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ENERGY SAVING AND CAPACITY INCREASE RETROFIT FOR A LARGE-SCALE AMMONIA PLANT

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1. INTRODUCTION

The ammonia installation of Guizhou Chitianhua Group Co., Ltd. in China was imported from KELLOGG , USA in 1974 and put into operation in October 1978. Its original design capacity was 300,000 tons per year. By the end of 2002, the ammonia output added up to 7.08 million tons for the last 24 years.

With the global energy supply tightening and its price rising, chemical fertilizer research and design companies all over the world have put forward new energy saving technologies one after another, which have been used either in new plants or in old plants' retrofit.

After careful investigations and studies, Chitianhua put forward its energy saving and capacity increase retrofit scheme after obtaining loan support from Asia Development Bank. Chitianhua successfully carried out the energy saving and capacity increase retrofit for its ammonia plant in 1990's.

2. PURPOSE OF THE REVAMPING

The revamping project aimed at an integrated renovation of energy saving, capacity increase and environment protection. Through systematic analysis to find out the bottle-neck, taking the world up-to-date ammonia synthesis technology progress into account, and under the principle of gaining maximum profit with minimum investment, we set our revamping target as to increase ammonia output by 22% to make the daily output reach to 1,220 tons, or 366,000 tons annually; to reduce the energy consumption of ammonia to 34.5 GJ per ton in order by increasing the capacity substantially while basically maintaining the same amount of natural gas consumption; and to drastically clear up the emission to environment by the process condensate discharged from the production equipments by paying close attention to the environment emission in our revamping scheme.

3. FEATURES OF THE PROJECT

During the technology study period, we realised that by entrusting the project to a general foreign engineering contractor, it would have the features of clear responsibility and high probability of successful renovation, but such a scheme would not be the best integration due to various reasons, including the non-incorporation of equipments made in our country. By comparing the various technologies, selection of advanced and matured individual technology from home and abroad, and either by independent or cooperative development for the deficiencies, the engineers and technicians of

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Chitianhua figured out the renovation scheme independently to realize the best integration, and finally obtained remarkable results.

The renovation scheme of Chitianhua has the following features:

Combining energy saving with capacity increase and fully tapping the latent capacity of technological renovation

The technological renovation of Chitianhua adopted the approach of combining energy saving with capacity increase, i.e. to make full use of the energy saved to increase the output ,thus saving energy per unit output. The effect of energy saving should be strived for the highest level, and the capacity increase would be determined by the bottle–neck and natural gas balance. The final result was that the capacity has been increased by 22%, i.e. 66,000 tons of increased synthesis ammonia per year. Renovation of combining energy saving with capacity increase can result in better economic benefit.

Combining hardware with software and striving for the most reasonable investment return

Energy saving renovation could neither be effectively realized by simply changing some equipments, nor could capacity renovation be increased simply by building paratactic small installations. The renovation goal of both energy saving and capacity increasing, however, must be comprehensively achieved by full software development according to the necessary hardware. For example, the primary reformer was required to increase its capacity substantially. It was not realized merely by increasing the pipelines, which was very complicated and difficult, but by transferring the primary reformer load to the secondary reformer, achieving both energy saving and capacity increasing. To prevent the secondary reformer from bringing the problem of removing the surplus nitrogen by the subsequent process arising from using surplus air converting, the secondary reformer adopted rich oxygen reforming technology. By building a new VPSA-O_2 installation of 1,000 Nm^3/h, the difficult problem of capacity increase of the primary reformer was solved. This was the combination of hardware (rich oxygen equipment etc.) with software (transferring the reforming load to the subsequent). Another example is that, after de-carbonization system was renovated by energy saving technology, the residual heat could not be used up any longer. The process method of reducing hydro-carbon ratio of reforming was then adopted to make the amount of the residual heat brought by the reforming gas match the new energy consumption of the de-carbonization system. The equipment for residual heat recovery was then omitted, and the process steam saved was therefore just the energy saved.

Combining advancement with reliability and striving for optimized renovation effect

Since the plant over ten years old, it was extremely difficult to achieve the energy consumption level of new installation by renovation, but to which we should try our best to approach. Therefore, during scheme selection, we tried to choose the world up-to-date technologies with full consideration of the project reliability. Among the technologies we chose, some were used for the first time in the renovation for old large-scale plants in China or even in the world. But for such technologies, they have been mature in new large-scale plants or medium or small plants. For example, the load transferring from the primary reformer to the secondary reformer, ICI Process and Boolean Process have been successfully used before, but they were used for the surplus air conversion in the secondary reformer, the residual nitrogen still must be separated in the subsequent process. For rich oxygen conversion in the secondary reformer, although it has been used and appraised in several small plants in China, but the capacity of rich oxygen produced is smaller. For the residual heat recovery in the primary reformer, many companies used it to preheat the combustion air in the primary reformer. As a result, the primary reformer has changed a lot, with longer time limit , thus worsening the operation condition on top of the reformer, and especially it had too close a relationship with the primary reformer. On the other hand, we used this residual heat to heat up two flows of process condensate from urea and ammonia battery limit, and installed natural gas saturation wetting unit to completely clear up the pollution to environment by the process condensate and recover energy and useful materials. Its energy saving effect is equal to that of air preheating method. The saturation technology has been used in many plants at home and abroad, the only differences were heating source and media.

Combining production development with environment protection and benefiting the society.

In the revamping scheme of Chitianhua, great efforts were devoted to environment protection. After the renovation, although the output has been increased, the emission to environment by the installation has been greatly reduced.

By means of the saturation wetting system, natural gas would strip away the pollutants (which were useful materials for production) in the waste water of the process, and the waste water could be recovered for the high pressure boiler as make-up water, thus achieving the level of zero discharge of the process waste water.

In addition, carbon dioxide in the flue gas was also recovered as raw material for urea production, thus making use of a waste material and greatly reduced carbon dioxide discharge. And by means of recovery of hydrogen in the purge gas, the ammonia content in the fuel gas was greatly reduced, therefore nitrogen oxide content in the flue gas was also reduced.

4. MAJOR ITEMS IN THE RENOVATION

The major items in the renovation of energy saving and capacity increasing for ammonia plant include:

1. Added an inlet ammonia cooler to the feed gas compressor to meet the requirement of capacity increasing without any renovation to the compressor and the drive turbine.
2. Added a saturation wetting system between the lower stream of the desulfurization system and the upper stream of the mixed gas preheating coil pipe to recover the residual heat in the flue gas from the primary reformer.
3. Reduced the water-carbon ratio in the conversion process as well as the conversion ratio in the primary reformer, and rich oxygen conversion method was used in the secondary reformer. Added a domestically made rich oxygen installation of VPSA technology.

4. Both high and low temperature shift converters were changed from axial flow to axial-radial flow.
5. The decarbonization system was revamped by independently-developed rich solution cooling technology. It could reduce the energy consumption in decarbonization on the one hand, made water balanced in the decarbonization system, and discharged no condensate on the other. The energy saving renovation for the decarbonization system matched low water-carbon ratio conversion technology.
6. Added an inlet ammonia cooler for the synthesis gas compressor after methanation to reduce the compressor's power consumption.
7. Added a molecular sieve drier after the ammonia cooler interconnected the synthesis gas compressor stages to remove oxygen contained compound from the fresh gas.
8. The synthesis loop flow was changed from the ammonia separation before the converter to that after the converter. Hot ammonia was transferred by the desorbed gas pressure, so the hot ammonia pump was omitted.
9. Hydrogen in the purge gas was recovered by cryogenic separation technology.
10. The rotors and internals within both the air compressor and synthesis gas compressor were renovated for the purpose of energy saving and capacity increase The high pressure steam turbine to drive the synthesis gas compressor was renovated to increase the efficiency, the rotor was changed from two stages to three stages, and the temperature of the high pressure steam was increased.

5. INTRODUCTION TO KEY TECHNOLOGIES

The natural gas wetting system with unique characteristics (see Fig.1)

The natural gas wetting system based on hydrolysis tower for urea process condensate and natural gas saturation tower is an unique technology developed by Chitianhua. It recovers the waste heat from the flue gas of the primary reformer, heats two flows of process condensate from both urea and ammonia plant, then goes through the natural gas wetting system. It can save 14 tons/hour of process steam of 3.8 MPa. It saves another 4 tons/hour of medium pressure steam by utilizing the residual heat of the flue gas to hydrolyze urea in the condensate (There is no hydrolysis installation built for urea plant any more). The stripper recovers ammonia, methanol and other useful materials as production material on the one hand, and puts an end to discharge condensate to protect the environment on the other, and recovers 90 tons/hour of process condensate as boiler feed water as well. The project combines energy saving and environment protection as a whole, and has a very good economic benefit. Furthermore, it keeps the operation condition on top of the primary reformer not to be worsened, and leaves space for further renovation in adopting gas turbine to drive air compressor and lean gas as combustion-aid air for the primary reformer.

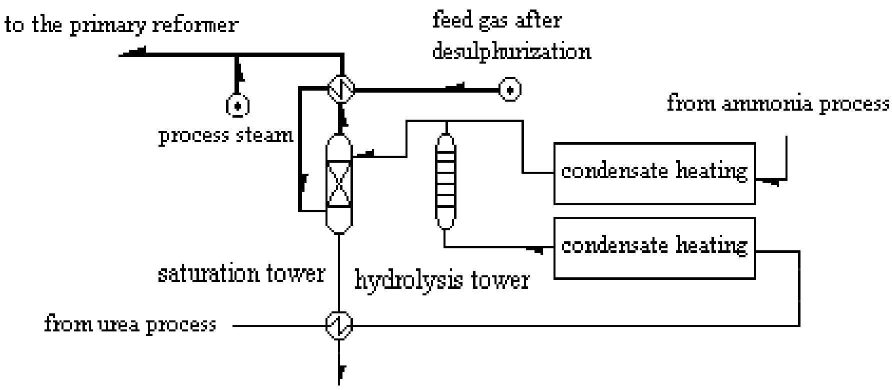


Fig.1 The flow diagram of the natural gas saturation humidification system

Axial-Radial flow shift Converter First Operated in the World (.see Fig.2)

Axial-radial flow reactor technology was used for the first in the world, in the high and low temperature shift converter. Before the renovation of the shift converter, the process gas went axially through the catalyst bed. However, after renovation, the gas goes axially and radially through the catalyst bed, the catalyst granule size was reduced to 3x5mm, and the conversion efficiency was therefore increased.

Under the condition of smaller sized catalyst granules and larger amount of gas, by changing the flow mode, fluid resistance can still be reduced by 0.01MPa, and as the pressure drop increases slowly, the catalyst service life lasts longer as well. The catalyst lasted as long as 6 years even though it was accidentally dipped in water when the project started, the service life of the catalyst in low temperature shift converter also increased from 2 years to 4 years.

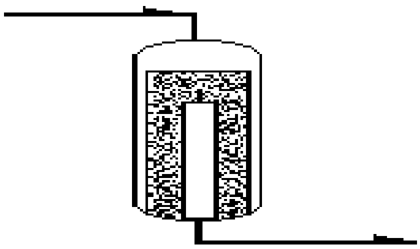


Fig.2 Axial-radial flow shift converter

Independently Developed De-carbonization Process of Low Energy Consumption (see Fig.3)

As to the renovation of de-carbonization system for energy saving purpose, we did not intend to import the patented 4 stages flashing technology which would cost large amount of foreign exchange, but successfully and independently developed rich solution cooling process.

The core of the rich solution cooling process lies in the usage of the rich solution to heat the boiling return water to produce atmospheric pressure steam and using of the residual heat of the process gas to produce low pressure drive steam. The atmospheric pressure steam, after being boosted by ejection of driving steam, shall enter into the regenerator along with all the others as the regeneration heat source. It is different from that of multi-stage flashing technology in approach but with equally satisfactory results.

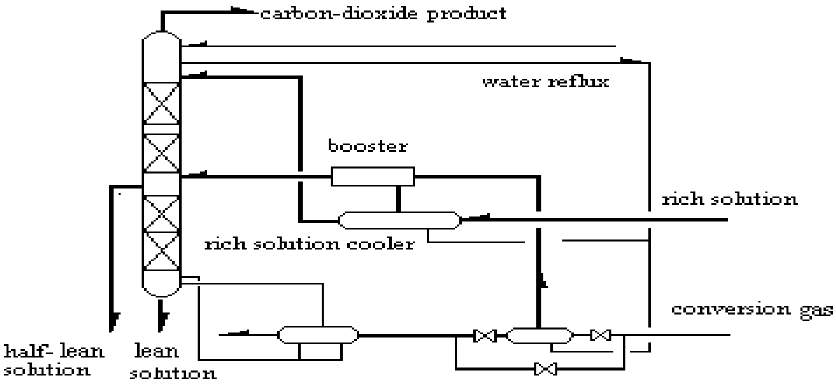


Fig. 3 The flow diagram of energy saving by rich solution cooling and decarbonization

Home-made Advanced Molecular Sieve Drying System (see Fig.4)

In order to realize the renovation of ammonia separation after converter, oxygen contained compound in the make-up gas of the synthesis ammonia has to be removed first, by molecular sieve drying technology. The molecular sieve drier which was designed domestically adopted local molecular sieve and other equipments. Its control program was developed by Chitianhua independently. The performances of the molecular sieve drier is very reliable.

The designed service life of the molecular sieve was 3 years, but actually it operated up to 6 years. After optimization, the adsorption period has been increased from 12 hours to 18 hours, the regeneration gas flow has been reduced from 6,000 standard cubic meters per hour to 3,000 standard cubic meters per hour, and the regeneration temperature has also been reduced greatly.

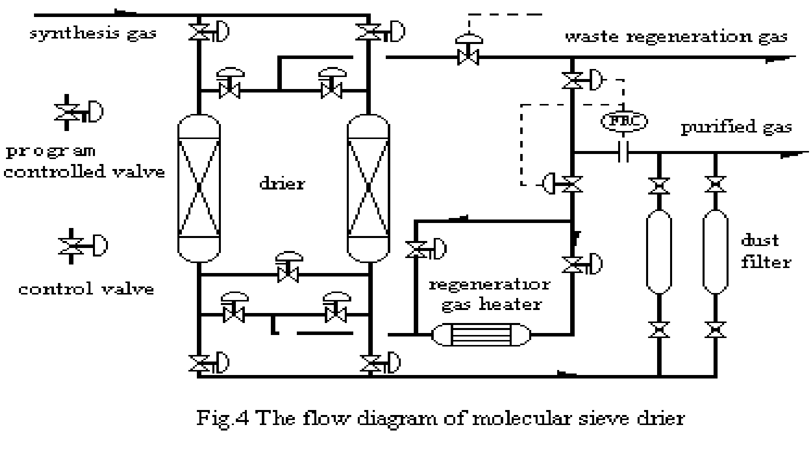


Fig.4 The flow diagram of molecular sieve drier

Excellent Performance of the Ammonia Synthesis Loop with Ammonia Separation after the Converter (see Fig.5)

The original design of ammonia separation before the converter consumed more energy. But if ammonia separation be changed to that of after the converter, the renovation would be challenged with some engineering difficulties since a molecular sieve drier had to be added so as to remove the oxide in the make-up gas, and the equipment and pipes within the loop were all of high pressure and big diameter. Chitianhua is the first one who adopted domestic design and equipments for such renovation in China.

The ammonia separation after the converter increased the synthesis efficiency, reduced the compressor energy consumption as well as increased the converter outlet temperature which is in favor of the residual heat recovery. The renovation of the synthesis loop as well as the energy saving renovation of the rotor of the compressor made the power of the syngas compressor not increase, but reduce from 15,463 kW to 14, 153kW, after the capacity was increased by 22%.

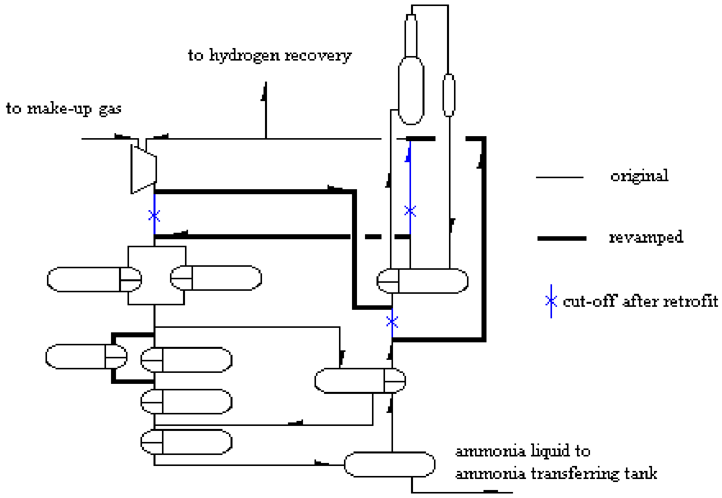


Fig.5 The flow diagram of ammonia synthesis loop before and after the renovation

Using Cryogenic Technology to Recover Hydrogen from the Purge Gas (see Fig.6)

The installation adopting cryogenic process to recover hydrogen from the purge gas by Chitianhua is the only one of its kind in China. The cryogenic process separation is characterized by higher separation efficiency, smaller amount of gas to be handled, higher energy saving benefit, more stable performance and a longer service life of the equipment. The reason why cryogenic technology is not popularized for a long time lies in the fact that price of the cold box manufactured by old technology is very high. However, our renovation uses new technology. Thanks to the information we collected, the price of the cryogenic equipment we imported was less than half price of imported membrane separation equipment.

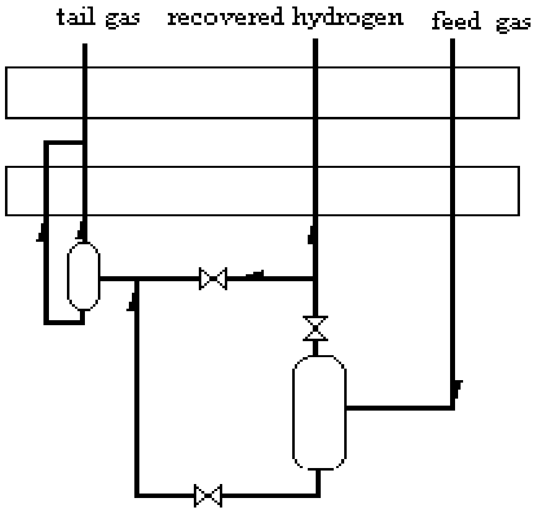


Fig. 6 The sketch map of the flow inside the cold box

6. MAIN TECHNOLOGICAL AND ECONOMIC DATA OF THE REVAMPING

Table 1: Main technological and economic indices of the revamping

	Ammonia output		Overall energy consumption
	MT/D	MT/y	GJ/MT-NH_3
Original design	1000	300□000	39.89
Revamping design	1220	366□000	34.5
Capacity increased	**22%**	**22%**	**Energy saved 13.5%**

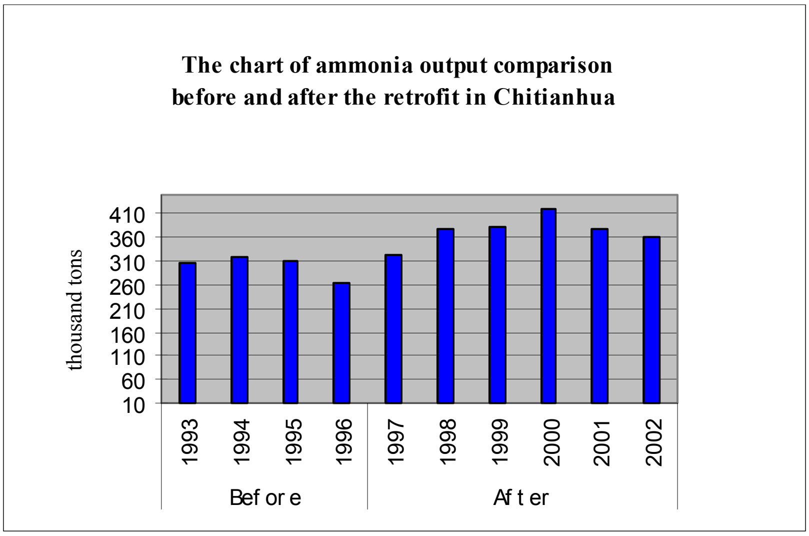
All process condensate shall be recovered, water pollution shall be cleared up completely.

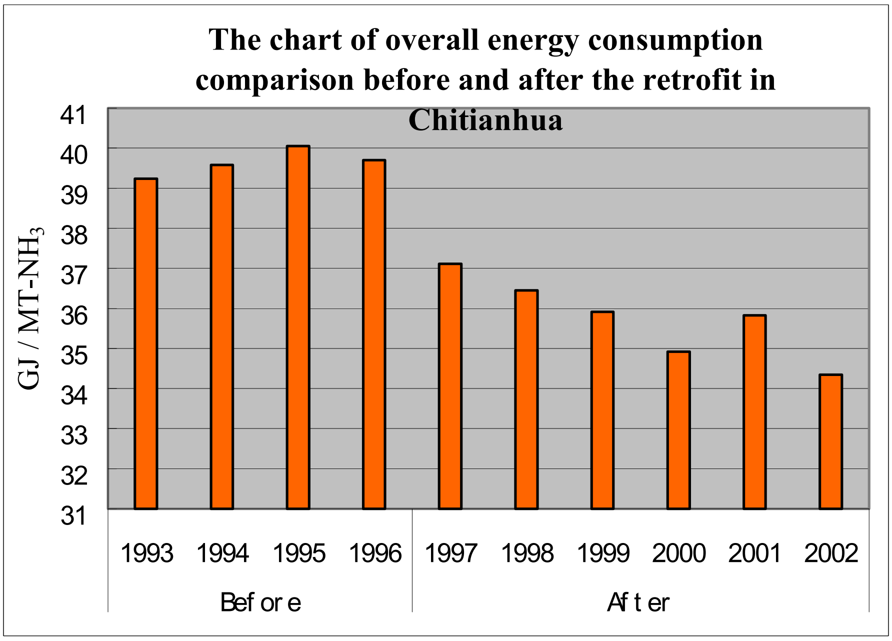
Table 1 shows the main technological and economic indices. From the table we can see that the ammonia output has been increased by 22% compared with that of the original design, the overall energy consumption of ammonia has been reduced by 13.5% compared with that of before the renovation, along with all process condensate has been recovered, and water pollution has been cleared up completely. Now all these targets have been achieved.

Table 2 compares the main technological and economic data before and after the revamping in Chitianhua. The energy saving and capacity increasing revamping in Chitianhua was completed in 1996. After 3 years of rectification, improvement and optimization, all expected targets have been achieved, and the revamping was tested and accepted in November, 2000.

Table 2: Comparison of the actual technological and economic indices before and after the revamping in Chitianhua

Year	Ammonia output	Energy consumption	Year	Ammonia output	Energy consumption
Before revamping	MT	GJ/MT-NH_3	**After revamping**	MT	GJ/ MT-NH_3
1993	306,896	39.24	**1997**	321,670	37.11
1994	317,116	39.58	**1998**	377,226	36.45
1995	310,006	40.05	**1999**	382,007	35.92
1996	263,614	39.70	**2000**	420,078	34.92
			2001	380,018	35.83
			2002	360,256	34.34





7. APPLICATION AND WIDESPREAD ACCEPTANCE

After the renovation, the key innovative technologies have been published on *Large Scale Nitrogenous Fertilizer Industry* for five sequential issues in 1999~2000, and the overall process scheme has ever been introduced as a major topic during the 13th annual session of the Chinese Large Scale Ammonia Plants, which offered a very good reference for energy saving and capacity increasing renovation for other large scale ammonia plants.

8. ECONOMIC AND SOCIAL BENEFITS ATTAINED

Table 3: Economic benefits attained (Thousand yuan, RMB*)

Total investment	285,530			Payoff period (year)	4
Year	Profit increased	Tax increased	**Profit adds tax**	Foreign exchange earned (USD)	Value from energy saving
1999	40,080	13,360	53,440	0	26,230
2000	72,380	24,130	96,510	0	36,700
2001	46,280	10,760	57,040	0	27,560
Average	**56,800**	**18,930**	**75,730**	**0**	**30,020**

USD=8.2 RMB*

Table 3 shows the economic benefits ever brought for Chitianhua by this project. Over the 3 years period from 1999 to 2001 as an example, it can be seen from the table that the average annual direct economic benefit brought by this project reached 75.73 million Yuan (USD 9.2 million), while the total investment of the project is 285.53 million Yuan (USD 34.8 million) , the investment payoff period is less than 4 years. The above benefit and investment include those for both ammonia and urea installation.

In recent years, the price of energy has increased steadily while the chemical fertilizer market is very weak, Chitianhua's fairly good financial standing is mostly due to its energy saving and capacity increase renovation.

This project also has the following social benefits:

1. It realized zero discharge of the process condensate from the ammonia and urea plant. The overall discharge of waste water from our company is reduced by 90 tons per hour, while ammonia and nitrogen content is only about 20 mg/l. In addition, the recovery of carbon-dioxide from the flue gas to balance the surplus ammonia has reduced waste gas discharge and improved the environment. After the renovation, the environment protection has stepped up to a high level.
2. Because this project combined energy saving with capacity increasing, and paid equal attention to environment protection with production development, it therefore has great value inapplication and widespread acceptance.
3. The engineering experience of this project will surely serve the same type of domestic enterprises for their technological renovation as a very good reference.