The use of heat pumps technology in automated distributed system for utilization of low-temperature energy of mine water and ventilation air

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Abstract
The article discusses the possibility of using heat pumps for heat utilization of mine water and ventilation air. In the article the classical methods of analysis parameters of the particular system at one of the mines of Kryvyi Rih Basin and methods of the modern theory of automatic supervisory control of distributed systems were used.
Keywords: MINE WATER, VENTILATION AIR, HEAT PUMP, MINE MICROCLIMATE, AUTOMATED DISTRIBUTED SYSTEM, SCADA

Introduction

Nowadays much attention is paid to sources of the low-potential heat energy (LPHE). A total of more than 6.7 million heat pump units were installed since 1994 [1]. Their use saved 99.1 TW·h of final and 47.1 TW·h of primary energy [1]. In this regard, in recent years a large number of studies and analytical materials have been published, which highlight heat pumping solutions and their potential for household and industrial usage [2–8]. One promising direction of heat pumps application is the using of low-temperature renewable energy sources of mines [9]. The use of mine water for space heating or cooling purposes has been demonstrated to be feasible and economic in applications in Scotland, Canada, Norway, and the USA [10]. In mines the sources of low-potential heat energy (LPHE) areas are as follows: a fan with the capacity of 500 m^3/sec produces $3.8 \cdot 10^8$ kJ of heat annually; mine drainage with the flow rate of 150 m^3/h produces up to $2.9 \cdot 10^9$ kJ heat annually. Mines annually release this tremendous amount of heat into the atmosphere or water in the form of mine water and ventilation air. With a heat pump we can reuse this heat for heating, production of hot water/steam for industrial processes and so on.

Materials and Methods

The annual volume of water with the constant year-round temperature of 14-17 C pumped out of 12 Kryvyi Rih mines is assessed to be about 12 mln m^3, its energy potential being 200 mln kWh per year. The feasibility study of the initial project that can be implemented in Kryvyi Rih is presented to demonstrate the above said. In the city with the population of 655,000 people centralized heating boiler stations produce over 4200 thousand Gcal a year.

The suggested pilot project can provide heat for a mine and partly for one of Kryvyi Rih wards and produce 58008,5583 Gcal annually that makes nearly 1,4% of heat consumption of the city. On average, when using the whole potential of low-temperature sources, it is possible to install heat pumps with total power of 13000 kW each of 12 mines of Kryvyi Rih. Calculation of required heat power is based on the information about volume of heated premises, difference between air temperature outside and required temperature inside the premises and dispersion coefficient (depends on the type of design and heat insulation of the premises). For the conditions of administration and service building of one of the Kryvyi Rih mine the calculation gives a value 1264 kW. The production buildings of the mine's crushing section and workshops require approximately the same amount of heat power as the above mentioned administration and service building, i.e. 1264 kW. Without heat consumption for hot water supply, the total calculated power for heating will make 2528 kW. The available statistics shows that the heat power for hot water supply is approximately equal to the power required for heating – 2600 kW. The total calculated heat power for hot water supply and heating will be consequently equal to 5128 kW. In 2013 the mine boiler station consumed 6361,95 thousand m^3 of gas, i.e. the necessary amount of heat made 51213,7 Gcal (gas caloricity of 8,05 Gcal/1000 m^3 was taken as the basis for the calculations). To fully refuse gas consumption for the mine it is necessary to install heat pumps with total power of 5846312,785 kcal·h (6798,04 kW). The divergence of over 1500 kW of the required heat power testifies unpractical use of heat at the mine (bad heat insulation of buildings, heat pipeline system, low boiler station efficiency, etc.).

The next step is to determine the possible heat power from mine waters and air and select heat pumps. Heat pump power is determined from the mine water volume consumption:

$$Q_{t(water)} = L_{(w)} \cdot p_{(w)} \cdot c_{v(w)} \cdot \Delta t_{(w)}, \qquad (1)$$

where $L_{(w)}$ – is water volume consumption, m^3/h; $c_{v(w)}$ –is the specific heat of water, kW·h/kg K; $p_{(w)}$– iswater density, kg/m^3; $\Delta t_{(w)}$– is difference between intake and returned water temperature, K. For the conditions of considered mine the calculation gives a value 3923 kW.

Air heat pump power is determined from volume consumption of mine ventilation air:

$$Q_{t(air)} = L_{(a)} \cdot p_{(a)} \cdot c_{v(a)} \cdot \Delta t_{(a)}, \qquad (2)$$

where $L_{(a)}$ –is air volume consumption, m^3/h; $c_{v(a)}$– is specific heat of air, kW·h/kg K; $p_{(a)}$– is air density, kg/m^3; $\Delta t_{(a)}$– is intake and returned air temperature difference, 12K. For the conditions of considered mine the calculation gives a value 4700 kW.

This power is utilized by heat pumps in ventilation shafts. Considering the fact that a heat pump is also placed in the cage shaft where air is intaken, the utilized power can double and then the total amount of power utilized by water and air pumps will make 13322,594 kW. For realization of the described system can be used WaterkotteDSheat pumps (Germany), that are the most powerful on our market [11]. It is also advisable pay attention to the products OilonChillHeat [12]. To ensure the effective functioning of described complex of equipment it is expedient to implement an automated process control system of utilization of low-temperature energy of mine water and ventilation air. Similar problems are solved at different stages of the ore extraction and its processing [7, 12–18]. The most appropriate control system for this complex is a SCADA (supervisory control and data acquisition) system with displaying models of processes of the complex on a screen of the operator's station. To solve the problem of optimal control of the process of generation and utilization of low-temperature energy of mine water and ventilation air is necessary to obtain an adequate mathematical model of the process. For this purposes work is underway on develop a system of supervisory control and data acquisition, which will display the status of the process equipment and the values of regime parameters of heat pumps, as well as collect data for further analysis.

Fig. 1 shows one page of developed SCADA for visualization of the state of the heat pump for the utilization of low-temperature energy of mine water (air). The system displays values of the temperature of the heat pump, the evaporation pressure and the condensation pressure, the electric power consumed by the compressor, heat power generated by the heat pump, the state of the equipment (pumps, compressors, valves, tank).

Results

The pilot project implementation effect: reduction of gas consumption due to operation of heat pumps on 6000 thousand m^3 a year (at the cost of gas of 4,02 UAH/m^3 the annual amount for gas consumption at a boiler station will make UAH 24,12 mln or 1,5075 mln EUR); reduction of atmospheric emissions by over 100 t/year; reduction of thermal pollution of the atmosphere by over 20 thousand Gcal/year. The amount of financing (the project and implementation) will make about 1810 thousand EUR. Taking into account electric power costs increase (982094 EUR in a year), the annual effect from implementation of the project will amount over 427906 EUR.The payback period of the project is 4 years and 3 months.

Conclusion

The results of the development of initial materials for the conceptual design of the automated distributed system for utilization of low-temperature energy of mine water and ventilation air on the basis of the technology of heat pumps for hot water supplying of mining premises on the surface and improving the microclimate of working area miners in deep horizons of mines are presented.

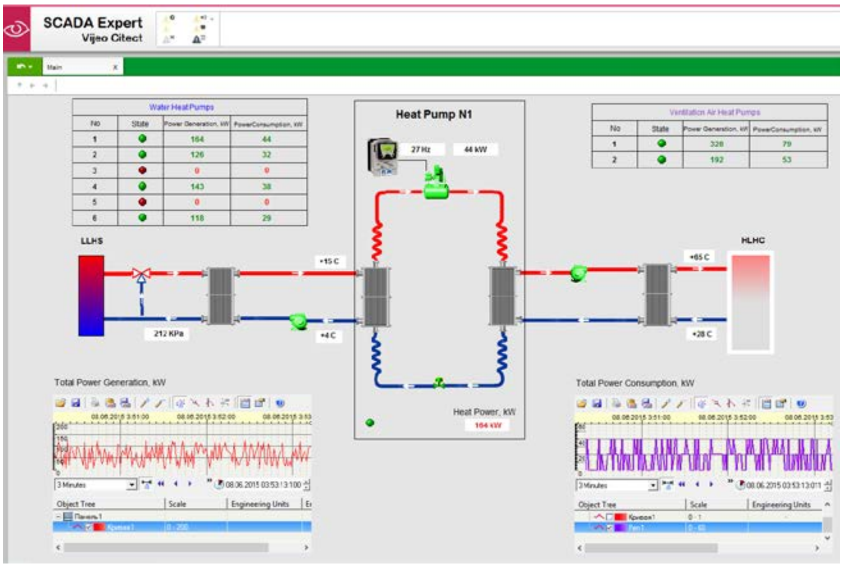

Figure 1. Visualization of the state of the heat pump for the utilization of low-temperature energy of mine water

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