International Fertilizer Industry Association

IFA Technical Conference

Beijing, China
20-23 April 2004

International Fertilizer Industry Association - Secretariat: 28 rue Marbeuf - 75008 Paris - France
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COAL-BASED AMMONIA PLANTS, NEW TECHNOLOGY AND TREND IN AMMONIA PRODUCTION IN CHINA

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INTRODUCTION

China is the world's largest ammonia producer. According to the national statistics, the 2002 ammonia production had reached 36.54 million metric tons and that of 2003 increased further to 37.5 million tons. It is expected that the ammonia production in China will continue to increase at a rate of 2~3% per annum in the coming decade.

China's energy resource is characterized by "abundant in coal, in-sufficient in gas and shortage in oil". Coal accounts for 68% of the total energy consumption, oil accounts for 23.6%, natural gas accounts for 2.5%, hydro and nuclear power accounts for 6.9% (2001). Even through the exploitation of natural gas is enhanced and large gas fields have been found in recent years, due to strong gas demand from residential and other industries, natural gas supply is not enough to meet the demand of ammonia industry.

Twenty years ago, during the planning economy system, the policy for the development of the ammonia industry is to encourage plants of all feedstocks: coal, oil and gas, due to the strong demand for fertilizers. Oil and gas accounted for ~20% in the ammonia feedstock respectively in 1980's, and coal accounted for 60%. Since 1990's, the market economy reform started and oil-based plants gradually lose their competitiveness due to the liberation of oil prices and withdrawal of subsidiary. Today, oil-based ammonia capacity only accounts for 10% of the total and coal increased to 70%, while the natural gas keeps the same 20% as before.

During past 50's years, China built the world's largest ammonia industry chiefly on coal material, and mostly on domestic technologies for ammonia production. China accumulated a lot of experience on coal-based ammonia plants. The coal-based ammonia technologies keep improving today and in the future. I hope this paper will be interesting to the world ammonia industry and especially to countries that lack cheap natural gas.

Received 14 January 2004 for presentation at the 2004 IFA Technical Conference, 20-23 April, Beijing, China
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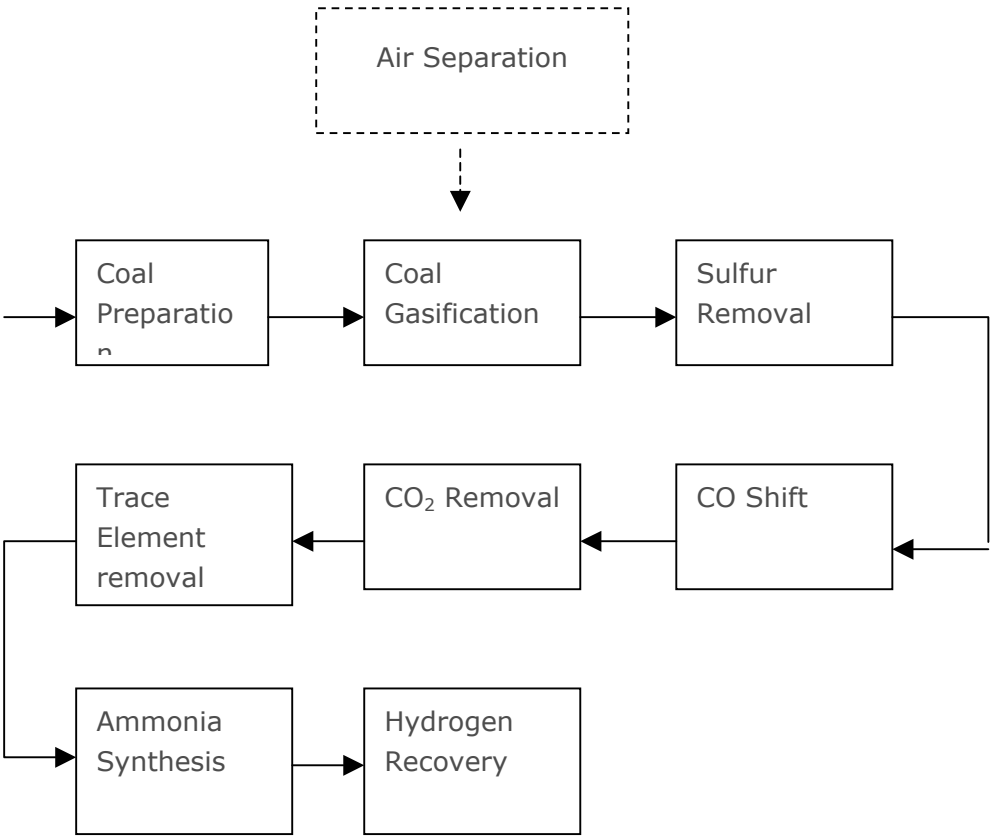
COAL-BASED AMMONIA TECHNOLOGY STATUS

Coal-based ammonia plants are generally more complex than gas-based plants: A coal-based ammonia plant is composed of the following sections:



Gasification

The coal gasification is the key section of the coal-based ammonia plants. There are dozens of coal gasification technologies in the world. But in China, only several gasification technologies are in commercial operation in ammonia industry, i.e atmospheric gasification, Texaco slurry gasification and Lurgi dry-bed gasification. Other new gasification technologies are under development or construction.

Atmospheric gasification technology, also called UGI gasification in China, is a very old technology. The gasifier use air, instead of oxygen and steam as agent; and only lump anthracite coal or coke (diameter 13-50mm) can be used.

The advantages and drawbacks of the technology are:

Advantages:

- Pure oxygen is not necessary. So the capital cost of air separation unit (ASU) and operation cost of it is saved. Normally, the ASU is very expensive and could cost same investment as the gasification unit.
- The gasifier is very simple and inexpensive. The gasifier is operated under atmospheric pressure and the equipment is simple and easy to be manufactured. And the spare parts are also cheap and easy to buy.

Drawbacks:

- Feedstock is limited. Only lump anthracite and coke can be used. Coke now is too expensive to be used in ammonia and lump anthracite is only produced in some areas, mostly in Shanxi province. Therefore, when the ammonia plants are far from anthracite coal mines, the cost of feedstock could be very high.
- High waste discharge. The gasifier has to vent gas pollution to the air and large amount of scrubbing water discharge. The pollution is higher than the "clean-coal" technology such as Texaco and Shell gasifier. But fortunately, there are solutions to the waste treatment now: vent gas now could be burned again to recover heat, and the waste water could be treated by biochemical process and water could be recycled after treatment.
- Low capacity for gasifier. For it is an atmospheric gasifier, the capacity for each gasifier is low. A large gasifier can only produce around 20,000 tons of ammonia per year. A commercial plant may need more than 10 gasifiers and large area. So it is a more suitable technology for small and medium-sized plants.
- Gas compression power consumption is high. The atmospheric coal gas shall be compressed to higher pressure for gas treatment and ammonia synthesis. Compared with pressurized gasifier, atmospheric gasifier needs more electricity. If the power prices are high, the ammonia production cost could also be high. Now steam turbine is also considered in small and medium sized plants to reduce the purchased power.

Presently, there are more than 500 coal-based plants (about 3000 gasifiers) in operation in China, still using the atmospheric gasification process. The total capacity of the gasifier amounted to about 60% of the Chinese total. Thanks to the past 50 years' experience, the technology has been improved in many aspects such as automatic control, grate structure and gas distribution, water treatment, using briquette powder coal, etc. And thus the technology could survive in China until today.

Regarding other Lurgi gasification technology, China adopted Lurgi gasification since 1950's. The first one is in Yunnan Jiehua Fertilizer Plant for ammonia production. Today there are numerous Lurgi gasifiers in China but mostly for town gas production. For ammonia production only two plants use it.

The plants are :

Lurgi Gasification Ammonia Plants in China

	Plant Name	Diameter mm	Coal Gasification Capacity (T/D)	Pressure MPa	Ammonia Capacity (t/a)	Start-up Date
1	Yunnan Jiehua Group Co. Ltd	Φ2600	850	2.0	170	1974
2	Shanxi Tianji Coal Chemical Group Co.	Φ3800	1500	3.0	300	1988

The Jiehua Group uses the Mark-I type gasifier with brown coal from Yunnan province. The Tianji Group use Mark-IV gasifier with the Shanxi bituminous coal as material. During start-up years, the plants meet a lot of problems in technology and equipment. After several years' operation, both the plants are operating very well and the nameplate capacity has been achieved.

Lurgi gasifier is widely used in the world for a lot of purposes. But for ammonia production, because the synthesis gas contains methane (8-10%), which has to be reformed again, the process will be long. In China it is seldom used in ammonia industry.

China is an early user of Texaco coal gasifier, since the first ammonia plant started up in Shandong Lunan Fertilizer Plant in 1993. The capacity for the plant is 80 kt/a ammonia. Thereafter, China also built several other ammonia plants based on Texaco gasification technologies, including Shanxi Weihe Coal Chemical Co. with an ammonia capacity of 300 kt/a and Anhui Huainan Chemical Co. with an ammonia capacity of 200 kt/a. of in the 8 currently operating Texaco Coal gasification plants worldwide, China has 4, with 3 for ammonia production. The details of the Chinese plants are:

Texaco Coal Gasification Ammonia Plants in China

	Plant Name	Diameter (mm)	Coal Gasification Capacity (T/D)	Pressure Mpa	Ammonia Capacity (kt/a)	Start-up Date
1	Shandong Lunan Chemical Fertilizer Plant	Φ2800	350	3.0	80	1993
2	Shanxi Weihe Coal Chemical Co.	Φ2800	1500	6.5	300	1996
3	Anhui Huainan Chemical Co.	Φ2800	900	4.0	180	2000
4	Helongjiang Haolianghe Fertilizer Plant	Φ2800	900	4.0	180	Under construction

Sulfur Removal

There are two types of sulfur removal technology in China: domestic and imported.

The domestic is called "wet oxidation-regeneration" process. The synthesis gas is washed first by a solution with sodium carbonate or ammonia and oxidation catalyst, normally anthraquinone, tanning extract, etc. The H_2S is oxidized by air to form sulfur in the solution. In this process, H_2S is removed and S is formed in one unit, no additional

S recovery unit is needed. A lot of catalysts have been developed for the process. It is a simple process widely used in medium and small plants in China.

For large plants with imported gasification technology, low temperature Rectisol and Claus sulfur recovery process is employed. It is the same sulfur removal process as other plants elsewhere.

CO Shift

The key for the CO shift process is catalyst. For the coal-based plants, China has developed new catalysis for low-temperature shift. Now there are two types of shift process: one is high-low-low temperature shift process, the other is total low temperature shift process. Both the processes are successful and widely used and could decrease the steam consumption to less than 0.5 t/t ammonia.

The imported shift technology and catalyst, such as sulfur-resistant shift process, are only used in several large plants.

CO_2 Removal

There are physical and chemical solutions used for coal-based ammonia plants for the heavy duty CO_2 removal in China. Physical solutions include propylene carbonate, polyglycol ether, methanol, etc. Chemical solutions include hot alkaline and amines, etc.

For coal-based plants, the physical processes are widely used, especially the propylene carbonate and polyglycol ether, which have low investment and easy to operate.

Some plants using the hot alkaline process also made great improvements by Chinese researchers. The important figure for hot alkaline process, the regeneration energy consumption has reached 3300Kj/m^3CO_2, an international advance standard, through the use of dual pressure regeneration and amine promotion agents.

Pressure Swing Adsorption (PSA) technology for CO_2 removal also has application in China. It is developed by a Chinese company and applied successfully in medium sized plants for its easy operation.

Trace Element Removal

The trace elements in the synthesis gas include CO, CO_2 and H_2S. A widely used process in China to remove them is acetic copper solution. The solution has strong capability to absorb the impurities but it has problems of complex equipment and copper solution contamination.

The methantion process with dry sulfur removal agent is gradually replacing the copper solution process for its simple equipment and low capital cost.

For several large plants, nitrogen wash is also used, but the investment is quite high.

Compression

For small and medium sized plants, reciprocating compressors, driven by electrical motors, are used widely. Normally, there are several compressors in parallel for each plant. Therefore, the electrical consumption is high for medium and small sized plants.

For large plants, the compressors are centrifugal type and driven by steam turbine, and the steam could be supplied by the in-plant boiler or by-product steam of the gasification process.

Ammonia Synthesis

China has made a lot of improvements in ammonia synthesis technology, especially the catalysts.

For most small and medium sized plants, the ammonia synthesis technology and catalyst are supplied by domestic companies. Most of the plants use high pressure (32Mpa) synthesis technology and several types of ammonia converters were invented in China.

For large plants, imported synthesis technology and converters are used. But the catalyst is supplied domestically now.

Hydrogen Recovery

Chinese companies have developed both pressure swing adoption (PSA) and membrane separation technology for the hydrogen recovery from ammonia plant, not only for small and medium plants, but also for large ones.

In summary, besides imported technologies, for each section of the coal-based ammonia plant, China has its own technology and equipment suitable for the special local conditions. The technology may not be the most advanced, but is feasible and practical especially for the small- and medium-sized plants. That is an important reason that during the market-oriented reform and removal of subsidiaries on fertilizer industry, most medium and small plants could survive and even export to the international market.

The technology improvements never end in ammonia industry. China's coal based ammonia technology will develop to a new level, and will concentrate on the coal gasification section.

NEW DEVELOPMENTS AND TREND IN COAL-BASED AMMONIA TECHNOLOGIES

Because the feedstock for most China's coal-based ammonia plants is anthracite, which is only produced in limited area such as Shanxi Province, when the transportation becoming tight, the coal prices will increase to a very high level. While other types of coal such as brown coal, bituminous coal are widely distributed in China, Chinese researchers have made a lot of effort to develop new gasification technologies. There are some breakthroughs now in coal gasification technologies, and some commercial plants are being built. Until now the successful domestic technology include Ende Powder Coal Gasification (EPCG), Ash Agglomeration Gasification (AAG) and New Slurry Gasification (NSG).

In the meantime, foreign technologies are also used by ammonia industry in China, in which the most important ones are Shell Coal Gasification Process(SCGP) and Texaco Coal Gasification Process (TCGP).

Domestic Technologies

EPCG was developed by Fushun Ende Company, China. Several ammonia plants using this technology are under construction or operating now. This is a similar technology to Winkler gasifier but has different gas distribution system. The gasifier is a fluidized bed, and could use oxygen or oxygen-rich air as gasification agent (when producing ammonia). The largest capacity for the gasifier is 40,000 Nm^3/h synthesis gas for one gasfier, or about 90 kt/a ammonia.

The typical operating data for synthesis gas production are as follows:

Items	Unit	Consumption (per 1000Nm^3 syngas)
Gas Specification		$CO+H_2$ 72~64 LHV 9080 KJ/Nm^3
Coal (LHV=22GJl/t)	Kg	565~577
Electricity	Kwh	150 (ASU included)
Steam	Kg	351-400
Cooling water	m^3	27.5-29
Oxygen	M^3	262~265 (98%)
By Product Steam	Kg	400
Heat Efficency	%	84%

The Ammonia plants now using EPG are :

- Anhui Huinan Chemical Co. capacity 20,000 m^3/h
- Jilin Changshan Fertilizer Plant, capacity 40,000 m^3/h
- Helongjing Fertilizer Plant, capacity20,000 m^3/h X 2

The disadvantage of this technology is that it can only gasify high-activated, brown coal, which is mostly produced in North-east China, etc., and cannot be used widely.

Ash Agglomeration Gasification (**ASG**) was developed by Shanxi Coal Chemistry Institute of Chinese Academy of Sciences. It is also a fluidized by process with oxygen as agent. The technology has the advantages of wide applicable coal, easy waste treatment, high efficiency and low capital cost. Presently, there is only one demonstration plant in operation in Shaanxi Province, China, with the ammonia capacity of 20 kt/a. On the plant, several types of bituminous coal are gasified. The result shows this technology is suitable for ammonia production.

The consumption data from the demonstration plant are as follows (gasification unit only):

Items	Specification	Consumption /per ton ammonia
Coal	25 GJ/t	1.5 t
Oxygen	92.5%	614 m^3
Steam	0.5Mpa	1.25 t
By-product steam	1.3Mpa	1.60 t
Electricity		375 kwh
Soft water		1.6 t
Fresh water		12 m^3
Cooling water		40 m^3

It is expected that there will be more users of AAG process in the future for its flexibility in using coal types.

NSG was developed by State Coal Gasification Center at Lunnan, Shandong Province. It uses four nozzle slurry gasification concept. The demonstration plant with capacity of 22 t/d was tested successfully and the result is:

Capacity: 22 t/d (coal input)

Effective gas content: $CO+H_2$ ~83%

Carbon conversion ratio: >98%

Oxygen consumption: ~380m^3/1000Nm^3($CO+H_2$)

Coal Consumption: ~550kg/1000Nm^3($CO+H_2$)

Now a gasification unit with capacity of 1,000 t/d coal is under construction in Shandong province and is expected to be commissioned in 2004.

Imported Technologies

The most commercially successful coal gasification technology in China recently is Shell Coal Gasification Technology (SCGP). SCGP was developed since 1972 and a commercial IGCC plant of 2,000 t/a coal was operated for several years in the Netherlands. SCGP was first introduced to China in 1998 and today, there are 8 planning projects for ammonia production, some are under construction, as follows:

Owner	Location	Input, t/d	Syngas output (10^6 Nm^3/d)	Start-up date
Shuanghuan Chemical	Yingcheng, Hubei	900	1.3	2004
Liuzhou Chemical	Liuzhou, Guangxi	1200	2.1	2005
Sinopec-Shell	Yueyang, Hunan	2000	3.4	2005
Sinopec	Zhijiang, Hubei	2000	3.4	2005
Sinopec	Anqing, Anhui	2000	3.4	2005
Dahua Chemical	Dalian, Liaoning	1000	1.5	2006
Yuntianhua Chemicals	Anning, Yunnan	2000	3.4	2006
Yunzhanhua Chemicals	Qujing, Yunnan	2000	3.4	200

SCGP has its advantages both in gasification efficiency and environmental performance, but the investment is high and only a few coal-based ammonia plants can afford it.

Texaco Coal Gasification Process (TCGP) is a mature technology here. China has accumulated a lot of experience on the process design, equipment manufacture, and plant operation. The capital cost of TCGP could be decreased lower through local fabrication of equipment and engineering. Currently there is only one TCGP ammonia project is under construction in Helongjiang Province.

CONCLUSION

Through many years' improvements in coal-based ammonia technology, today we are lucky to have a lot of choices in each section of ammonia process, from coal gasification, to gas purification and until ammonia synthesis and hydrogen recovery. Coal-based plants are becoming more competitive with the elevating gas and oil prices. More attention should be paid to coal-based ammonia plants not only in China, but also in other parts of the world.

Based on our experience, several suggestions for selecting the technology for coal-based plants are:

- Coal type.

  Each gasification technology has its suitable coal type, some maybe wide and some may be narrow. A good gasification technology should be applicable to local coal.

- Economics

  Economics may be the most important factor in selecting a gasification technology. It is affected by coal price, capital cost, process performance, etc. Generally speaking in China, an imported technology with high performance has high capital cost, while the domestic technology with lower performance has lower capital cost. Especially, when the gasification needs pure oxygen and ASU, the capital cost could

increase to an unacceptable level. There should be a compromise between the capital cost and performance. For example. In Shanxi province, the atmospheric gasification process is most suitable for the low capital cost (without ASU) and low anthracite prices there.

- Environmental Performance

Environmental aspect is sometimes the key factor of selecting processes. With more and more strict environmental protection regulation, ammonia producers have to choose clean coal technology or adopt more technologies to meet the regulations. This will increase cost.

It would be prudent to say that the best process for a coal-based ammonia process depends on a lot factors. The final decision should be made after comparison in technology and economy.

As a longtime coal-based ammonia producer, we would like to share the experience in coal-based ammonia plants with you.

Thank you for your attention.