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Application research of low concentration methane oxidation heat supply for underground refrigeration

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Abstract: In order to solve the problem of low concentration coal mine methane (CMM) emission and low utilization rate in coal mine and the underground refrigeration demand of coal mine, this paper puts forward a technology of regenerative thermal oxidation (RTO) to provide waste heat vapor for lithium bromide refrigeration unit, which can effectively solve the problem of low concentration CMM utilization and provide stable heat source output for the refrigeration unit. The integrated process of oxidizing heat supplying to refrigerating unit includes low concentration CMM transportation security system, CMM RTO system and waste heat utilization system. The designed methane concentration is 1.2%, with flow rate 100,000 Nm³/h, and steam heat of 7537kW. The expected effect of project operation is analyzed, and the economy of the project is demonstrated. The technology of CMM RTO supplying steam for underground refrigeration, through the destruction of methane, and the output of heat for underground refrigeration, has multiple meanings of energy saving and emission reduction, improving the utilization efficiency of coal bed gas in coal mine area, and promoting the safe production of coal mine.

1.Introduction

With the signing of the sino-us joint statement, the Chinese government's commitment to peak carbon emissions by 2030 has intensified the importance it attaches to carbon emissions. Low concentration CMM (1% ~ 30%) emitted by coal mines in large quantities every year is highly fluctuating in concentration and flow, unstable in gas source conditions, and low in utilization rate for a long time, resulting in energy waste and a large number of greenhouse gas emissions [1-5]. Because of this, relevant scientific research institutes and enterprises have developed a low concentration CMM RTO technology [6-9], used for treatment of the low concentration CMM and ventilation air methane (VAM) with methane concentration as low as 1%, which can solve the low concentration CMM's problems of concentration fluctuation and unstable combustion [10-12].

At present, most coal-fired boilers are used in coal mines to meet the thermal load requirements. Due to the heavy air pollution caused by coal-fired boilers, the state has successively issued relevant policies and is gradually banning the use of coal-fired boilers in coal mines. However, the fuel cost of gas and oil-fired boilers is high, and the operation is not economical enough. Low-concentration CMM RTO utilization technology can be used as an effective energy solution to meet the thermal load demand of coal



mines. At the same time, according to relevant national policies, the use of methane can also obtain certain policy subsidies. According to the latest financial policy, the subsidy income of 0.3 RMB/Nm³ will be obtained for methane treatment or utilization. Especially in Shanxi, a big coal province, the subsidy income has increased to 0.4 RMB/Nm³. National and local financial subsidy policies will further lay low the cost of low concentration CMM utilization projects, and with the continuous progress of CMM RTO utilization technology [13-20], it will be more conducive to the popularization and application of low concentration CMM RTO technology in coal mines.

Low concentration CMM oxidation produces high temperature flue, which can be sent to waste heat boiler to generate steam, used for building heating (BH), shaft inlet air heating (SIAH), power generation (PG), bathing load (BL), etc., with broad use of heat energy and economic benefits.

At present, some engineering companies related to low concentration CMM utilization have carried out industrial test or practical application projects of low concentration CMM oxidation utilization in coal mine sites, such as the 30MW VAM RTO power generation project in Gaohe coal mine, Shanxi Province. And the application of low concentration CMM RTO technology in coal mine refrigeration system is introduced in this paper.

2.Low concentration CMM RTO technology

The common principle of the low concentration CMM RTO used in coal mine is as follows: the methane is preheated in the fixed-bed regenerative layers, reacted in the combustion chamber, and released heat at the same time for sustaining the system heat balance and output heat flue for thermal utilization. During the reaction flue flows through the opposite side of the regenerative layers, heat would be stored there gradually. After certain time, the flow direction would reverse, then the output of the RTO would become inlet for balance the heat wave and maintain the reaction nonstop.

In the start-up stage, it is necessary to heat the regenerative layers of the RTO to a certain temperature by means of electric heating, fuel oil or gas to ensure that the CMM flow can be preheated to the reaction temperature when passing through. The following figure is the schematic diagram of a four-bed CMM RTO device. The left two chambers are the inlet sides, the upper chamber is the combustion chamber, and the right two chambers are the outlet sides on the present situation. In the next process, the flow direction will be changed to make the outlet chamber become the inlet chamber. But in order to avoid the switching process of large flow fluctuations on the fan pressure head and system safety, switch a room at a time, that is, a complete switching cycle has four flow steps.

Step1, room 1 and room 2 inlet, while room 3 and room 4 outlet; step2, room 2 and room 3 inlet, while room 4 and room 1 outlet; step3, room 3 and room 4 inlet, while room 1 and room 2 outlet; step4, room 4 and room 1 inlet, while room 2 and room 3 outlet.

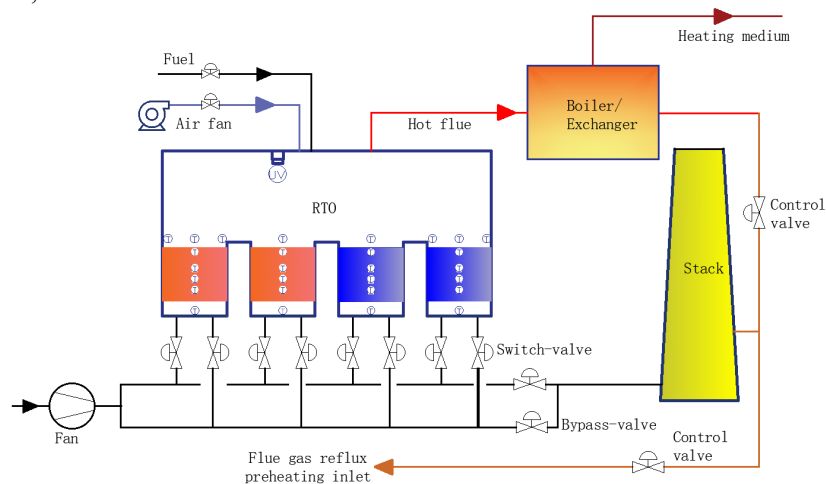


Fig1.The principal of CMM RTO by 4-beds structure devices

3.Design of low concentration CMM RTO for underground cooling system

3.1 refrigeration load requirements

Take a coal mine in north China as an example, the refrigeration load is large, and the underground cooling needs to be provided for up to 7 months in a year. From June to September, when the refrigeration load was biggest, the steam consumption of the lithium bromide refrigeration unit was 8.4t/h, equivalent to 6765kW of heat. The amount of steam consumed in May, October and November was 5.5t/h, equivalent to 4450kW of heat. The steam parameter is 0.6MPa saturated steam.

3.2 Methane source conditions

Referring to the design data of this coal mine and the data obtained from field investigation, the available CMM concentration of this mine is about 10%, the methane pure flow is about 20Nm³/min, the VAM concentration is about 0.1%, and the VAM flow is about 11000Nm³/min.

3.3 RTO output heat

The treatment concentration of CMM RTO is designed according to methane source conditions and heat load requirement. Because the concentration of VAM is too low, its utilization value is small, and it is found in the field investigation that the ventilation is far away from the CMM pump station, which would make the mixing of VAM too expensive, so the CMM is designed to be directly mixed with air, and the methane in the VAM is not utilized.

A set of 100000 Nm³/h CMM RTO device is designed, the concentration of 1.2%, the maximum processing pure methane amount to 20 Nm³/min, regarding heat loss of the device itself, the exhaust gas heat loss and liquid water in CMM absorbing heat during evaporation, which can provide the heat output of 8867 kW, and meet the demand of refrigeration unit's largest steam load 6000 kW.

3.4 CMM RTO generating steam for refrigeration system

The main components of the whole low concentration CMM RTO generating steam for refrigeration system are low concentration CMM transportation security system, CMM/air mixing and mixed gas transportation system, CMM RTO device, waste heat boiler, chimney and boiler steam transportation system. See the following figure for the process flow of the system.

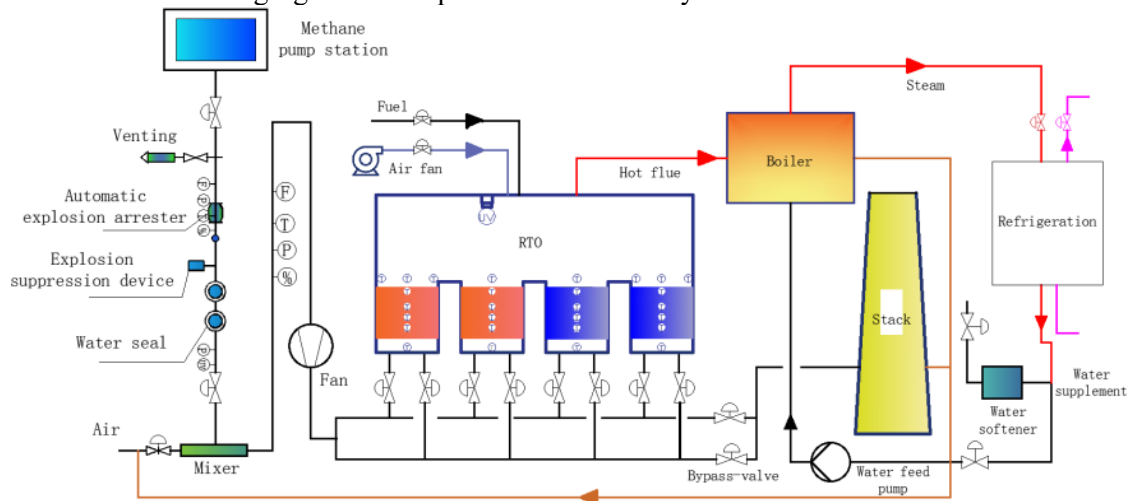


Fig2. Low concentration CMM RTO system supplying steam for refrigeration

(1) Low concentration CMM transportation safety system

The known data shows that CMM is under the condition of atmospheric pressure explosion limit range, so according to the “Low Concentration CMM Pipeline Safety Security System Design Specification” (AQ 1076-2009) request, and to meet the needs of the project operation safety, this project design 1 path of DN500 high negative pressure CMM pipeline with methane concentration of 10%. In addition, an

actuator of conveying security system of low concentration gas is set up on the pipeline. The system is equipped with a regulating valve, a quick shut-off valve, a water seal fire and explosion relief device, an automatic powder spraying explosion suppression device, an explosion prevention valve and so on.

(2) CMM/air mixing and mixture conveying system

The structure of the CMM/air mixer is a double spiral channel structure, with obvious turbulence effect and small resistance, which can ensure that the CMM in the mixer is fully mixed with the air. The flow rate in the mixer is designed at 10m/s, and the pipe diameter of the mixer is DN2000 with a wall thickness of 10mm. One set is required. Resistance is designed to be no more than 500Pa.

(3) CMM RTO device

The CMM RTO device is designed to deal with a flow rate of 100,000 Nm³/h. It is a four-bed structure of double-in and double-out type. The structure is compact. Heat preservation effect is good for small heat loss design. The use of horizontal valve is plate reversing valve, stable and reliable action, low leakage, high methane oxidation efficiency up to 98%.

(4) Waste heat boiler

The waste heat boiler is designed as a horizontal structure, which is arranged on the upper part of the RTO. The evaporation capacity is 10t/h, with production of saturated steam and the pressure is 0.7Mpa.

(5) Stack

The design of the steel chimney, referring to the "Environmental Air Quality Standards" (GB3095-1996) for design, and the chimney suction force was checked and calculated.

(6) Boiler steam conveying system

The steam generated by the boiler is transported to the refrigeration machine room to supply the lithium bromide refrigeration unit. According to the actual situation of the load, the steam flow rate is adjusted, and then the methane treatment concentration of the CMM RTO device is adjusted.

4.Expected operation effect

4.1 Heating analysis

(1) Influence of gas moisture content

When the mixed CMM entering the RTO device with liquid water, water vaporization absorbs heat, which will reduce the available heat output of the RTO device, thus reducing the steam supply. Take the RTO unit with the capacity of 100,000 Nm³/h as an example. When the methane concentration is 1.2% and the water content in the gas changes, the corresponding changes in water evaporation heat absorption, heat output of the RTO unit and steam output are shown in the following table.

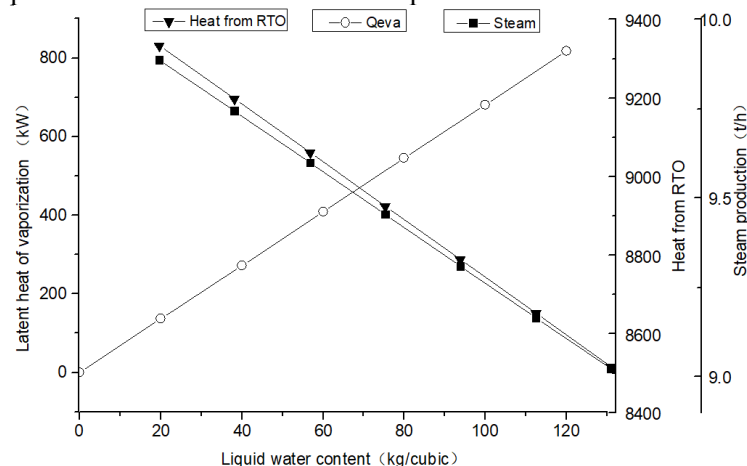


Fig.3 Effect of different water content on heat output and steam output

According to the field measurement data, the water content of the CMM mixture is about 30kg/10,000 Nm³, the heat output of the RTO device is greater than 9100kW, and the steam output is 9.7t/h,

which can meet the demand of the maximum refrigeration load.

(2) Influence of concentration fluctuation

When the methane concentration changes, the heat output of the system will also change correspondingly, as shown in the figure below. When methane concentration is 1.0%, the actual consumption of methane by the system is about $16.7\text{Nm}^3/\text{min}$, and the steam output is 8.2t/h . When the CMM pure flow is stable at $20\text{Nm}^3/\text{min}$, the methane treatment concentration of the system is 1.2%, the steam output of the system is 9.7t/h , which can meet the steam demand of the refrigeration unit.

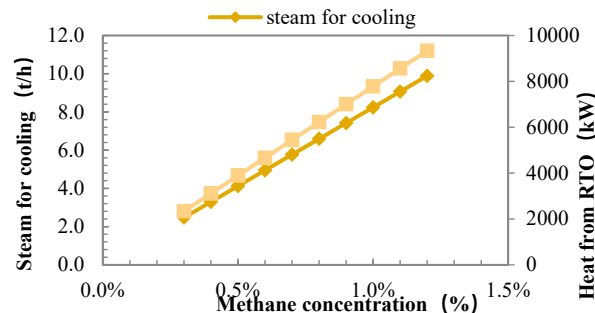


Fig.4 The relationship between methane concentration, heat output and steam production

(3) Influence of load fluctuation

When the load fluctuates, the concentration of methane treated by the CMM RTO unit can be adjusted according to the corresponding thermal load demand to reduce the pure amount of CMM.

As can be seen from figure 4, when the system operates from June to September, the heat load required is 8.4t/h of steam, the corresponding methane concentration of the mixture is 1.03%, and the pure methane consumption is about $17.2\text{Nm}^3/\text{min}$; When the system operates in May, October and November, the heat load required is 5.5t/h steam, the corresponding mixture methane concentration is 0.68%, and the pure methane consumption is $11.3\text{Nm}^3/\text{min}$.

4.2 Analysis of operational economic benefits

The main operating costs of the project are water, electricity, start-up fuel consumption, workers' wages, equipment maintenance, depreciation, etc. The total power consumption of the system is 303kW , and the annual operating cost is 1.8416 million RMB. The main income of the project is methane utilization subsidy and steam income. The gas subsidy is $0.3\text{RMB}/\text{Nm}^3$, and the steam price is $150\text{RMB}/\text{ton}$ according to the local market price. The annual operating income is 6.741 million RMB. The financial evaluation index of the project is shown in the table below.

Table 1 project financial evaluation index

No.	Covariance items	unit	value
1	return on investment	%	72.63%
2	Net profit margin of project capital	%	18.29%
3	Project investment internal rate of return (before income tax)	%	23.89%
4	Net present value of project investment (before income tax)	Ten thousand yuan	1148
5	Project investment payback period (before income tax)	year	4.78
6	Internal rate of return on project investment (after income tax)	%	21.07%
7	Net present value of project investment (after income tax)	Ten thousand yuan	887
8	Project investment payback period (after income tax)	year	5.11
9	Project capital internal rate of return (irr)	%	20.85%
10	Break-even point (utilization rate of production capacity)	%	67.89%

5. Conclusion

Replacing coal fired boiler with CMM RTO device to provide steam heat source for lithium bromide refrigeration unit in coal mine refrigeration machine room, it has the advantages of less pollutant emission, lower operating cost compared with fuel and gas fired boiler and convenient maintenance, etc. After the state has issued the corresponding policies, it will have a good value of promotion and

application. According to the preliminary estimation, the application of this project can reduce the annual carbon dioxide equivalent by 63,000 tons with obvious ecological benefits. By mixing the CMM with VAM or air for RTO utilization, the bottleneck problem of unstable utilization of low concentration CMM is solved, which will help the coal industry better achieve the goal of energy conservation and emission reduction.

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