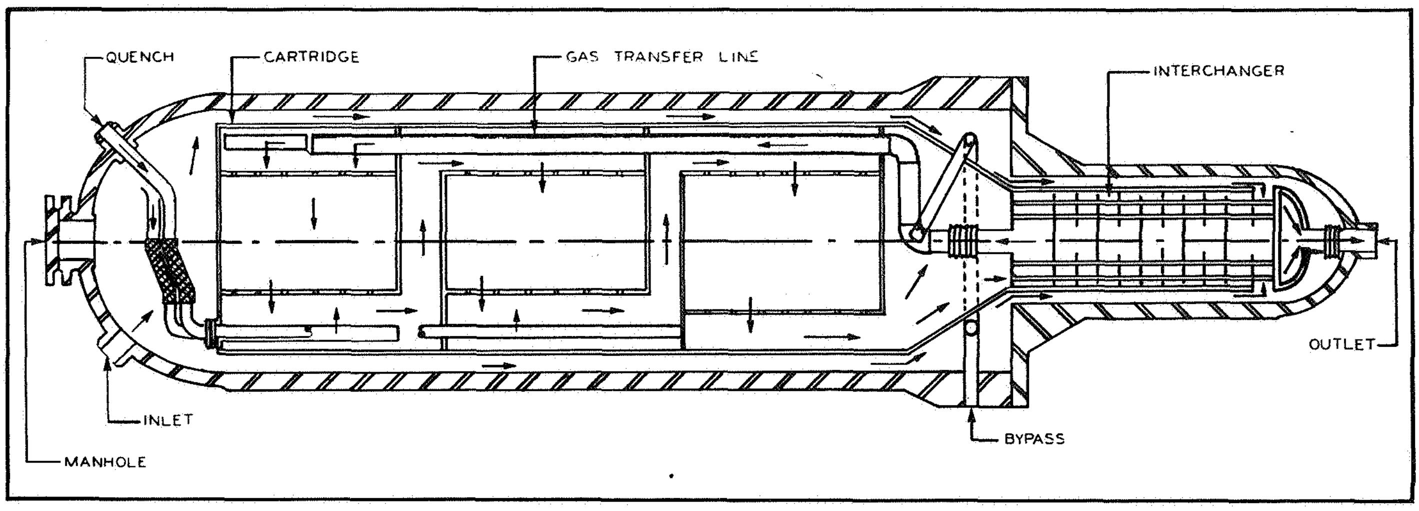



**Figure 5. Horizontal ammonia converter.**

quench or externally heated startup flow can be introduced to control the temperature of the reactants to the first bed.

The reactants flow through the gas transfer line to the first bed and are distributed over the catalyst. The reactants flow downward through the catalyst bed, then enter the space below each bed. Quench is distributed over the length of the bed and mixes with the reactants exiting the catalyst bed. The mixture then flows up through the passage provided between adjacent bed and is charged to the next bed of catalyst. Flow is continuous in a similar manner successively through each of the catalyst beds.

The effluent from the last bed is directed toward and flows through the tube side of the interchanger giving up heat to the reactants being charged to the first bed. The cooled product gases leave the reactor through the outlet nozzle.

In the heat exchanger, heat is exchanged between the hot gases leaving the last bed and the cooler feed gas prior to being charged to the first bed of catalyst. The exchanger is of a conventional design, using one-pass, countercurrent flow. Access to the exchanger is facilitated by locating it external to the basket, thereby permitting inspection and or repair without pulling the basket or removing any catalyst.

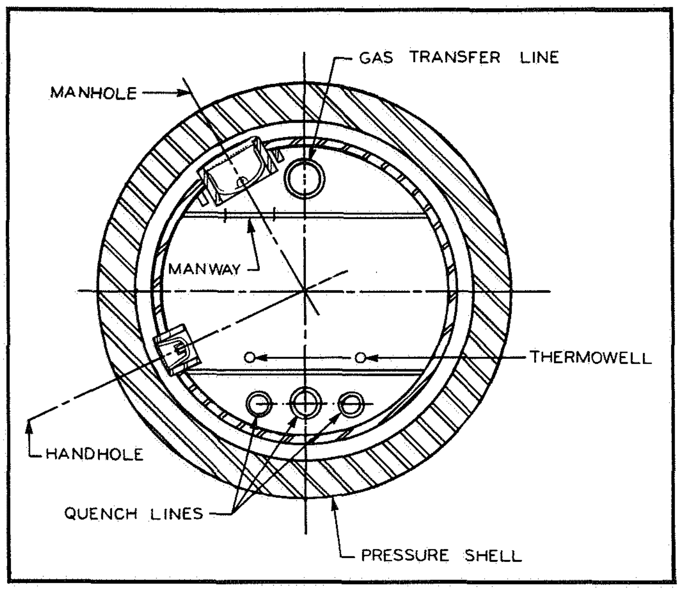



**Figure 6. Cross section of an ammonia converter.**

The horizontal slab type ammonia converter consists of a low pressure cartridge within a high pressure shell. The horizontal positioning of the converter permits easy installation and removal of the inner cartridge, including catalyst, without the use of heavy lifting equipment as is usually required of the conventional converters. The cartridge houses the catalyst and the internal heat exchanger. The catalyst within the cartridge is distributed among several beds spaced so as to permit passage of the reactants from one to another. The design contains three beds of catalyst. The number of beds is determined by the kinetics of the reaction and the linear pressure drop required for good distribution through the beds. A series of grids and screens located above and below the catalyst is used to distribute the flow of reactants to the catalyst, and to support the catalyst, respectively.

The disposition of the beds provides a larger catalyst bed cross section for gas flow than is normally possible in conventional reactors, which results in savings in total pressure drop and, therefore, horsepower requirements. This arrangement also permits the use of smaller sized catalysts than normally used with conventional designs. Smaller catalyst provides greater active surface area and permits the use of less catalyst volume which, in turn, permits a decrease in the size and total cost of the reactor.

Reasonably close temperature control of the reaction is required for optimum operating conditions. To control the catalyst bed temperatures, a quench system is provided to distribute relatively cold gas to each of the catalyst beds. For best distribution, individual quench lines are provided, Figure 6, to assure a positive method of temperature control. The quench is introduced into the effluent from all but the last bed. The areas below the beds and the space provided between adjacent beds provide more intimate mixing between quench and reactants than would be possible by introduction of the quench directly into the catalyst bed. In addition, a quench line is provided to the gas transfer line to control the temperature of the reactants to the first catalyst bed. This line also is used for the introduction of preheated feed gas for the catalyst reduction and/or startup cycles.

## Model study of gas distribution

With any catalyst bed configuration mal-distribution of reactants above the catalyst could result in a significant volume of catalyst not being adequately contacted by the reactants. Therefore, to make full use of the available catalyst good vapor distribution is essential. To

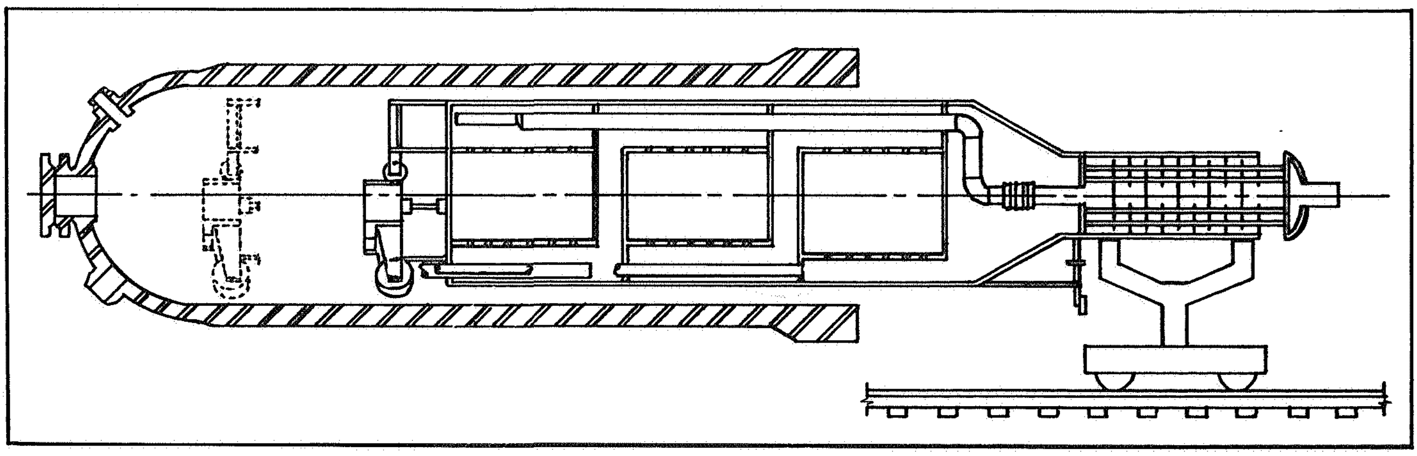


Figure 7. Insertion of catalyst basket into converter shell.

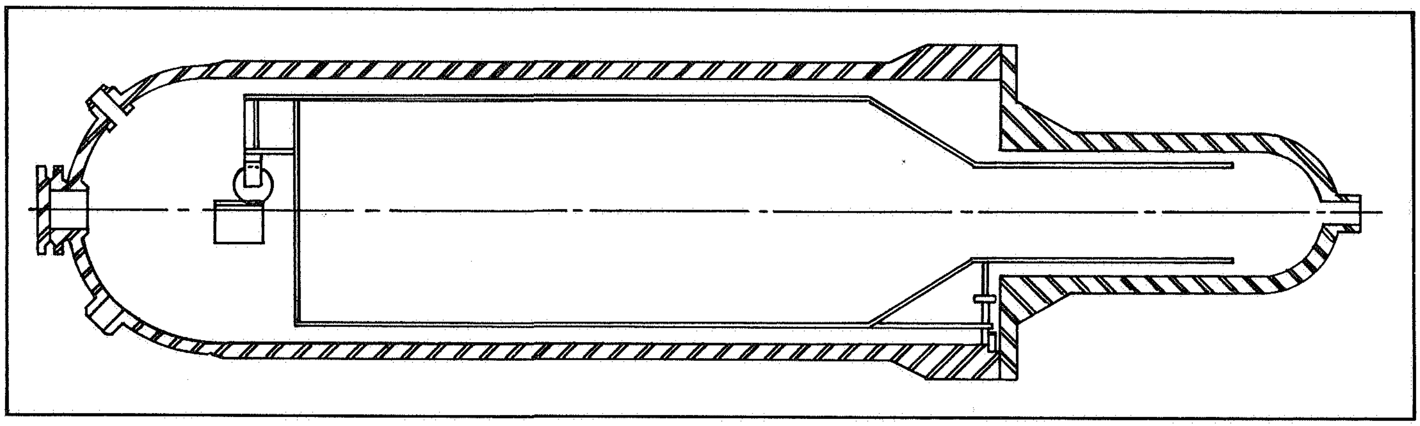
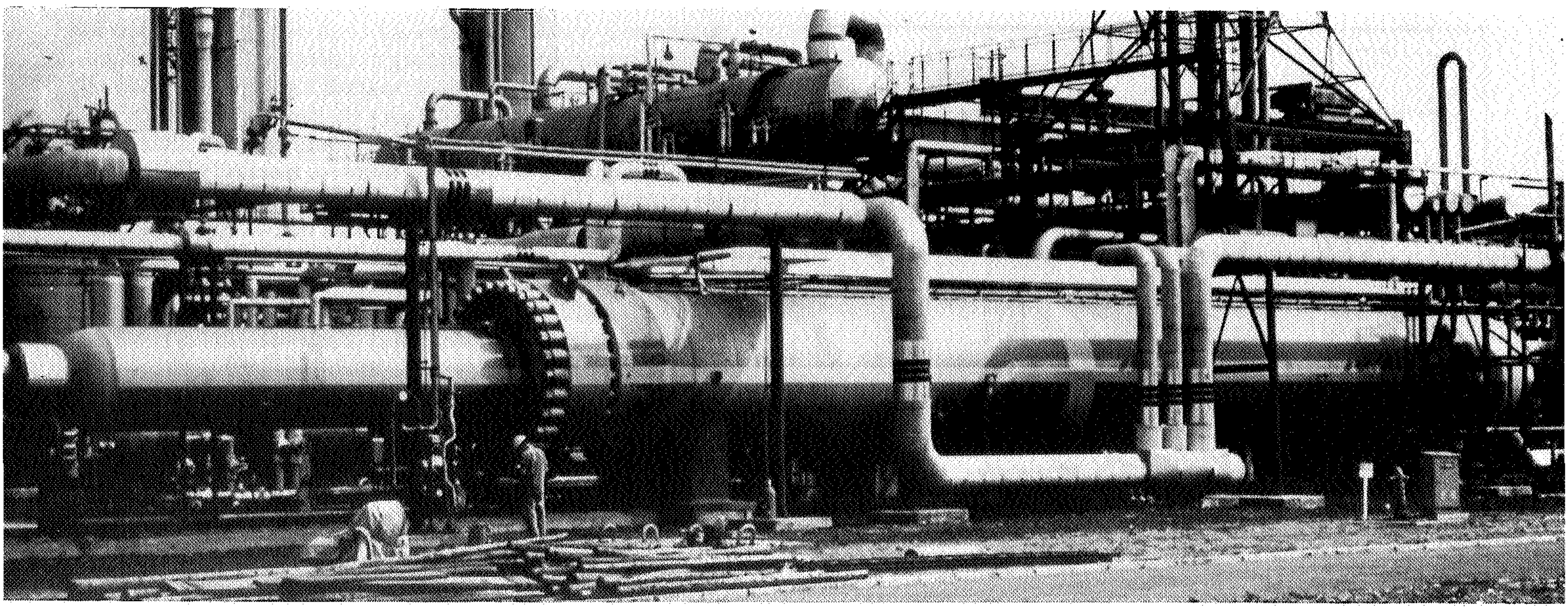


Figure 8. Two point basket support system in a horizontal ammonia converter.

achieve this, several designs were tested on a laboratory model. Of the designs tested, a distributor consisting of two parallel perforated plates, one atop the other and spaced about 1 in. apart, proved best. The holes in either plate are positioned in such a way that they do not overlap when viewed from above. To ensure good distribution during operation, the reactants are subjected to a pressure drop of about 1 lb./sq. in. across the top plate. The resultant high gas velocity is dissipated against the lower grid because of the hole positioning. The turbulence



The M.W. Kellogg horizontal ammonia converter.

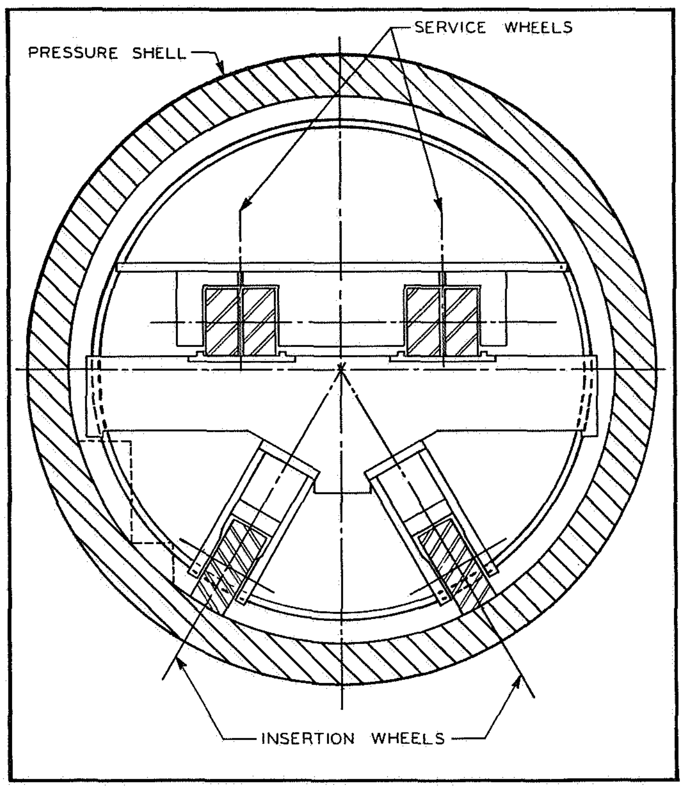



**Figure 9. Cross section of an ammonia converter showing the service and insertion wheels.**

caused and the space provided between plates helps to equalize the gas flow. The lower plate is designed to allow passage of the reactants at low gas velocities, since high gas velocities would tend to scatter the upper layers of catalyst causing depressions in the surface of the bed, as well as attrition of the catalyst. The double grid design accomplishes two design objectives:

1. Distribution of the reactants over the length and width of the catalyst bed
2. Minimization of movement in the upper layers of the catalyst

## Loading of catalyst

Prior to insertion of the basket and interchanger into the converter shell, catalyst is loaded into the basket compartments, Figure 7. During loading, one end of the basket is supported by the insertion wheels at the converter shell opening while the opposite end of the basket is supported by a trolley resting on railroad tracks. Access to the catalyst compartments is through several manholes in the basket and manways through the top head distributor grids. The bottom layer of catalyst, just above the supporting grid, is of a particle size larger than the openings in the metal screens to the laced grid. Successive layers of catalyst are usually of the smaller particle size permitting optimum usage of the available catalyst volume. The technique of using several layers permits installation of any particle size even if these particles used are smaller than the openings of the installed screens. The lower layers, approximately 6 in. deep, act as a support for the smaller particle catalyst.

Actual loading of the catalyst is conventional, and experience on an installation requiring approximately 2,000 cu. ft. of catalyst has shown that a realistic time of 50 hr. maximum would be required to load the basket. This time did not include preparation for loading.

After evaluating several basket support designs, we settled on a two point support system, Figure 8. When installed, the basket is supported on both ends. The fixed point is on the right of Figure 8 near the shell closure. This support rests in a groove of the pressure vessel shell preventing any axial movement at that point. The other end is supported on service wheels permitting free lateral expansion of the basket. During installation of the basket it is supported on a trolley and on two insertion wheels, Figure 7. With a cable the basket is then pulled into the converter shell, Figures 7 and 9. Once the basket has been fully inserted into the converter shell with the fixed support resting in its permanent position, hydraulic jacks are used to lift the cross bar and basket end. The insertion wheels are removed through the converter manhole, and the cross bar is then lowered onto a shelf on the pressure shell. The weight of the basket is now carried by the service wheels permitting free lateral movement due to differential thermal expansion between basket and pressure shell.

Actual experience with an insertion has shown that preparation will take approximately one day, while actual insertion was accomplished within an 8 hr. shift. The total weight of basket, interchanger, and catalyst was approximately 300 tons and a single pulley system with a force of approximately 5 tons was sufficient to move the basket into the pressure shell.

## Startup experience

Recently the first unit of this design was put in operation for the world's largest ammonia plant. Reduction of the ammonia synthesis catalyst required eight days. During early stages of reduction, some deformation of the converter shell was observed. This was attributed to insufficient coolant flow through the annular space between the pressure shell and inner cartridge. Uneven heating of the pressure shell resulted in the top side of the horizontal vessel being warmer than the bottom side. As reduction progressed and with increased coolant flow, the vessel returned to its initial shape.

Startup and early operating data have confirmed the design basis and have demonstrated the anticipated performance of this converter. #

## Literature cited

1. Exchenbrenner, G.P. and C.A. Honigsberg, U.S. Patent 3,475,136.
2. Axelrod, L.C., et al. U.S. Patent 3,567,404.
3. Quartulli, A.O., J.B. Fleming, and J.A. Finneran, *Hydrocarbon Process.* (November 1968).
4. Nielson, Anders, "Radial Flow Ammonia Converter," paper presented at AIChE 70th National Meeting, Atlantic City (May 16-19, 1971).

**G. P. Eschenbrenner** received his Diploma Engineer degree from the Technical University, Darmstadt, Germany, and his M.S.M.E. degree from Columbia University. He has attended Cambridge University and the Massachusetts Institute of Technology. At the M. W. Kellogg Co., he is responsible for the technical and administrative management of all organizations of the Civil-Mechanical Engineering Dept., which includes design disciplines for pressure vessels, heat exchangers, furnaces, specifications, civil engineering, piping mechanical and special areas. He has published various technical papers and articles in the field of pressure equipment analysis and design.

**G. A. Wagner III** received his B.S.Ch.E. from Manhattan College and is working towards an M.S.Ch.E. at New York University. At M. W. Kellogg Co. he is a process engineer with responsibilities for process design, evaluation and improvement of chemical facilities specifically ammonia, hydrogen, and methanol plants. He provides technical assistance to the other departments during all phases of the job including startup.

# DISCUSSION

**Q.** In this new design, although it's a short time in operation, have you had any trouble with the closure and what type of closure do you use for that large diameter?
**ESCHENBRENNER:** Double cone, with no problem.
**Q.** And in this design, do you have an insulation layer in the pressure shell?
**ESCHENBRENNER:** Yes, the removable basket is insulated.
**Q.** What type of insulation do you use?
**ESCHENBRENNER:** It is rock wool of either German or Canadian origin.
**Q.** Is this the type you have used in the past?
**ESCHENBRENNER:** Yes.
**Q.** With the same specifications?
**ESCHENBRENNER:** Yes.