Economic Operation Analysis of Environmental Protection Facilities in Coal-fired Power Plants under the New Environmental Protection Policy

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Abstract. With the transformation of ultra-low emissions and the increasingly stringent emission standards for environmental pollutants, power plants have to seek the best economic operation mode to meet the requirements of the policy. In this paper, taking a power plant in North China as an example, the economic operation mode of denitrification and desulfurization under the new local policy is considered. When the emission concentration of NOX at the outlet of selective catalytic reduction reactor is controlled in 20 mg/Nm³ and 15 mg/Nm³, the power plant has a significant economic effect. However, the desulfurization system is inappropriate if reduces the SO2 emission concentration.

1. Introduction
The power plants in North China have basically completed the ultra-low emission transformation [1-2]. However, with the influence of the fog and haze environment, new environmental standards have been put forward in each area, and a new test is put forward for the power plant [3]. According to the provisions of <Notice on adjusting the charging standard of sewage charges and other related issues> for Hebei province, it is stipulated that the differential pollution charge policy should be adopted to adjust the standard of pollutant discharge fees [4]. Since January 1, 2017, the standard of sulfur dioxide and nitrogen oxide discharge fee in the exhaust gas has been adjusted to 4.8 yuan per pollution equivalent; when the pollutant emission concentration is below 50% of the prescribed pollutant discharge limit, the sewage charge is halved.

With the adjustment of the policy, if we do not consider the changes in the total pollutant emission, the cost of pollutant discharge will gradually increase year by year [5]. However, according to the policy stipulates that if the emission concentration of the power plant is below the limit of more than 50%, the discharge fee will be reduced by half. In this paper, a power plant in North China is taken as an example. The purpose of this study is to analyze and study the economic operation of the denitrification and desulfurization of two units in the factory and to seek the economic operation model of the policy based on the contents of the regulations concerning the differential pollution charge policy in the notice on the adjustment of the charges for the adjustment of the pollution discharge fee.

Table 1. List of different pollutant discharge charges in different years.

| Dates     | Charging standards of SO2 and NOX, yuan/equivalent |
|-----------|-----------------------------------------------------|
| 2015.1.1  | 2.4 100%-50% of the requirement of emission concentration | 2.4 50% less than the requirement of emission concentration |
2. Experiment and method

In order to realize the low concentration emission of NO\textsubscript{X}, the amount of ammonia in the selective catalytic reduction (SCR) reactor can be increased. Therefore, the additional cost of the increased ammonia injection and the reducing cost of pollutant discharge are required to determine the more economical operation mode [6].

\[
\text{Liquid ammonia consumption} = \text{Utilized hours} \times \text{flue gas} \times (\text{inlet concentration of NO}_x - \text{outlet concentration of NO}_x) / 2.706 / 100000
\]

NO\textsubscript{X} discharge fee = NO\textsubscript{X} emissions / 0.95 * 2.4 (thousand)

In the same way, it is necessary to invest more reducing agents and increase the operating power of the slurry circulating pump to realize low concentration emission of SO\textsubscript{2}. Therefore, it is necessary to calculate the additional cost of the reducing agents, the additional cost of the operating power of the slurry circulating pump and the reducing cost of pollutant discharge by reducing the emission concentration, determining the more economical operation mode [7].

The formula for calculating the environmental cost of SO\textsubscript{2} emissions in different years is as follows:

Before 2017, SO\textsubscript{2} discharge fee = SO\textsubscript{2} emissions / 0.95 * 2.4 (thousand);

After 2017, SO\textsubscript{2} discharge fee = SO\textsubscript{2} emissions / 0.95 * 4.8 (thousand).

Table 2. Experimental contents and experimental instruments.

| Items            | Contents                                                                 |
|------------------|--------------------------------------------------------------------------|
| Experimental load| 300MW.                                                                   |
| Experimental instruments | Flue gas analyzer, temperature tester, thermocouple, ammonia escape tester |
| Experimental content | NH\textsubscript{3} concentration, O\textsubscript{2} concentration, NO\textsubscript{X} concentration and temperature |

3. Results and discussions

3.1. Economic operation analysis of DeNO\textsubscript{x}

Taking the electricity generation in October 2016 as an example, table 3 is a statistical table of generating capacity and NO\textsubscript{X} emission of two generating units (2*1000MW) in October 2016.

Table 3. Statistical table of power generation and NO\textsubscript{X} emission of two units.

| Unit | Monthly average load (MW) | Monthly utilized hours (h) | Flue gas of designed rated load (Nm\textsuperscript{3}) | Inlet NO\textsubscript{X} (mg/m\textsuperscript{3}) | Outlet NO\textsubscript{X} (mg/m\textsuperscript{3}) | Liquid ammonia consumption (t) |
|------|--------------------------|----------------------------|--------------------------------------------------------|-----------------------------------|----------------------------------|-------------------------------|
| 1#   | 942.73                   | 488.36                     | 3185966                                                | 182.43                            | 33                               | 85.89                         |
| 2#   | 940.97                   | 483.38                     | 3185966                                                | 187.52                            | 31                               | 89.05                         |

Table 4 shows that the monthly ammonia consumption and the increased ammonia consumption compared with the current operation when the outlet concentration of NO\textsubscript{X} was controlled as 15/20 mg/m\textsuperscript{3}.

Table 4. Statistical of two units when the NO\textsubscript{X} emission concentration is controlled as 15/20 mg/m\textsuperscript{3}.

| Unit | Monthly average load (MW) | Monthly utilized hours (h) | Flue gas of designed rated load (Nm\textsuperscript{3}) | Inlet NO\textsubscript{X} (mg/m\textsuperscript{3}) | Outlet NO\textsubscript{X} (mg/m\textsuperscript{3}) | Liquid ammonia consumption (t) | Increased ammonia consumption (t) |
|------|--------------------------|----------------------------|--------------------------------------------------------|-----------------------------------|----------------------------------|-------------------------------|----------------------------------|
| 1#   | 942.73                   | 488.36                     | 3185966                                                | 182.43                            | 15.00                            | 96.23                         | 10.35                            |
| 2#   | 940.97                   | 483.38                     | 3185966                                                | 187.52                            | 15.00                            | 98.15                         | 9.10                             |
| 1#   | 942.73                   | 488.36                     | 3185966                                                | 182.43                            | 20.00                            | 93.36                         | 7.47                             |
| 2#   | 940.97                   | 483.38                     | 3185966                                                | 187.52                            | 20.00                            | 95.30                         | 6.26                             |

When the NO\textsubscript{X} emission concentration of the chimney outlet is controlled at 15mg/m\textsuperscript{3}, the monthly ammonia consumption of the two units will increase by 10.35 and 9.10t respectively, and the cost of denitrification agent will increase by 48.6 thousand yuan. When the NO\textsubscript{X} emission concentration of the chimney outlet is controlled at 20mg/m\textsuperscript{3}, the monthly ammonia consumption of the two units will
increase by 7.47 and 6.26 thousand yuan, respectively, and the cost of denitrification agent will increase by 34.3 thousand yuan.

Table 5 compared the costs of two different NOx emission concentrations. In October, if the two units of the plant were in accordance with the current emission concentrations, the NOx sewage charges in 2016 October were 250.3 thousand yuan. Under the condition that the emission concentration is not reduced, the single price of the pollutant is raised to 4.8 yuan/equivalent. When the emission concentration was reduced to 15 and 20 mg/m³ respectively, the NOx discharge fee in October 2017 reduced to 125.1 and 93.9 thousand yuan respectively, with an decrease of 175.3 and 206.5 thousand yuan compared with non-cutting emission concentration. From the point of view of the total cost, when the NOx emission concentration is reduced to 15 and 20 mg/m³, the total cost is reduced by 140.9 and 157.9 thousand yuan respectively, respectively, and with significant economic effects.

Table 5. Comparison between the costs of two different NOx emission concentrations (thousand yuan).

| Unit | Outlet NOx concentration (mg/m³) | Ammonia consumption costs | Annual environmental cost | Total cost | Reduced cost | Annual environmental cost | Total cost | Reduced cost |
|------|---------------------------------|--------------------------|---------------------------|------------|-------------|---------------------------|------------|-------------|
|      | Current running value           |                          |                           |            |             |                           |            |             |
| 1#   | 214.7                           | 129.7                    | 344.4                     | 155.7      | 370.4       |                           |            |             |
|      | 20                              | 78.6                     | 312.0                     | 32.4       | 62.9        | 296.3                     | 74.1       |             |
|      | 15                              | 59.0                     | 299.5                     | 44.9       | 47.2        | 287.8                     | 82.6       |             |
| 2#   | 222.6                           | 120.6                    | 343.2                     | 144.7      | 367.3       |                           |            |             |
|      | 20                              | 77.8                     | 316.1                     | 27.2       | 62.2        | 300.5                     | 66.8       |             |
|      | 15                              | 58.4                     | 303.7                     | 39.5       | 46.7        | 292.1                     | 75.3       |             |

3.2. Economic operation analysis of desulfurization

Statistics of generating capacity, SO2 emission and sewage charges for two generating units were shown in table 6. The cost of SO2 discharge fee in October 2016 was 154.5 thousand Yuan, and the cost of SO2 discharge fee in October 2017 without adjustment measures was 308.9 thousand Yuan. If the total SO2 emission did not change, the plant's SO2 discharge fee would be gradually increasing year by year. According to the policy, if the emission concentration of plant is less than 50% of the prescribed limit, the sewage charge will be reduced by half. The SO2 super net emission quality standard of the plant is 35 mg/Nm³ (hourly mean), and the emission concentration below the limit of 50% is less than 17.5 mg/Nm³.

Table 6. Statistics of generating capacity, SO2 emission and sewage charges for two generating units.

| Unit | SO2 concentration (mg/m³) | Emission standard | inlet average concentration | outlet average concentration | efficiency % | Monthly utilization hour | Flue gas of designed rated load (Nm³) | SO2 emission (t) | Discharge fee (Thousand) |
|------|---------------------------|-------------------|-----------------------------|----------------------------|--------------|-------------------------|--------------------------------------|-----------------|-------------------------|
|      |                           |                   |                             |                            |              |                         |                                      |                 |                         |
| 1#   |                           | 35                | 1374                        | 19.1                       | 98.61        | 488.36                  | 3185966                             | 29.72           | 75.1                    |
|      |                           | 2#                | 35                          | 1394                       | 20.4         | 98.54                   | 483.38                              | 3185966         | 31.42                   |
|      | Sum                       |                   |                             |                            |              |                         |                                      |                 |                         |
| 1#   |                           | 35                | 1374                        | 17.5                       | 98.73        | 488.36                  | 3185966                             | 27.23           | 68.8                    |
|      |                           | 2#                | 35                          | 1394                       | 17.5         | 98.74                   | 483.38                              | 3185966         | 26.95                   |
|      | Sum                       |                   |                             |                            |              |                         |                                      |                 | 68.8                    |

When the SO2 emission concentration drops to 17.5, the SO2 sewage charge is calculated as 136.9 thousand yuan based on the standard of 2.4 yuan/ equivalent, with a reduction of sewage charges is 308.9-136.9=172.0 thousand yuan.

Table 7. Increased electricity consumption after the reduction of SO2 emission concentration for two units.

| Unit | monthly average load (MW) | Utilization hours (h) | Inlet concentration (mg/m³) | Outlet concentration (mg/m³) | Increased current of slurry circulation | Hours with a mean of more than 17.5 (h) | Increased electricity bill (thousand) |
|------|---------------------------|-----------------------|-----------------------------|------------------------------|----------------------------------------|----------------------------------------|--------------------------------------|
|      |                           |                       |                             |                              |                                        |                                        |                                      |
|      |                           |                       |                             |                              |                                        |                                        |                                      |
The electricity charges are calculated according to 0.4 yuan/kW h. In accordance with the need to start another slurry circulating pump above 17.5 mg/m$^3$, the plant will increase the monthly electricity charge by 499.6 thousand yuan. As mentioned above, if the SO$_2$ emission concentration is adjusted, the monthly SO$_2$ emission fee is 172.0-499.6=-327.6 thousand yuan, so the desulfurization system is inappropriate if reduces the SO$_2$ emission concentration.

4. Conclusions
When the emission concentration of NO$_x$ at the outlet of SCR reactor is controlled in 20 mg/Nm$^3$ and 15 mg/Nm$^3$, the total monthly denitrification cost of the whole plant (2*1000 units) is reduced by 140.9 and 157.9 thousand yuan respectively, having significant economic effect. If the SO$_2$ emission concentration is adjusted to 17.5 mg/Nm$^3$, the SO$_2$ emission fee will be increased by 327.6 thousand yuan per month, so the desulfurization system is inappropriate if reduces the SO$_2$ emission concentration.

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