Comparison on techno-economic analysis of ammonia production using urea from SCR denitration reducing agent in 300MW coal-fired unit

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Abstract. Under the current environmental protection situation, comparison on techno-economic analysis of the ammonia production using urea can provide reference and guidance for the coal plant's transformation project of replacing liquid ammonia with urea. Taking eleven 300MW SCR denitrification reducing agent urea replacing liquid ammonia in 4 power plants as an example, the technical characteristic and material consumptions, investment cost and operation cost were compared on urea pyrolysis with electric heater, urea pyrolysis with gas heat exchanger and urea hydrolysis, the main influence factors and reasons of Urea to replace liquid ammonia transformation project on such unit had been mastered. The results show that the processes of ammonia production by urea pyrolysis and urea hydrolysis were mature and feasible, and both had their advantages and disadvantages.

1. Introduction
In recent years, environmental security events are occurring, some local governments began to increase restrictions and supervision over the use of liquid ammonia, particularly with the latest emergency notification was issued, which calls for a strengthening of the comprehensive control of hazardous chemical safety in the power industry (National energy comprehensive security [2019] No. 132) [1], the demand for coal plant's transformation project of replacing liquid ammonia with urea is increasing. Liquid ammonia belongs to dangerous goods, the relevant national standards classify it as acute toxicity, skin corrosion/irritation, serious eye injury/eye irritation category of flammable substances, its storage, unloading, preparation, procurement and transportation routes are relatively strict provisions, more than 10 tons will become a major source of danger. Ammonia water is the aqueous solution of ammonia gas, colorless and transparent and has pungent smell, ammonia water is volatile, to the eyes, nose, skin has irritant and corrosive, is "dangerous chemicals" (gb12268-90) dangerous goods, ammonia water containing 10~35% for 82503 dangerous goods. Urea, on the other hand, is a non-toxic and harmless chemical with no possibility of explosion and no danger. It is more suitable for flue gas denitrification engineering, especially for coal-fired power stations close to cities and residential areas[2-4]. Urea was used as a reducing agent of SCR flue gas denitrification, which must be decomposed into ammonia first. The ammonia production methods used in power plants include urea pyrolysis[5-8] and hydrolysis[9,10]. The urea pyrolysis is divided into flue gas heat exchanger pyrolysis and electric heaters. The urea hydrolysis is divided into two types, which include adding catalyst and without adding catalyst. To this end, this article adopts a benchmark comparison method to compare and analyze the ammonia production process of 11 300MW SCR denitrification and
reducing agent urea replacement liquid ammonia retrofit projects in 4 power plants. In order to provides reference and experience for the technical and economic analysis under the new situation.

2. Research methods and content

In this research, 11 300MW SCR denitrification reducing agent urea replacing liquid ammonia in 4 power plants were studied, which include changes in investment costs and operating costs of the new urea preparation and storage systems, diluting air retrofit system, urea ammonia production equipment of urea replacement liquid ammonia retrofit project, meanwhile, compare different urea ammonia production processes, namely urea pyrolysis with electric heater, urea pyrolysis with flue gas heat exchange and urea hydrolysis in order to understand their technical characteristics. Table 1 shows the unit status of this study (referred to as Unit A, B, C, and D respectively, the same below), and Table 2 shows the urea ammonia production process of this study (referred to as Scheme 1, Scheme 2, and Scheme 3 respectively, the same below), from which it can be seen that the unit and retrofit plan of this study have strong representativeness, and can effectively reflect the actual status of the SCR denitrification and reducing agent urea ammonia production retrofit project of 300MW coal-fired unit.

Table 1. The unit status for the study.

| Unit capacity /MW | 335 | 330 | 300 | 330 |
|-------------------|-----|-----|-----|-----|
| Number of units /station | 4   | 1   | 4   | 2   |
| Design value of NOx at denitration inlet /mg/m³ | 450 | 450 | 400 | 500 |
| Design value of NOx at denitration outlet /mg/m³ | 50  | 50  | 50  | 50  |
| Power plant title | A   | B   | C   | D   |

Table 2. The urea ammonia process for the study.

| Pyrolysis of urea | Scheme 1 | Scheme 2 | Scheme 3 |
|-------------------|----------|----------|----------|
| Electric heaters  |          |          |          |
| Flue gas heat exchanger |          |          |          |
| Urea-normal hydrolysis |          |          |          |
| Hydrolysis of urea |          |          |          |
|                       |          |          |          |

3. Analysis and discussion

3.1. Technical analysis

The new urea preparation and storage systems between the urea pyrolysis and hydrolysis are basically the same, that is, the urea particles are dissolved to make a urea solution with a concentration of about 50% and stored in the urea solution storage tank. The biggest difference between the two processes is that the urea pyrolysis sends the dissolved urea solution into the metering and distribution module through a high-flow circulation pump, and then sprays it into the pyrolysis furnace by a spray gun. The ammonia gas is decomposed under the condition of hot air at 350 ~ 650 °C. The required heat source is generally heated by an electric heater (scheme 1). In order to reduce power consumption, a method of replacing the electric heater with a high-temperature flue gas heat exchanger (scheme 2) has also appeared in recent years, that is, 600 ~ 700 °C high temperature flue gas was leaded from the boiler steering chamber, so as to heat the flue gas; urea hydrolysis (scheme 3) is to send the dissolved urea solution into the hydrolysis reactor through a high flow circulation pump. Ammonia is decomposed under the condition of 0.4~0.7MPa and 130~160 °C saturated steam. The heat source for hydrolysis is generally low-quality steam, so its energy consumption level is relatively low. However, scheme 1 and scheme 2 have extremely fast startup response speeds and strong load tracking capabilities, scheme 3 (urea-normal hydrolysis) has a longer cold start time and a relatively slow hydrolysis reaction rate. If a catalyst is added during the hydrolysis process, the response rate will be improved. The specific technical comparison of the three schemes is shown in Table 3.
Table 3. Technical comparison table of three design schemes for the study.

| Project | Pyrolysis of urea | Hydrolysis of urea |
|---------|-------------------|-------------------|
|         | Scheme 1 (Electric heaters) | Scheme 2 (Flue gas heat exchanger) | Scheme 3 (urea-normal hydrolysis/catalytic hydrolysis) |
| Key equipment | Electric heaters, Pyrolysis furnace | Flue gas heat exchanger, Pyrolysis furnace | Hydrolysis reactor |
| Temperature reflex/℃ | 350~650 | 130~160 |
| Reaction pressure/MPa | Atmospheric | 0.4~0.7 |
| By-product[11,12] | Isocyanate, Melamine | Periodic discharge of impurities |
| Conversion rate/% | 80~90 | 99 |
| Response time/s | 5~30 | 300~1800/60 |
| Ammonia storage/kg | 0 | 50~1200 |

3.2. Material consumption analysis
The comparison of material consumption of the three schemes in this study is shown in Table 4. It can be seen from Tables 3 and 4, which is that Scheme 1 and Scheme 2 have complicated intermediate reaction by-products, so that their urea conversion rate is generally considered to be slightly lower than Scheme 3. Therefore, the urea consumption and demineralized consumption of Scheme 1 and Scheme 2 are slightly higher than that of Scheme 3. At the same time, since the chemical reaction of Scheme 3 is a highly endothermic reaction and requires a certain quality of saturated steam supply, its steam consumption is higher. In addition, the power consumption of Scheme 1 is the highest among the three schemes because of the high power electric heater. In scheme 2, the high temperature flue gas of the boiler is introduced into the flue gas heat exchanger to replace the electric heater, so that the power consumption is significantly reduced. However, the flue gas heat exchanger also exists a certain resistance, resulting in a higher power consumption than Scheme 3.

Table 4. Material consumption table of three design schemes for the study.

| Project | A | B | C | D |
|---------|---|---|---|---|
| Transformation design scheme Urea consumption/ t h⁻¹ | Scheme 1 | Scheme 2 | Scheme 3 | Scheme 1 | Scheme 2 | Scheme 3 | Scheme 1 | Scheme 2 | Scheme 3 |
| Desalination consumption/ t h⁻¹ | 1.49 | 1.49 | 1.30 | 0.37 | 0.37 | 0.32 | 1.34 | 1.34 | 1.16 | 0.79 | 0.79 | 0.70 |
| Steam consumption/ t h⁻¹ | 1.49 | 1.49 | 1.30 | 0.37 | 0.37 | 0.32 | 1.34 | 1.34 | 1.16 | 0.79 | 0.79 | 0.70 |
| Power consumption/ kW | 0.58 | 0.58 | 4.00 | 0.14 | 0.14 | 1.00 | 0.51 | 0.51 | 3.60 | 0.30 | 0.30 | 2.10 |
| Urea consumption/ t h⁻¹ | 2671 | 287 | 71 | 679 | 60 | 30 | 2628 | 268 | 37 | 1495 | 100 | 61 |

3.3. Investment analysis
Table 5 and Table 6 show the comparison of the total investment and process system renovation investment of the three schemes in this study. As can be seen from Tables 5 and 6, scheme 1 has the lowest static investment overall, scheme 3 is slightly higher than scheme 1, and scheme 2 has the highest static investment, indicating that the urea heater pyrolysis process using the electric heater has a slightly lower investment than the urea hydrolysis process transformation. The urea pyrolysis process
using high-temperature flue gas heat exchangers has the highest overall renovation investment cost due to higher equipment costs. Among them, the adoption of high-power electric heaters will lead to high voltage emodification, so the investment of electrical system in scheme 1 is higher than scheme 2 and 3; meanwhile, it can be seen that process system investment is an important component of the entire engineering transformation investment, and the cost of core equipment (pyrolysis furnace, electric heater, flue gas heat exchanger, and hydrolyzer) of the three schemes is the main factor that affects the investment in process system transformation.

Further analysis of Table 5 and Table 6 in conjunction with Table 1 shows that the more units, the lower unit investment, that's because the urea zone system is a public plant-wide system; it can also be found that the greater the number of units, the more obvious the advantages of scheme three, which are mainly because the core equipment of schemes 1 and 2 adopts the unit system, and scheme 3 uses the public system, resulting in a single unit investment Relatively lower, so the power plant should reasonably formulate according to its own situation when selecting the transformation process route.

### Table 5. Total investment comparison table of three design schemes for the study.

| Project                        | Scheme 1 | Scheme 2 | Scheme 3 | Scheme 1 | Scheme 2 | Scheme 3 | Scheme 1 | Scheme 2 | Scheme 3 | Scheme 1 | Scheme 2 | Scheme 3 | Scheme 1 | Scheme 2 | Scheme 3 |
|--------------------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Transformation design scheme   |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |
| Process system/million         | 18.06    | 33.80    | 24.61    | 8.75     | 13.39    | 15.49    | 21.38    | 36.44    | 23.15    | 11.59    | 19.03    | 15.37    |          |          |          |
| Electrical System/million      | 4.38     | 1.15     | 1.16     | 2.31     | 1.08     | 1.09     | 3.97     | 1.11     | 1.12     | 3.26     | 0.95     | 1.17     |          |          |          |
| Thermal control system/ million| 6.18     | 6.12     | 3.94     | 2.73     | 2.70     | 3.62     | 5.15     | 5.22     | 3.76     | 2.71     | 2.72     | 2.36     |          |          |          |
| Installation and commissioning/million | 0.55   | 0.55     | 0.55     | 0.14     | 0.14     | 0.14     | 0.56     | 0.56     | 0.56     | 0.28     | 0.28     | 0.28     |          |          |          |
| Other/ million                 | 3.46     | 47.63    | 35.46    | 18.02    | 21.85    | 25.08    | 38.96    | 52.16    | 35.91    | 23.13    | 28.34    | 24.00    |          |          |          |
| Static investment/million      | 4.50     | 47.63    | 35.46    | 18.02    | 21.85    | 25.08    | 38.96    | 52.16    | 35.91    | 23.13    | 28.34    | 24.00    |          |          |          |
| Unit investment/yuan▪kW        | 25.57    | 35.54    | 26.46    | 54.59    | 66.20    | 76.01    | 43.46    | 29.92    | 35.05    | 42.93    | 42.93    | 36.36    |          |          |          |

### Table 6. Process system transformation investment comparison table of three design schemes for the study.

| Project                        | Scheme 1 | Scheme 2 | Scheme 3 | Scheme 1 | Scheme 2 | Scheme 3 | Scheme 1 | Scheme 2 | Scheme 3 | Scheme 1 | Scheme 2 | Scheme 3 | Scheme 1 | Scheme 2 | Scheme 3 |
|--------------------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Transformation design scheme   |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |
| Urea zone system/ million      | 4.50     | 47.63    | 35.46    | 18.02    | 21.85    | 25.08    | 38.96    | 52.16    | 35.91    | 23.13    | 28.34    | 24.00    |          |          |          |
| Ammonia injection system       |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |
| (including hot dilution wind)/ million | 3.70   | 3.70     | 3.60     | 1.00     | 1.00     | 3.90     | 4.00     | 3.90     | 1.80     | 1.80     | 1.90     |          |          |          |          |
| Pyrolysis furnace/ million     |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |
| Hydrolysis reactor/ million    |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |
| Electric heaters/ million      |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |
| Flue gas heat exchanger/ million|          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |
| Desuperheater/ million         |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |
| Pipes, valves, accessories, etc./ million | 3.06 | 5.00     | 2.97     | 2.30     | 2.54     | 4.59     | 6.38     | 7.34     | 4.05     | 3.49     | 3.93     | 3.82     |          |          |          |
3.4. Operating cost analysis

The comparison of operating costs of the three schemes is shown in Table 7. It can be seen that the cost of the additional reducing agent in schemes 1 and 2 is higher than scheme 3; the electricity consumption cost of scheme 1 is much higher than schemes 2 and 3; the low pressure steam cost of schemes 1 and 2 is much lower than scheme 3; schemes 3 has the lowest overall operating cost, schemes 2 is second, and schemes 1 is the highest. According to the above analysis, it can be found that this is mainly because the urea pyrolysis conversion rate of scheme 1 and scheme 2 is lower than scheme 3, the scheme 1 uses a high-power electric heater to cause higher energy consumption. and scheme 3 using low-pressure steam as heat source has the lowest energy consumption. Although the energy consumption of the scheme 2 is not high, the overall operating cost is higher than the scheme 3 due to the highest static investment.

Table 7. Running cost comparison table of three design schemes for the study.

| Project                          | Scheme 1 | Scheme 2 | Scheme 3 | Scheme 1 | Scheme 2 | Scheme 3 | Scheme 1 | Scheme 2 | Scheme 3 | Scheme 1 | Scheme 2 | Scheme 3 |
|----------------------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Project total investment / million | 34.26    | 47.63    | 35.46    | 18.02    | 21.85    | 25.08    | 38.96    | 52.16    | 35.91    | 23.13    | 28.34    | 24.00    |
| Annual utilization hours / h     | 5500     | 5500     | 5500     | 6000     | 6000     | 6000     | 5500     | 5500     | 5500     | 6000     | 6000     | 6000     |
| Annual electricity sales GWh     | 6755     | 6755     | 6755     | 1866     | 1866     | 1866     | 6118     | 6118     | 6118     | 3671     | 3671     | 3671     |
| Depreciation cost / million      | 3.30     | 4.58     | 2.27     | 1.16     | 1.40     | 1.61     | 3.75     | 5.02     | 2.30     | 2.23     | 2.73     | 1.54     |
| Repair fee / million             | 0.69     | 0.95     | 0.71     | 0.36     | 0.44     | 0.50     | 0.78     | 1.04     | 0.72     | 0.46     | 0.57     | 0.48     |
| Cost of production / million     | 3.27     | 3.27     | 1.08     | 1.60     | 1.60     | 0.91     | 5.61     | 5.61     | 3.67     | 2.59     | 2.59     | 1.53     |
| Electricity cost / million       | 5.17     | 0.56     | 0.14     | 1.62     | 0.14     | 0.07     | 4.16     | 0.42     | 0.06     | 3.66     | 0.24     | 0.15     |
| Low-pressure steam costs / million | 0.48   | 0.48     | 3.30     | 0.07     | 0.07     | 0.51     | 0.56     | 0.56     | 3.96     | 0.34     | 0.34     | 2.40     |
| Desalination costs / million     | 0.08     | 0.08     | 0.07     | 0.01     | 0.01     | 0.01     | 0.07     | 0.07     | 0.06     | 0.07     | 0.07     | 0.06     |
| Total / million                  | 12.98    | 9.92     | 7.58     | 4.81     | 3.66     | 3.61     | 14.94    | 12.74    | 10.77    | 9.35     | 6.54     | 6.16     |

4. Conclusion

The processes of ammonia production by urea pyrolysis and hydrolysis were mature and feasible, and both had their advantages and disadvantages.

1. The urea consumption and desalination consumption in the process of urea pyrolysis is slightly higher than hydrolysis, the steam consumption is relatively low and the electricity consumption is relatively high. Among them, the electricity consumption of the urea pyrolysis using the electric heater is much higher than the other two schemes, which are using high-temperature flue gas heat exchangers and urea hydrolysers, and the operation cost of the transformation project with urea hydrolysis was the lowest, followed by the high-temperature flue gas heat exchanger scheme, and the electric heater scheme was the highest.

2. The static investment of the transformation project with the electric heater scheme was the lowest, the urea hydrolysis scheme was the second, and the high-temperature flue gas heat exchanger scheme was the highest;

3. The cost of pyrolysis furnaces, electric heaters, flue gas heat exchangers, and hydrolysers is the main factor that affects investment in process system transformation;

4. The more units in the power plant, the lower the unit investment, and the more obvious the advantage of urea hydrolysis scheme;

5. The power plant should reasonably formulate according to its own situation when selecting the transformation process route.
Reference

[1] Energy department of NDRC [2014]2093: Notice on the action plan for upgrading and transformation of coal power energy conservation and emission reduction (2014-2020) [S]

[2] Zhang Chi 2014 Comparison on technologies of preparing ammonia by urea in flue gas denitration[J]. Energy Chemical Industry 35(6) 35-39

[3] Lv Hongkun, Yang Weijuan, Zhou Zhijun, et al 2008 Application of selective non-catalytic reduction on a power plant boiler[J]. Proceedings of the CSEE 28(23) 14-19

[4] Chen Zhenchao, Yang Weijuan, Zhou Junhu, et al 2011 Experimental investigation on the properties of urea thermohydrolysis with catalysts[J]. Proceedings of the CSEE 31(35) 41-46

[5] Zhang Qiang 2007 Technology and engineering application of SCR flue gas denitration in coal-fired power station[M]. Beijing: Chemical Industry Press

[6] Zhao Dongxian, Liu Shaopei, Wu Xiaofeng, et al 2009 Application of urea pyrolysis to prepare ammonia technology into SCR denitrification [J]. Thermal Power Generation 38(8) 65-67

[7] Ye Mao, Yang Zhizhong, Yan Shunjuan, et al 2015 Research on the flue gas-air heat exchanger of urea pyrogenation for SCR flue gas De-NOx technology[J]. Dongfang Electric Review 29(2) 76-82

[8] Xu Wei 2017 Research on flue gas heater for urea pyrolysis of SCR flue gas De-NOx system[J]. Electric Power 50(1) 177-180

[9] Meng Lei 2016 Research on the urea catalytic hydrolysis technology for flue gas SCR denitrification of thermal power plant[J]. Electric Power 49(1) 157-160

[10] Hui Runtang, Wei Fei, Yan Shiping, et al 2014 The industrial application and technical optimization of first domestically-made urea hydrolysis unit in large power plants[J]. Electric Power 47(7) 150-155

[11] Fang H L, Dacosta H F 2003 Urea thermolysis and NOx reduction with and without SCR catalysts[J]. Applied Catalysis B(Environmental) 46(1) 17-34

[12] Schaber P M, Colson J, Higgins S, et al 2004 Thermal decomposition(pyrolysis)of urea in an open reaction vessel[J]. Thermochimica Acta 424(1) 131-142