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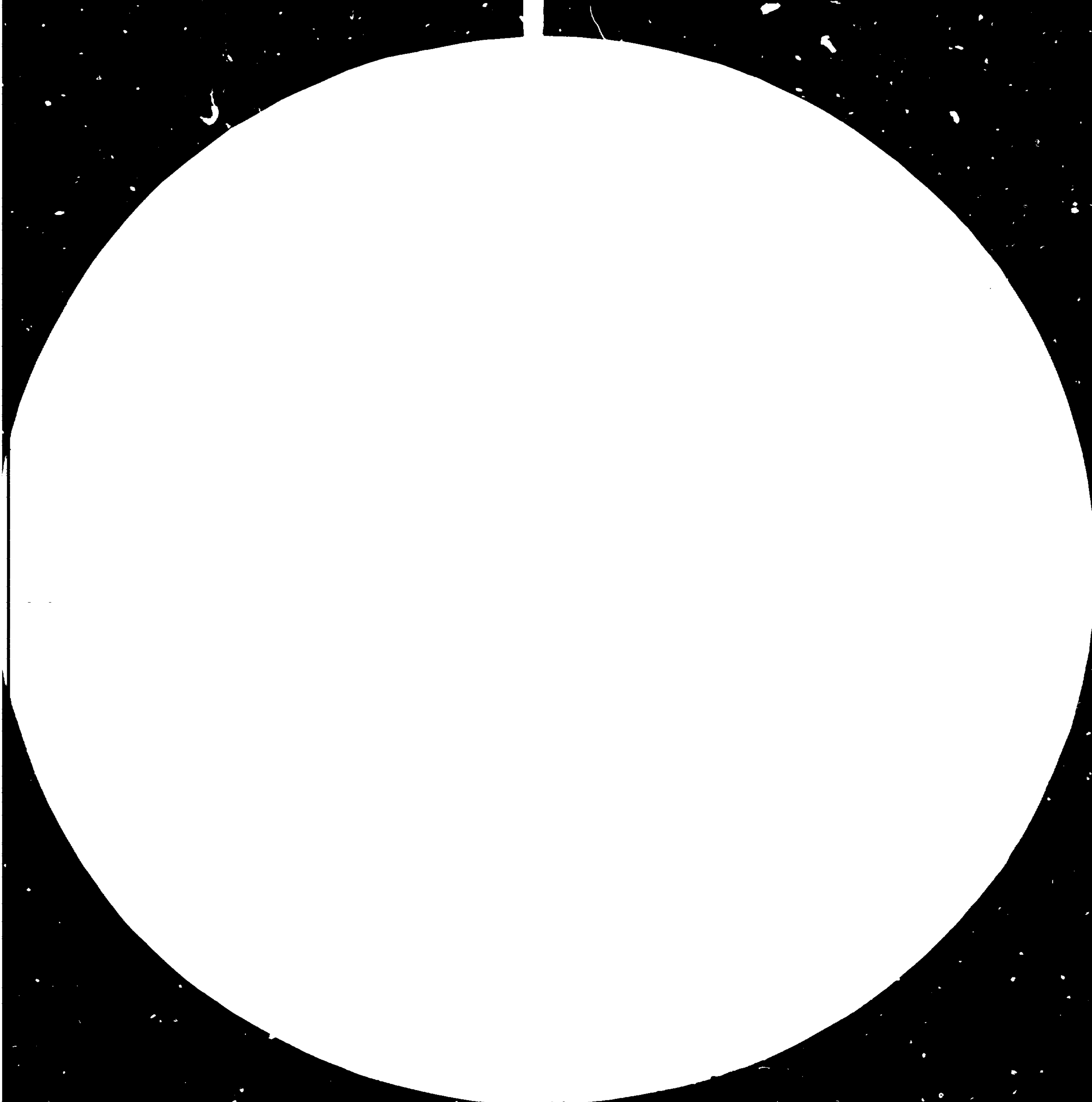

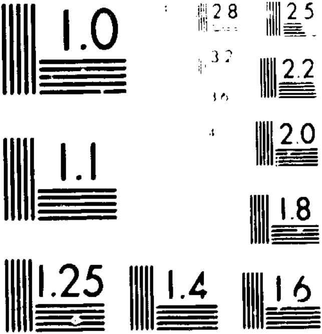

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STUDY ON THE STRUCTURE OF THE AMMONIA CONVERTER CARTRIDGE*

by

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ABSTRACT

This article has summarized and analyzed in six aspects the experimental data collected from the structure design and production experiences in the medium-and small-sized converter cartridges over the past two decades in China. It is recommended that the co-current two-bed converter cartridges with inner cooling/tubes be applied for medium-sized converters and co-current single tubular exchanger with spiral plates for small-sized converters.

1. General description:

The ammonia converter is one of the critical equipments for the production of ammonia and determines the production capacity, stability and reliability of operation of a synthetic ammonia plant. However, the main factor which determines the features of the converter is the internal cartridge structure.

Great changes have taken place in China over the past twenty years in the structure of ammonia converter (including the structures of the pressure vessels and cartridges). The dimensions for the pressure vessels have been gradually enlarged with the increasing requirements of production capacity.

Tab. 1 shows the development of the construction dimensions of ammonia converters in China.

Table 1. The development of the construction dimensions of ammonia converters in China

Years / Items	1958	1966	1974
Production capacity of ammonia T/D	85	200 - 260	500
Inside diameter of converter mm	800	1000	1600
Operating pressure kg/cm^2	320	320	320
Converter weight ton	65.7	80.3	168

The ammonia converter cartridges have been successively developed in China from a single type of co-current double tube into more than twenty types such as co-current three-fold tube, co-current single tube, radial-spiral bed with cooling plates and co-current two-bed cartridge with inner cooling tubes, etc.

We consider that a rational and matured design of an advanced ammonia converter cartridge should meet the following fundamental requirements:

1. The characteristics of catalysts should be fully brought into play so as to increase the ammonia production per unit of catalyst.

2. The stable operation and convenient adjustment are required to satisfy the changes of various operation conditions.

3. When the production capacity of catalyst is high, small pressure drop and low power consumption are required.

4. Better recovery of reaction heat and increase of economic efficiency.

5. Simple structure, reliable operation, easy maintenance and repair as well as convenient loading and unloading of catalysts.

A. Modification of the catalyst basket to enable the temperature profile of catalyst bed to approach the optimum temperature profile curve:

The type of catalyst bed is in principle divided into two groups: Group I uses a single continuous bed and Group II consists of several catalyst beds with devices for removing and controlling reaction heat between beds. The conventional types of catalyst baskets for Group I are co-current three-fold tubes and co-current single tube while the types of catalyst baskets for Group II are multi-bed quench and multi-bed indirect heat exchange between catalyst beds.

1) The co-current three-fold tubes:

The sturcture of the co-current three-fold tubes is shown in Figure 1. A thin inner lining tube is inserted in the inner cooling tube of the co-current double tubes to form a dead space between the tube walls. When the gas flows thru the inner lining tube, there will be nearly no temperature rise, but the temperature difference between the gas and catalyst beds will be increased, thus enhancing the cooling efficiency, making the temperature profile of catalyst bed better rational (For the details, see Fig.2) and bringing the catalyst activity into full play. The ammonia yield can increase by 5-10% by using the co-current three-fold tubes as compared with the co-current double tubes. A Ø800 ammonia converter with co-current three-fold tubes will bring us the ammonia yield over 170 t/d and catalyst production strength to 60 T/m^{3}d.

2) Multi-bed quench and multi-bed indirect heat exchange between catalyst beds:

The position of active zone of ammonia catalysts is moved downwards with the time of usage. It is difficult to make the temperature profile of catalyst bed to approach the optimum temperature profile by using the co-current single bed inner cooling structure. On the contrary it is feasible to make the working temperature of all catalyst beds to always approach the optimum temperature profile by adjusting the quench gas ratio if the multi-bed type is adopted.

B. Reduction of catalyst pressure drops for saving the circulating power and increasing the production capacity of equipment:

In general, the pressure drop thru the catalyst bed of the axial converter occupies approximately 60% of the whole converter pressure drop. Big pressure drop of catalyst bed will have an effect on the space velocity, yield and circulating power consumption. Therefore, efforts should be made to reduce the pressure drop of catalyst bed in design. Attention should be specially paid to the use of small particle catalysts.

Viewing from the various factors affecting the pressure drop of catalyst bed, the pressure drop of the catalyst bed is proportional to the flow length of fluid and inversely proportional to the square of the flow sectional area, to the 3-4 power of the void fraction of catalyst as well as to the 1-2nd power of the shape factor of catalyst. Therefore, the way of reducing the pressure drop of catalyst bed is to shorten the flow length, enlarge the flow sectional area, use the spherical catalysts and improve the loading method of catalysts.

1) Radial ammonia converter:

It is one of the most efficient means to use radial ammonia converter for the reduction of the pressure drop of catalyst bed. The gas flow velocity and flow length in the radial converter are smaller than those of the axial converter. For this reason even if the highly active catalysts with small particle size are used in the radial ammonia converter, the pressure drop of catalyst bed is still very small, thus obtaining the aim of increasing the production capacity and reducing the power consumption.

Figure 3 shows the catalyst basket with spiral cooling plates which has been adopted by us and which is rolled with two thin metal sheets with a certain space in between the two walls in which the cold gas flows and has a heat exchange with the reaction gas from outer shell.

The practice has proved that the pressure drop in the radial ammonia converter with spiral cooling plates is reduced 50% and more as compared with that of axial ammonia converter. If a ∅800 radial ammonia converter with spiral cooling plates is put into operation, the ammonia production capacity will be raised up over 200 tons and the catalyst production strength brought to 74 t/m^3d.

2) Co-current two-bed converter:

The other means to reduce the pressure drop of catalyst bed is to use the co-current two-bed converter. The schematic Figure 4 shows that the catalyst layer is divided into two beds. The gas flows co-currently thru the catalyst beds to make the flow path and flow velocity half of the original ones respectively, and the pressure drop 1/8 of the original one.

Take the Ø1000mm ammonia converter for example: The original converter is one-bed co-current single tube converter cartridge with an ammonia daily production of 240 t/d. After the co-current two-bed inner cooling converter cartridge is adopted, the highest and lowest capacities have reached 330 t/d and over 300 t/d respectively and the converter has been put into operation for three years. As the pressure drop of catalyst bed is considerably reduced, the pressure drop of the whole converter will be also reduced about 6kg/cm^2 accordingly. This means 15kwh/TNH_3 of compression power of the circulating compressor will be saved.

3) Spherical catalyst and improvements on loading and unloading of catalysts:

The pressure drop of catalyst bed is reduced by using spherical catalysts. The improvement of catalyst charging can avoid the crushing of catalysts and increase the void fraction of the bottom-bed catalysts. Since the above two methods were adopted, the power consumption per ton of ammonia has been reduced 9 kwh as compared with the original figure.

C. Recovery of reaction heat for the increase of economic efficiency:

The reaction heat of ammonia synthesis amounts to about 13000 Kcal/kg mol., which is normally carried away by the outlet convertor gas. The said heat needs to be removed by cooling water, thus wasting a lot of heat energy and power consumed by cooling water. A rational design should make full use of this reaction heat. In general, the production of by-product steam is required for this purpose. The by-product steam is classified into two types: 1) steam generated inside the converter and 2) steam generated outside the converter. What we utilized is the latter, which can be further classified into three types: 1) front-position type 2) middle-position type and 3) rear-position type (see Table 5 and Table 6). The comparison of the three types of by-product steam generated outside the converter is shown in Table 5.

Table 2. Comparison of the Three Types of By-product Steam of Converters

Type Item	Rear-position type	Middle-position type	Front-position type
Boiler inlet gas temp. °C	200-230	370-380	450-480
By-product steam pressure	4	13-15	25-40
Steam generated per ton of ammonia T	0.5	0.8	0.7-0.9
Average temp. of heat exchanger inside converter	high	lower	low
Heat transfer area of heat exchanger inside converter F	small	bigger	bigger than that of middle-position type
Utilization rate of converter volume	high	low	lower
Construction	simple	more complicated	simpler
Average temp. of steam boiler ΔT m	low	higher	high
Heat transfer area F	big	smaller	small
Requirements for the quality of construction material	The temp. of outlet converter gas is high. specific requirement should be made for construction material.	The temp. of outlet converter gas is comparatively high. The material required should be resistant to hydrogen attack and high temperature.	Resistance to high temp., hydrogen attack and nitridation because of high outlet converter temperature.

The Table 2 shows that the middle-position structure converter produces medium pressure steam, which is suitable to and required by the system, and a comparatively large amount of by-product steam. Furthermore, the equipment and material are easily obtained, suiting the production of medium-and small-sized ammonia plants. The by-product steam generated in a medium-sized ammonia plant can be used for the urea unit while the by-product steam generated in a small-sized ammonia plant can be utilized in the high temperature conversion section.

In case the operating pressure is 300kg/cm^2, the medium-position structure converter will generate 0.8 ton of by-product steam (13kg/cm^2). It can save 42T/T NH_3 of recirculation water and 44kwh/TNH_3 of electricity as compared with the ammonia systhesis system without by-product steam. If the Ø1000 ammonia converter with a middle-position boiler is used for production of by-product steam, the heat transfer area of the boiler is 7m^2, with a recovery of over 0.7 ton of steam (13kg/cm^2).

D. Adoption of High Efficient Heat Exchanger for Improvement of the Coefficient of Catalyst Volume:

The adoption of high efficient heat exchanger can reduce the volume occupied by the heat exchanger, diminish the height of high pressure vessel for a newly designed ammonia converter and load more catalysts for a conventional converter, thus further increasing the output. For instance, after the change of the heat exchanger of the Ø500mm ammonia converter from the tubular type into spiral plate type, the charging capacity of catalysts has been increased from 0.46m^3 to 0.65-0.67m^3 and the production capacity increased from 27t/d to 34-40t/d.

The main types of heat exchangers used at present are tubular heat exchanger type and spiral plate type.

1) Tubular heat exchanger:

The tubular heat exchangers have been widely used in ammonia converters because they are subjected to a comparatively big pressure difference, easy for cleaning, matured in manufacture technology and small pressure drop, etc. But its transfer heat coefficient is comparatively is low.

The main methods to increase the capacity of the tubular heat exchangers are as follows:

reduction of tube diameter,
insertion of twisted bars inside the tubes,
compact arqangement of tubes,
change of the space between the baffles,
reduction of axial leakage, and
increase of heat transfer coefficient.

For examplo, the Table 3 shows the comprison of the heat exchangers of the Ø800mm ammonia converter before and after modification.

Table 3. Comparison between the heat exchangers of the Ø800mm ammonia converter before and after modification

Item	Operating pressure	Volume of catalyst charged	Tube specification	Height of heat exchanger	Number of tubes	Heat transfer coefficient
Unit	kg/cm^2	m^3	mm	mm	pieces	Kcal/m^{2}hr$^\circ$C
Before modification	320	2.33	Ø14x2	3722	960	450
After modification	320	2.8	Ø10x15	2252	2242	580

2) Spiral plate type heat exchanger:

The spiral plate type heat exchanger is a high efficient heat exchanger (see Fig. 7). It is rolled up with two flat plates, constituting two passages in which the fluids exchange heat with each other respectively.

The gas flow direction is mentioned below:

The cold gas flows in from the outer shell, circulates semi-circularly into the spiral plates and then flows out from the central tube. The hot gas enters from the opening of the top spiral plate, whils counter-currently with the cold gas and then whirls out from the bottom opening of the spiral plate. The cold gas directly enters the catalyst basket from the bottom of by-pass and bypasses the spiral plate. The advantages of the spiral plate type in comparison with those of the tubular type are as follows:

1) High heat transfer efficiency: The heat transfer coefficient of the spiral plate type heat exchanger is ranged from 800 to 1000 Kcal/m^{2}hr.°C.

2) The temperature difference is big due to full counter-current, facilitating the heat transfer and recovery of low temperature heat.

3) Compact structure, simple manufacture, material save and low price.

For example, the Table 4 shows the comparison between the tubular type and spiral plate type of the Ø600mm ammonia converter.

Table 4. Comparison between the tubular type and spiral plate type of the Ø600mm converter heat exchanger:

Item / Type	Heat transfer area	Dimension	Heat transfer coefficient	Weight of material
	m^2	mm	$Kcal/m^2hr^{\circ}C$	T
Tubular type with the tube Ø14x2	35	Ø580 x 1200	600	0.8
Spiral plate type	18.40	Ø580 x 800	900	0.6

Its disadvantage lies in big pressure drop and is not subjected to too big pressure difference and more difficult in repair and maintenance.

E. Reduction of the temperature difference of the catalyst bed on the horizontal level for the increase of the ammonia concentration differential:

The temperature difference on the horizontal level on the catalyst bed is not considered in design calculation in general. Actually, the temperature difference between the radial level and horizontal level exists in the catalyst beds of axial converter. There are many facters affecting the temperature difference of the catalyst bed on the horizontal level, mainly two factors: 1) The ununiform gas distribution causes the ununiformity of the reaction rate and the heat released from the reaction on the cross section perpendicular to the gas flow direction; 2) On account of the catalyst beds of some of the converters inlaid with cooling tubes, the trouble of radial heat transfer and radial temperature gradient were caused.

The reduction of the temperature difference of the catalyst bed on the horizontal level enables the gas to react under a suitable temperature which promotes the ammonia concentration differential. The methods adopted are: 1) a rational design of gas distribution structure and a uniform charging of catalysts; 2) adoption of multi-bed adiabatic structure. For instance, the converter with the heat exchanged between axial and radial catalyst beds was formerly used in China. As compared with the cooling tube type converter of the same specification, the former can reach 15% of the ammonia concentration differential under the conditions of 300 kg/cm^2 and 24000 $hr.^{-1}$ while the latter can only reach 12% under the same conditions. When the latter is used, the multi-tube uniform distribution method will be adopted for the reduction of the temperature difference on the horizontal level of the catalyst bed of radial direction. For instance, the adoption of the co-current single tube construction is shown in Fig. 8.

F. Simplification of the structure for promotion of the reliability of the ammonia converter operation:

The operation reliability is the basic requirement for the design of an internal cartridge. The equipment should be stably operated as long as possible. The most important factors to guarantee the reliability of the mechanical structure require simple structure and less key parts. The main measures adopted are as follows:

1. The suitable connections between parts are required in order to avoid causing of hot stress. Furthermore, the emphasis should be put on the solution of free expansion of the converter cartridge. For instance, the double casing tube is commonly used in the structure of thermocouple well. The welding of the thermocouple well to the top cover has been changed into the stuffing box structure, which has been proved in practice for many years to be quite efficient in operation.

2. The material of parts should be rationally

selected. The material of construction should be properly selected according to its high temperature-resistant and hydrogen attack-resistant characterristics. Care should be taken for the effects on hydrogen attack. For instance, 1Cr18Ni9Ti is generally used for the middle-position by-product steam boilers.

3. The by-product steam coils have been moved to the outside of the converter with no cooling coils installed inside the converter.

4. Simplification of the structure of the cooling catalyst bed.

Conclusion

To summarize the above factors of effect, it is recommended that different types of converter cartridges may be used for the converters with different capacities. The details are as follows:

1) Co-current two-bed converter cartridges with inner cooling tubes applied for medium-sized converters:

The medium-sized converters may select axial flow co-current two-bed inner cooling type structure which has the advantages of low pressure drop, high yield of single converter, low power consumption of gas circulation, stable production and easy manufacture and installation of cartridges.

2. Co-current single tubular exchanger with spiral plates used for small-sized converters:

The small ammonia converter has the advantages of small diameter, high pressure drop and short production and operation period. Therefore, the converter cartridge which is simple in structure and comparatively approaches the optimum temperature profile may be used for small-sized ammonia converters. The co-current single tube spiral plate type structure can fundamentally meet the above requirements.

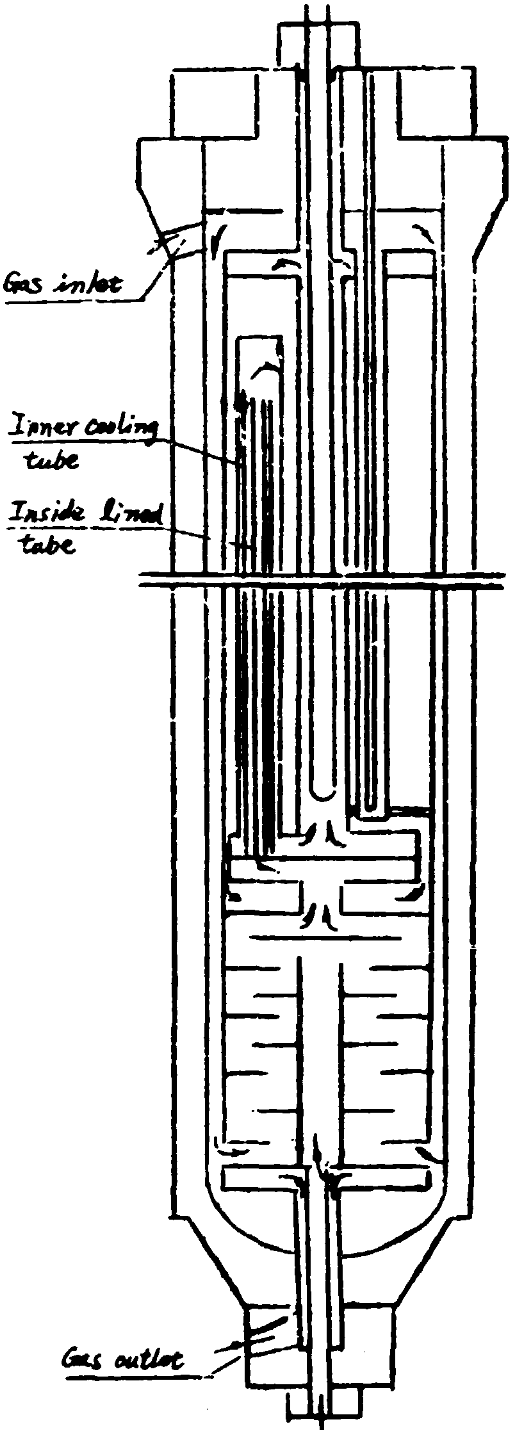


Fig 1.Co-current,Triple-tube Ammonia Converter

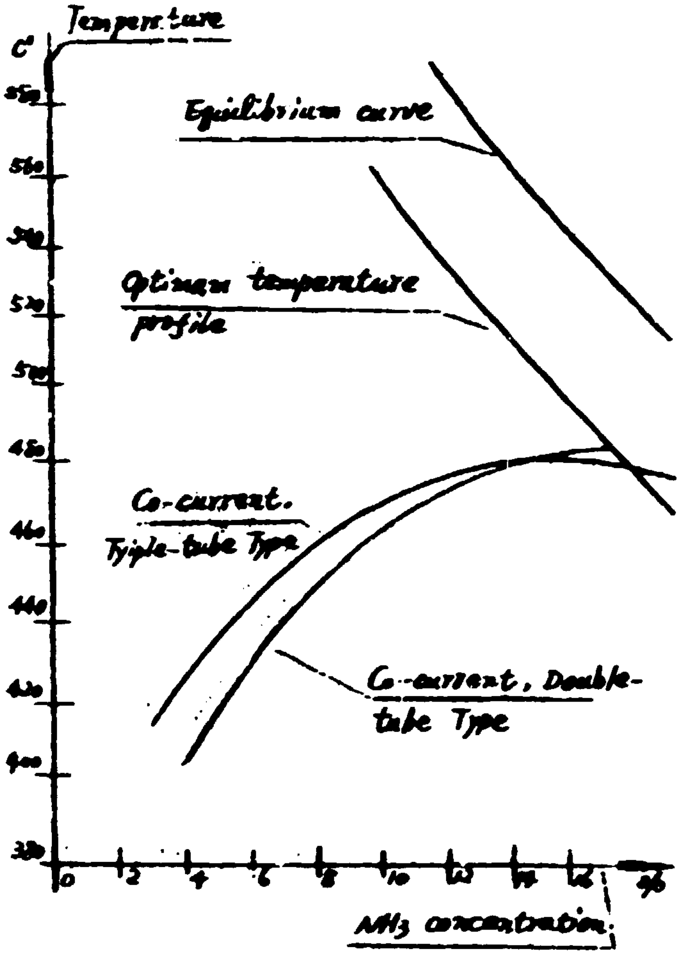


Fig 2.The Temperature Profile of Catalyst Beds of Co-current Double-tube and Co-current Triple-tube Type.

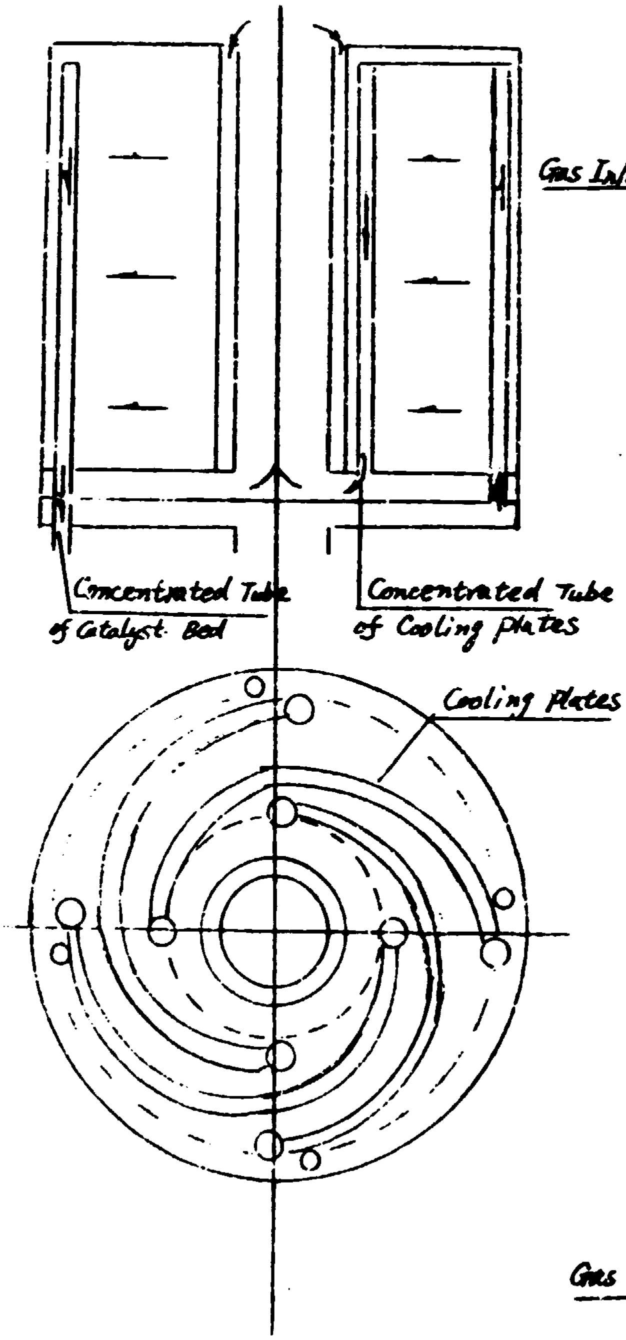


Fig 3. Catalyst Basket With Radial Spiral Cooling Plates

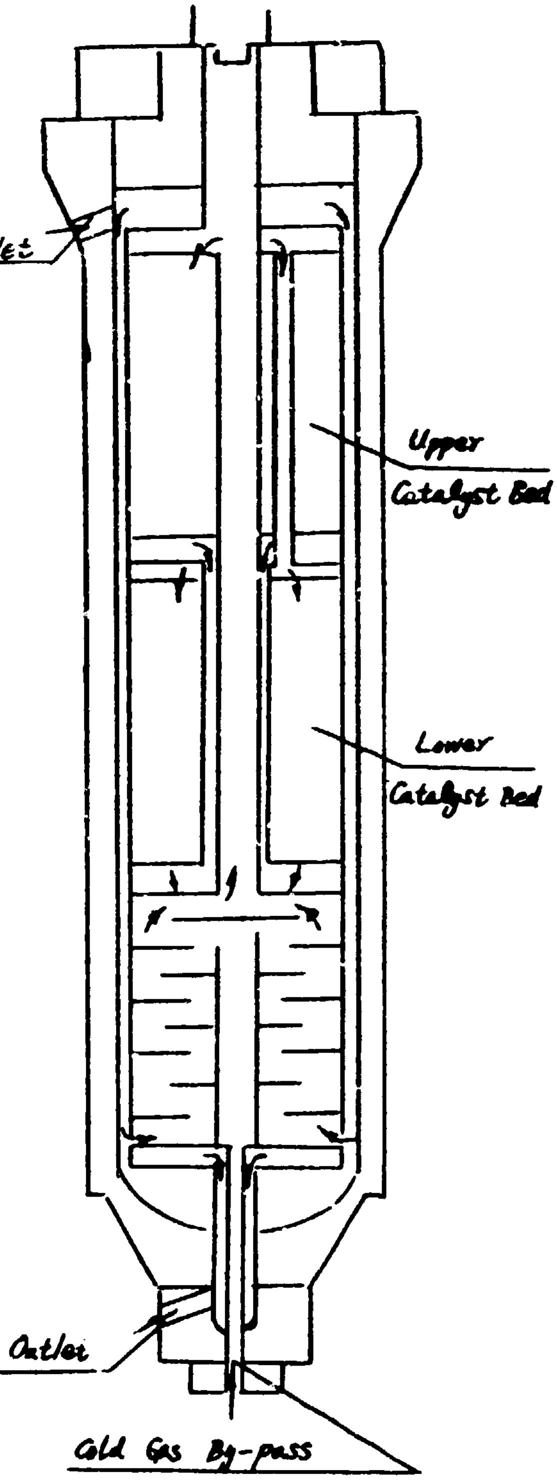
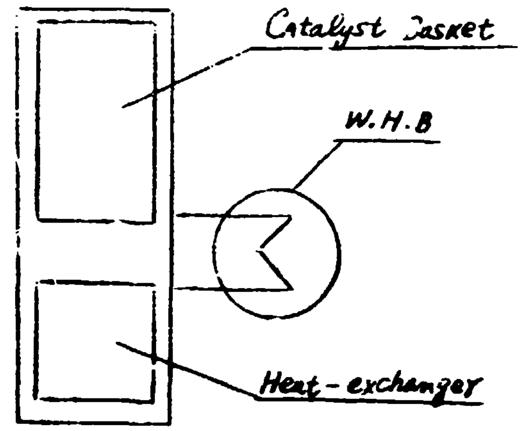
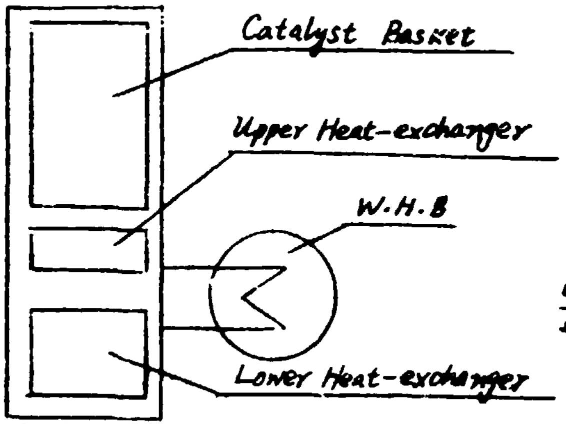


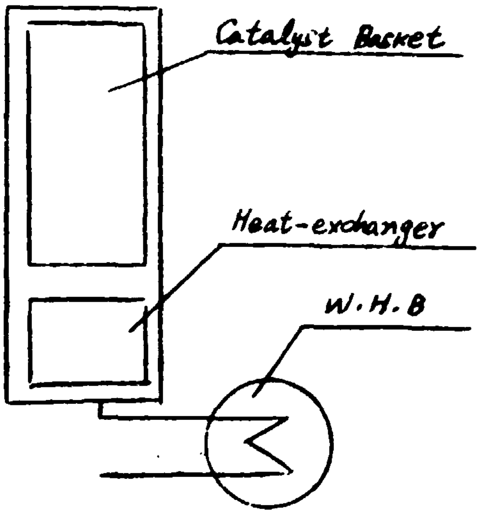
Fig 4. Co-current, Two-bed Ammonia Converter



A. "Farward" Type



B. "Intermediate" Type



C. "Backward" Type

Fig 5. Converter with External -By-Product steam

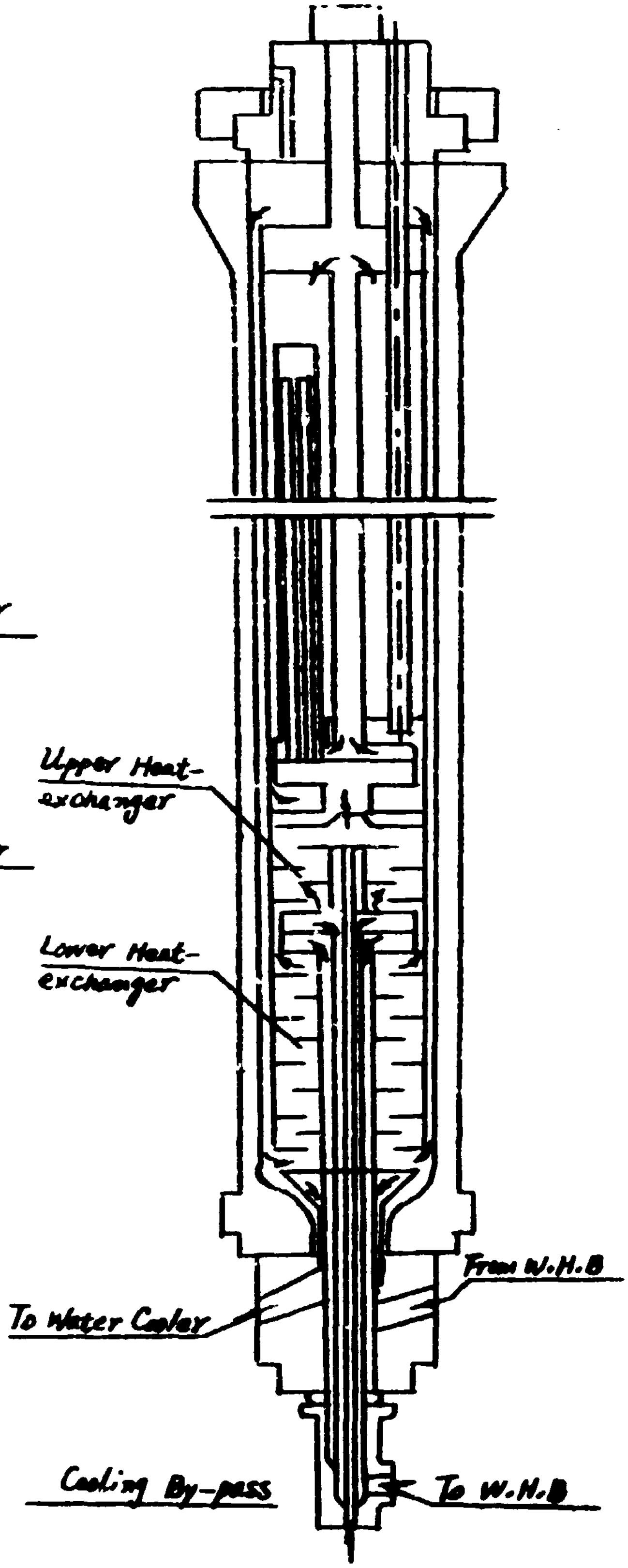


Fig 6. "Intermediate"Type Converter with By-product steam

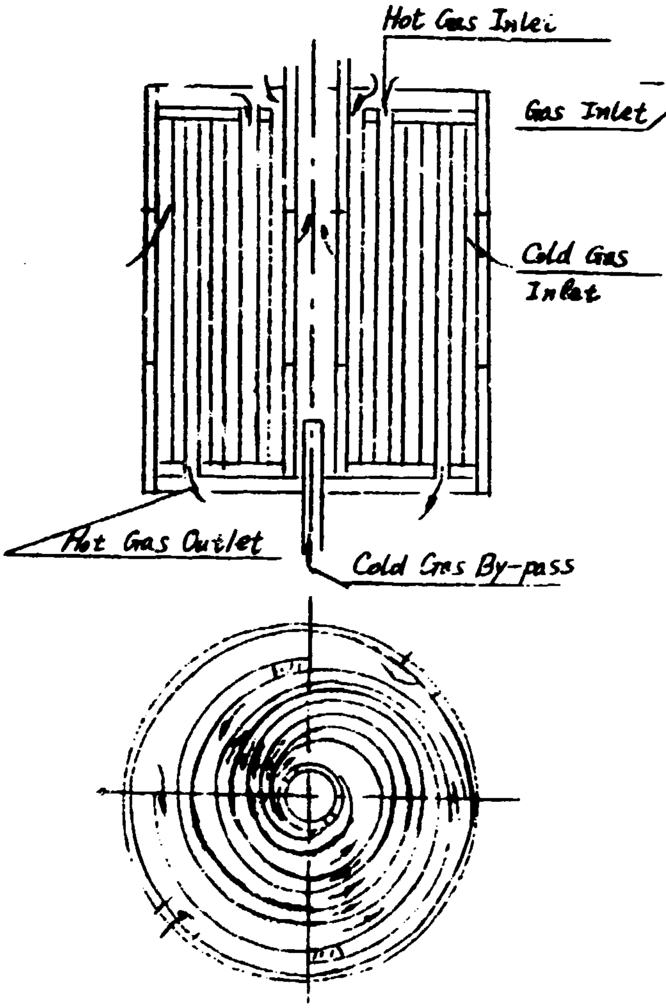


Fig 7. Heat-exchanger with Spiral Plate

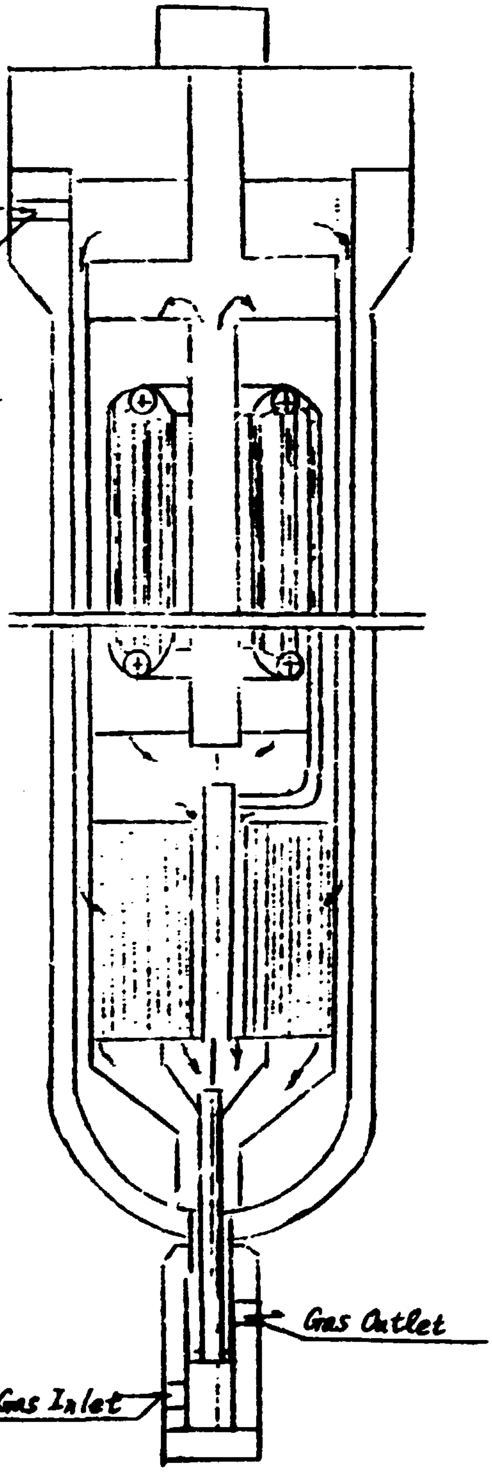


Fig 8. Co-current, Single-tube Ammonia Converter