Study on Waste Heat Resource Utilization System for a Mine

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Abstract: There are a lot of low temperature heat energy in mine return air, and the temperature and humidity are basically constant. This part of heat energy has considerable use value. In this paper, a combination of heat pump technology and return heat recovery unit is proposed, and a small amount of electric energy is used to convert low level heat energy into high heat energy in the return air of the mine, thus replacing the traditional coal-fired boiler system, providing heat source for heating, wellhead antifreeze, and living hot water in the whole year, reducing the use of coal mine in mining area. Reducing the discharge of pollutants has realized the ecological concept of coal mining without coal in the real sense. The research project is located at 20km, west of Fengtai County, Anhui province. The administrative divisions belong to zhangyue Town, Fengtai county. This paper, based on the principle of the mine air source heat pump system, expounds the composition and characteristics of the system, and finally analyzes the economic and social benefits of the project. As the coal mine air source heat pump system uses the waste heat of the mine, the utilization cost of energy is far lower than that of other forms of energy supply. Therefore, the mine return air source heat pump system has good benefits in both social and economic sense. It is worth extensive research and research.

Keywords: Mine Return Air, Air Compressor Waste Heat, Recycle, Economic Analysis

1. Introduction

In China, the energy structure is mainly dependent on the combustion of minerals, especially the coal mineral combustion produces a large number of harmful gases such as CO₂ and SO₂, and the environmental problem can not be overlooked [1]. Coal mine industrial sites have heating needs such as bathing hot water and building heating, which are generally provided by coal (oil) fired boilers, and in the process of burning coal (fuel), a large amount of exhaust gas is emitted to the surrounding environment, resulting in environmental pollution [2-4]. There is a rich heat energy in the mine air return. According to incomplete statistics, the air return temperature of the mine is kept at 18 ~ 28 degrees, the relative humidity is more than 90%, which is almost unaffected by the external environment. It is a kind of stable high quality waste heat resource [5]. It is found that there is a lot of heat energy in the ventilation of the mine and the operation process of the fan. It is a great significance to change the traditional heat supply mode of coal mine and save energy and reduce emission of air pollutant by using the coal mine air source heat pump technology and the waste heat recovery technology of the fan [6]. In 2009, in view of the environmental problems such as low pressure and low temperature in the Northwest Plateau, Sheng and Xin [7, 8] proposed the idea of building the recovery system for the waste heat heat pipe of mine ventilation, and demonstrated the feasibility of this concept from two aspects of economy and technology. According to the characteristics of Zhangxiaolou Coal Mine, Guo adopted return air from the deep mine as the cooling energy for deep mine cooling system [9]. Taking Sanhejian coal mine as an example, Ting introduced the technology scheme of heat disaster governance by using surface water cold source [10].

The research project is located at 20km, west of Fengtai County, Anhui province. The administrative divisions belong to zhangyue Town, Fengtai county. The project will combine the actual situation of the mining area, applying the existing advanced energy saving technologies, carrying out the analysis and designing of waste heat recovery and utilization, adopting the new technology of recovery of the mine air return
heat pump and the residual heat of the fan. It can provide the heat resource for the winter heating, the wellhead antifreeze and the living hot water in the factory area. Meanwhile, it also practices the concept of "low carbon operation ecological mine construction".

Figure 1. The system diagram of mine return air heat pump system.

Figure 2. The principle of air compressor.

2. Work Principle

The coal mine air source heat pump system is composed of the mine air return heat exchanger and the diffusion tower (the two parties constitute the return air heat exchange device), the power plant, the pool, the sink and the accessories. The core device of the mine return air heat recovery system is the return air heat exchanger. The return air of the mine is pressed into the diffusion tower under the fan, so that the return air of the mine is converted into low-speed, uniform and stable air flow. The air flow is fully contacted with the high density atomized water droplets in the air return heat exchanger to complete the heat and moisture exchange between the gas and water. After the exchange, the return air of the mine is discharged to the atmosphere through the baffle plate, and the spray water enters the sink and then is transported to the heat pump unit. The System diagram [11] is shown in Figure 1.

|                                | Winter | Transition season | Summer |
|--------------------------------|--------|-------------------|--------|
| building heating load (kW)     | 648    | —                 | —      |
| bathing hot water load (kW)    | 195    | 160               | 160    |
| Wellhead anti-freezing load (kW)| 1725   | —                 | —      |
| Total                          | 2568   | 160               | 160    |

The mine fan is a common power equipment with a large energy consumption. In the working process of the mine fan, some heat energy is converted into the potential energy of compressed air, and the other part of the heat energy discharged into the air in the form of waste heat is wasted. At the same time, in order to ensure the normal operation of the air compressor, it is necessary to consume electric energy to start the cooling fan to reduce the oil temperature of the air compressor. In the process of compressor operation, the heat energy of high temperature oil and gas can be transmitted to
water in normal temperature through high efficiency heat exchanger. As shown in Figure 2, energy conversion is used to preheat the domestic hot water while reducing the temperature of the compressor oil, so as to realize the waste heat recovery [12].

3. Engineering Situation

3.1. Calculating Total Heat Consumption in Mine Wind Field

1) Floor building heating area is about 7000m², and the temperature requirements of heating indoor is 18-24 degrees;
2) A year about 300 staff members need bathing hot water, and the temperature of bathing hot water is more than 45 degrees.
3) Inlet shaft is antifreeze and heated in winter, the air intake is 2200-2500m³/min, and the inlet temperature is more than 2°C in winter.

After calculation, the maximum load of building heating is 648kW, the maximum load of bathing hot water is 150kW, and the wellhead anti freezing heating load is 1725 kW. Calculating loads is shown in Table 1.

| Item project                  | Number |
|-------------------------------|--------|
| Waste heat of pressure fans   | 160*3  |
| Average loading rate (%)      | 75     |
| Cooling oil temperature (°C)  | 65-90  |
| Return air volume(m³/min)     | 6500-8500 |
| Mine return air               |        |
| Exhaust air temperature (°C)  | 15-18  |
| Relative humidity of exhaust air (%) | 60-80 |

3.2. Investigation and Analysis of Waste Heat Resource in Mine

According to field investigation, the situation of waste heat resource with available value in the mine shaft yard is as follows:

3.3. Calculation of Residual Heat

1) Calculation of residual heat of pressure fans

The waste heat of pressure fans was evaluated by:

\[ Q_y = N \times n \times \rho \times K \]

Where N is the single machine capacity for the fan, n the operation number, \( \rho \) the average loading rate, K the heat recovery rate.

2) Calculation of residual heat in mine [13]

According to the investigation, air return volume of the coal mine is about 6500-8500m³/min, the temperature is 15°C and the relative humidity is 60%. After the comprehensive heating device, the design air temperature is 2°C, and the relative humidity is 95%. The residual heat in mine is evaluated by:

\[ Q_f = \frac{L \times \rho \times (H_i - H_o)}{60} \]

Where L is the design of air return volume (6500m³/min), \( \rho \) the return air density, \( H_i \) and \( H_o \) the enthalpy value of return air entering and exiting the comprehensive heat collector.

3) Calculation of total waste heat in mine

The total residual heat of well field in mine is given in Table 3. The total heat of the mine shaft is 2659kW, and the remaining heat fully meets the demand of the air shaft heating load that is 2568kW.

| Residual heat(kW) | Pressure fan | Mine exhaust air | Total |
|-------------------|--------------|------------------|-------|
| 214               | 2445         | 2659             |

4. The Scheme of Waste Heat Utilization

According to the situation of the residual heat resources of the pressure fan, the index of heat can fully meet the heating demand of the bath hot water in this field, such as scale, continuity and stability. So the residual heat of the fan can be used as the heating source of the bath hot water system [14]. The residual heat of the fan is about 214kW, thus three devices are selected for the waste heat recovery. The average heat recovery is 107kW, and two devices are in operation and one is spare. The operation number of device is corresponding to the fan, and the device runs in a chain. Besides, the system use a separate outdoor pipe network system.

The main engine of the return air heat pump can choose two sets of SRSL-1210, its heat supply is 1220kW, and the supply and return water temperature is 50°C and 45°C, respectively. Two main sets run in heating season, and two sets of pipe network systems are installed outside the room, which are connected by the distributor and collector in the engine room, one for building heating, another for the wellhead heat use, other seasons stop operating.

In order to ensure the temperature in the borehole to meet the production requirements, facilitating the operation and management, saving energy, six antifreeze air heating equipment are chosen for air heating design of downcast, whose heating capacity is 303kW and air volume is 15000m³/h, so the total heating capacity is 1818kW.

5. System Investment Estimation

According to the planning and design of heating system and the selection of main equipment [15], the total investment of the heat recovery heating system for the coal mine field waste heat recovery is about 10.97 million yuan, which is detailed in Table 4.

| Device name                      | Number | Unit price(thousand yuan) | remarks   |
|----------------------------------|--------|---------------------------|-----------|
| Waste heat recovery unit          | 3      | 105                       | One spare |
| First hot water circulating pump  | 2      | 4.6                       | One spare |
6. Analysis of System Benefit

6.1. Energy Consumption Analysis [16]

1) Annual energy consumption of bathing hot water preparation system

The system has only two pumps to consume electricity all year round, and power consumption of each pump is 1.5kW, which run for 24 hours a day and 365 days a year, so its annual electricity consumption is as follows:

\[
1.5 \times 2 \times 365 \times 24 = 26,300 \text{ kWh}
\]

2) Antifreeze and heating system for building heating and measure wells

In winter, two heat pumps, one hot water circulating pumps and six heating units are operating. The winter heating season is calculated for 24 hours a day and 120 days a year. The power consumption is as follows:

\[
(169 \times 2 \times 4 + 45 + 3 \times 6) \times 120 \times 24 = 57,080 \text{ kWh.}
\]

3) The total annual electricity consumption of the waste heat heating system in the mine shaft yard is 597,100 kWh.

6.2. Investment and Operation Cost Analysis

1) Energy cost

According to the local average electricity price of 0.68 yuan/kWh, the annual heating power consumption cost of coal mine ventilation shaft heat recovery system is 406,000 yuan.

2) The operation and management cost of a year

About three people are deployed to operate and manage the waste heat supply system. The average annual salary is calculated by 50,000 yuan, so the management cost is about 150,000 yuan.

3) The annual maintenance cost of the system equipment

The total investment of the system is about 5,244,400 yuan. According to previous engineering experience, the annual operation and maintenance cost of the system can be calculated by 2% of total investment: 5,244,400 x 0.02 = 104,888 yuan.

4) The total annual operating cost of the waste heat supply system is about 661,000 yuan.

5) If the traditional coal-fired steam boiler is adopted to heating, according to the maximum design heat load calculated before, one steam boilers need to be configured whose vaporization is 6 t/h. The overall distribution load of the boiler house is about 60 kW, the comprehensive thermal efficiency of the coal-fired steam boiler is 50% annually, and the total annual cost is 1,420,000 yuan. The calculation is shown in Table 5.

| Device name                                      | Number | Unit price (thousand yuan) | remarks |
|-------------------------------------------------|--------|---------------------------|---------|
| Secondary hot water circulating pump            | 2      | 4.6                       | One spare |
| Plate heat exchanger                            | 2      | 49                        |         |
| Thermal storage tank                            | 2      | 20                        |         |
| Heat preservation and heating water tank        | 1      | 8                         |         |
| Water softener device I                         | 1      | 10                        |         |
| Constant pressure device with makeup water I   | 1      | 10                        |         |
| Compressor condensing unit with return air heat pump | 2      | 600                       |         |
| Return air heating box                          | 8      | 118.                      |         |
| Hot water circulating pump                      | 2      | 20                        | One spare |
| Water softener device II                        | 1      | 18                        |         |
| Constant pressure device with makeup water II  | 1      | 18                        |         |
| Special air heating unit for coal mine          | 6      | 90                        |         |
| Conveyance system                               |        | 180                       |         |
| Total                                           |        | 5244.4                    |         |

| Unit                      | Cost       | remarks                              |
|---------------------------|------------|--------------------------------------|
| Heating load              | kW 2568    | Installed capacity of heating equipment |
| Annual heat supply        | GJ 25,000  | Annual average                        |
| Average daily heating time| h 24       | Raw coal 5500Kcal/kg                  |
| Annual consumption of raw coal | t 2174       | Raw coal price is 200yuan/t           |
| Annual power consumption  | yuan 435,000| Electricity price is 0.68 yuan / degree |
| Annual environmental protection cost | yuan 330,000 | Removal of PM2.5 with desulphurization and denitrification |
| Softening water consumption Cost       | t 7,000     | Soft water treatment unit price IS 15 yuan / ton |
| Annual management cost    | People number 4 | Management fee of per capita is50 thousand yuan per year |
| Annual transportation cost| t 2500     | 25yuan/t                              |
| Plant maintenance and upkeep cost | yuan 62,500 | Accounting for 2% of the total investment cost |
| Annual total cost         | yuan 1,420,000|                                      |
6.3. Benefit Analysis

6.3.1. Economic Benefit

By calculating, the total investment of the traditional gas boiler and waste heat recovery system is about 3,000,000 yuan and 5,244,400 yuan, respectively. Compared with the coal-fired steam boiler heating system, 759,000 yuan can be saved which is the annual operating cost. The total new investment of this project is about 2,244,400 yuan, and the static investment recovery period is 2.95 years. It can be seen that the project has notable economic benefits.

6.3.2. Social Benefit

The annual maximum heating load of the project is 2568kW, the annual heat consumption of the coal-fired steam boiler is 25,000 GJ, and the waste heat utilization system consumes 791 thousand and 800 degrees. According to China’s coal and electricity conversion standard which 1 degree of electricity consume 0.298 kilogram coal, the project is equivalent to the consumption of the standard coal for 236 tons in the whole year. If coal-fired boiler are used for heating and its annual comprehensive thermal efficiency is calculated by 50%, coal fired boiler will consume 1708 tons of standard coal. After the implementation of this project, the burning capacity of standard coal can be reduced about 1472 tons, and its energy saving and emission reduction rate will be as high as 86%. The amount of pollutant reduction is shown in Table 6 and the environmental value of emission reduction is shown in Table 7.

From the above table, it can be seen that various pollutants can be reduced about 5,800 tons and the environmental benefit is about 331,000 yuan after the implementation of this project.

7. Conclusion

Compared with the coal-fired boiler, by using the coal mine waste heat resource utilization system the operating cost can be saved about 971,000 yuan each year. About 1,472 tons of standard coal and 5,800 tons of pollutants are reduced, and the environmental benefits are about 331,000 yuan. This technology possesses significant social, economic and environmental benefits. The utilization system of waste heat resources in mine is used to effectively extract the waste heat of low grade energy and pressures fan in the mine air return, which reduces energy consumption and realizes the low carbon and efficient operation of the system in real sense.

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