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 3.8·10$^8$ kJ of heat annually; mine drainage with the flow rate of 150 m$^3$/h produces up to 2.9·10$^9$ 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 Kriviy 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 Kriviy 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 Kriviy 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 Kriviy 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 Kriviy 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:

$$Q_{\text{(water)}} = L(w) \cdot P(w) \cdot c(w) \cdot \Delta t(w),$$  \hspace{1cm} (1)

where $L(w)$ – is water volume consumption, m$^3$/h; $c(w)$ –is the specific heat of water, kW·h/kg·K; $P(w)$– is water 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:

$$Q_{\text{(air)}} = L(a) \cdot P(a) \cdot c(a) \cdot \Delta t(a),$$  \hspace{1cm} (2)

where $L(a)$ –is air volume consumption, m$^3$/h; $c(a)$– 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 it is necessary to obtain an adequate mathematical model of the process. For this purposes work is underway on develop a system of supervisory
Automatization
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 m³ a
year (at the cost of gas of 4,02 UAH/m³ 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.

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