Design and economic evaluation of low concentration methane (CMM) regenerative thermal oxidation heating system

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Abstract: Based on the pursuit of coal mine methane (CMM) emission reduction, CMM utilization and the tendency of heating system in the coal mines sites, a design of the low concentration CMM regenerative oxidation technology (RTO) specified in a coal mine was introduced. The design method of the technology was carried out in detail, and the low concentration CMM regenerative oxidation heating system replacing traditional heating by coal-fired boiler in coal mines was compared technically and economically, including method of “Incremental return on investment” and corrected-cost method. In addition, the application of low concentration technology was prospected. And it would give a great contribution to the design and project promotion in this area.

1. Introduction

Methane is the second largest greenhouse gas after carbon dioxide, accounting for 8% of man-made methane emissions from coal mining, and this proportion is on the rise. It is expected that coal mine gas emissions will reach 793Mt of CO₂ equivalent by 2020[1]. Limited by the storage characteristics of coal seams, CMM accounts for a large proportion of the methane emitted by coal mines, especially the methane with a large concentration less than 8%, which cannot be used for power generation by gas internal combustion engine and is discharged in large quantities, resulting in a significant trend of greenhouse effect and waste of energy. CMM regenerative thermal oxidation technology is a new technology of CMM treatment, and the methane concentration of utilization is less than 1% for completely destruction. Based on the oxidation reaction of methane at high temperature as the basic principle, the technology destroys methane, maintains the heat balance and exports the excess heat output of the system to meet the requirements of different heat loads. This technology can replace the coal burning boiler used in coal mine heating, save coal fuels, reduce the capital and operation cost of desulphurization equipment. At the same time, CMM utilization can obtain national policy subsidies and promote the extraction of CMM for promoting the safety of coal production, which kill two birds with one stone.

According to this technical principle, a lot of research work has been carried out [2-8]. Relevant RTO manufacturers have developed various structures of RTO, and the RTO technology is currently in the stage of popularization and application [9-12].

The research and application of methane regenerative oxidation technology are mainly carried out
by MEGTEC Company of USA and DURR Company of Germany, and so on. The main cases include
Chongqing Songzao Coal Power Co., Ltd. 6×60,000Nm3/h RTO units by MEGTEC company and
Shanxi Lu'an Mining Group Co., Ltd. Gaohe Coal Mine 12×90,000 Nm3/h RTO units by DURR
company for ventilation air methane (VAM) power generation with the capacity of 30MW. In short,
the technology of coal mine methane RTO has a broad application prospect in coal mine field. This
paper designs the scheme of heating by applying this technology to coal mine, and evaluates the
technology and economy, which can be used as a reference for the popularization and application of
related engineering projects.

2. Design of technical scheme

2.1 Technical scheme design conditions

The design conditions of low-concentration methane (CMM) RTO for heating technology scheme
include methane source conditions of coal mine, heating load and supporting facilities of water and
electric public works, and so on.

(1) Methane source conditions
Coal mine has methane drainage pump station, with methane extraction concentration by about 4%,
methane pure flow by 20Nm³/min, stable methane source conditions and stable extraction life by more
than 10 years.

(2) Heating load requirements
Heating load demand mainly includes wellbore heating (WH), building heating (BH) and bathing
load (BL), etc., and the total heat load fluctuates with the change of weather conditions in different
seasons. The annual statistical average heat load of each month can be seen in the figure below.

Figure 1. Coal mine heat load variation by month

The legend "minimum average" in the figure above represents the average monthly minimum
thermal load, "monthly average" represents the average monthly total thermal load, and "maximum
average" represents the average monthly maximum thermal load. The maximum load in actual
operation occurs in January, and the "minimum average", "monthly average" and "maximum average"
are 3624kW, 4567kW and 5510kW respectively. Among them, the "highest average" value of 5510kW
is composed of WH load, the BH load and the BL load, which are respectively 3402kW, 1642kW and
467kW.

With the continuous upgrading of environmental protection requirements, the original coal-fired
boiler heating system cannot meet the environmental protection standards. Therefore, it is necessary to
carry out environmental protection transformation or replace it with a new heating system.

(3) Construction conditions and supporting public works
Coal mine industrial square has a relatively open land for project construction. Water, power supply
and other conditions can meet the needs of the project.
2.2 Technical scheme design method and results

According to the coal mine heating load to determine the construction scale of CMM RTO for heating system, combined with the site conditions to determine the equipment layout plan and equipment selection plan.

(1) Construction scale determination

According to the methane source conditions and the actual heating demand of coal mine, the heat supply capacity of the RTO for heating system is designed to be 7285kW to meet the ultimate load demand. The heat loss coefficient of the hot water transmission pipe network for WH load and BL load is 10%. The heat loss of heating load has been considered in the heating index. The oxidation efficiency is 95%, the heat utilization rate of the oxidation device is 80%, the heat exchange efficiency of the waste heat boiler is 85%, and the concentration of the designed treatment of the oxidation device is 1.2%. Then the calculation scale of oxidation device corresponding to heating capacity of 7285kw equal to 101503Nm³/h, and equivalent pure methane flow is about 20.3Nm³/min.

According to the above calculation results, considering the reliability of system operation, the RTO device size is designed as 100,000 Nm³/h, and two devices of 50,000 Nm³/h should be designed and constructed.

The total maximum methane flow dealt by the RTO device equals to 110,000Nm³/h, which can provide heat of 7653kW. Considering the loss of the WH and the hot water transportation pipe network with BL, it can still meet the annual demand of the maximum total heat load of 7285kW.

(2) RTO for heating process flow and site layout plan

The CMM RTO for heating system constructed by this project needs to provide site conditions with 20m x 50m.

The system is mainly composed of low-concentration CMM conveying security system, CMM/air mixing conveying system, RTO devices, waste heat boiler, chimney, flue gas reflux preheating intake system, monitoring system and so on. The low-concentration CMM is pumped from the ground methane pumping station and sent to the mixer by the security system of low-concentration CMM transportation for mixing with air. The mixture gas is then sent to the RTO by the main fan for oxidation reaction, with heat released to generate high-temperature smoke. In order to prevent the CMM/air mixing and transportation process from freezing in winter, the flue gas discharged from the outlet of waste heat boiler to the chimney is returned to the mixer to mix with the air, so as to increase the inlet temperature of the mixture and avoid potential risks of freezing. The process flow is arranged as follows.

![Figure 2. Process of the methane regenerative oxidation heating system](image)

(3) Equipment selection scheme
1) Low-concentration CMM safety guarantee system

Low-concentration CMM safety guarantee system is mainly composed of water seal, fire retardation and explosion relief device, automatic powder spraying and explosion suppression device, automatic explosion suppression device, flame sensor, pressure sensor, automatic water ejector and monitoring sub-station, and so on.

2) Mixing and conveying system

It is mainly composed of CMM and air mixing device, air inlet pipe, mixed conveying pipe, concentration sensor, flow sensor, flow control valve and other parts.

3) RTO system

It is mainly composed of RTO device, main fan, starting combustion system, chimney and other parts. The treatment flow rate of single unit is 50,000 Nm³/h, with designed methane dealing concentration by 1.2%.

4) Thermal energy utilization system after oxidation

The excess heat generated after oxidation is output in the form of high-temperature flue gas, and hot water is generated by the waste heat boiler to supply the WH, BH and BL load. The main components include flue gas heat pipe, waste heat boiler, heat exchanger, water pump, water softener and other parts.

5) Monitoring and power supply and distribution system

Monitoring system mainly includes analog quantity/digital quantity control system, data acquisition system, display/operating system, power supply/distribution system and other parts. The main hardware equipment is industrial PC, PLC control cabinet, LCD, distribution cabinet and other parts.

6) Public works system

Public works include water treatment system, air compression system, lightning grounding system, fire protection system, water supply/drainage system and other parts.

3. Economic evaluation of technical programs

3.1 Investment estimation of technical scheme

The total static investment is estimated to be 27.92 million yuan, including construction engineering, equipment purchase, installation engineering and other construction costs.

3.2 Economic evaluation index

The economic evaluation index adopts the static investment payback period and the incremental investment return rate method commonly used in engineering technology economy to analyze, compared with the present situation of heat supply by coal-fired boiler. Before adopting the CMM RTO for heating project scheme, the original heating system of coal mine needs to be retrofitted by desulfurization and denitrification. The evaluation index is to compare the original desulphurization and retrofit of the original system with the scheme of using CMM RTO for heating scheme. The details can be seen below.

Table 1: Financial comparison between previous modification and methane regenerative oxidation heating system

| No. | Cost                          | Coal-fired boiler reform | New CMM RTO for heating system (Equipment investment) |
|-----|-------------------------------|--------------------------|------------------------------------------------------|
|     | Unit price | quantity | Amount | Unit price | quantity | Amount |
| 1   | Project investment | 550        | 1      | 550       | 2637      | 1      | 2637   |
| 2   | Fuel cost       | 0.023     | 6000   | 138       | 0.8       | 7.5    | 6.0    |
| 3   | Electric charge | 0.5       | 64.8   | 32.4      | 0.5       | 82.6   | 41.3   |
| 4   | Environmental protection cost | 100 | 1 | 100 | -0.3 | 392 | -117.6 |
| 5   | Carbon emission reduction | 0 | | | 44000 | 0 |
| 6   | Subtotal of differential costs | | | | 270.4 | | -70.3 |

Unit: 10,000 RMB
Artificial, water use, maintenance, etc. The newly built CMM RTO for heating system is highly automated and requires the same number of operators and maintenance personnel as the existing personnel allocation of coal-fired hot air furnace. The other costs are the same.

Relative payback period: (2637.55 – 550) / 340.7 = 6.2 (year)

3.3 Results of technical and economic evaluation

As can be seen from table 1, the CMM RTO for heating system replaces coal-fired boilers for coal mine heating, and the payback period of investment is 6.2 years (the stable life of the CMM RTO system exceeds 15 years). When the project is put into operation, the economic benefits are significant.

In order to have a more comprehensive understanding of the heating solutions and facilitate the decision-making of the project scheme, a variety of alternative solutions for the transformation or elimination of coal-fired boilers are compared, including gas-fired boilers and electric boilers. And the operation economy of the alternative energy supply modes are compared and analyzed as follows.

Since the useful results corresponding to different energy supply schemes are the same (all of which provide certain heat), the commutation cost method can be used to calculate the comparison (commutation cost = production cost + investment×benchmark rate of return, the smaller the value is, the better the economy will be). The comparison results are shown in the following table.

Table 2: Economic comparison between different processes

| No. | Comparative item     | Scheme 1         | Scheme 2         | Scheme 3         | Scheme 4         |
|-----|---------------------|------------------|------------------|------------------|------------------|
| 1   | Heating mode        | Coal-fired boiler reform | CMM RTO for heating system | Gas-fired boilers | Electric boilers |
| 2   | Project investment  | 550.0            | 2637.0           | 650.0            | 460.0            |
| 3   | Cost of production  | 431.3            | 90.6             | 750.6            | 1321.5           |
| 4   | Base earnings ratio | 10%              | 10%              | 10%              | 10%              |
| 5   | Commutation cost    | 486.3            | 354.3            | 815.6            | 1367.5           |

The unit price selected in calculation shows that the electricity price is 0.5 RMB/kWh, the water price is 4 RMB/ton, the diesel oil used by oil-fired boilers is 6.01 RMB/liter, and the natural gas price for industrial pipelines is 2.11 RMB/m³.

As can be seen from table 2, although the initial investment of the CMM RTO for heating scheme is the highest, the commutation cost value calculated by the commutation cost method is the lowest, which means the optimal economic solution.

4. Conclusion and prospect

The technology of CMM RTO for heating is mature and safe, and has many application cases in coal mine. This technology can make use of low concentration CMM and ventilation air methane difficult to use by conventional technology, and greatly improve the utilization ratio of coal mine methane, which conforms to the development trend of the coal mine industry and can meet the requirements of environmental protection.

This design scheme can meet all kinds of thermal load requirements of normal production and life of the mine, by replacing coal-fired boilers to achieve station heating, which is not only conducive to safe production of coal mine, but also has the dual effect of energy saving and environmental protection. The results of economic comparison show that the technical scheme is more economical when the technology is used to replace the coal-fired boiler.

The total amount of low-concentration methane emission in China is huge, resulting in a large amount of waste of resources and serious greenhouse effect, which is extremely destructive to the ecological environment. This project uses the low-concentration CMM discharged as fuel, and the annual carbon dioxide equivalent reduction is 44,000 tons, with obvious energy-saving and emission reduction benefits. At the same time, the project will also provide a new direction and opportunity for the transformation and upgrading of coal mining enterprises.
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