Use of natural draught for improvement of airing efficiency in the oil mine production unit

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Abstract: A method of airing the oil mine production unit, in which a heated oil reservoir is separated from the working area with a thermal barrier, is proposed. The evaporator of the air conditioning system will cool the air in the working area, and the heated air will be "blown out" from the condenser behind the thermal barrier and further through the well to the surface. In this case, two sections will be formed: one with heated air and the other with cooled air flows, thus causing a natural draught that contributes to airing. In this case, in addition to providing comfortable working conditions in the working area of the production unit, it will be possible to reduce energy costs for oil mine airing.

1. Introduction

The method of oil production is determined depending on its physical and chemical properties. In world practice, there are quite a lot of such methods, which allow carrying out the present process effectively, but the production of high-viscosity oil is especially difficult. Unique is the method of production used in the Yaregskoe oil titanium field of high-viscosity oil (12000 - 16000 mPa·s, at the reservoir temperature of 6-8 ºC), which is called “thermoshaft” method of production [1-3]. This method implies superheated steam injection into the pay zone. After steam penetrates into the pay zone, it is uniformly heated. As a result of this increase in the reservoir temperature, the oil in the reservoir passes from solid-state to liquid, i.e. becomes more flowing, after which it is possible to extract it.

Since the thermoshaft method of production involves heating the reservoir to a sufficiently high temperature, there is a problem of deteriorating hygiene and sanitary conditions in the working area. Nowadays, traditional methods are used to solve this problem:

1. Increase of air velocity in the mine opening due to an increase in capacity of the main fan unit (HVU).
2. Cooling of the air entering the oil mine in cooling units located on the surface.
3. Cooling of air immediately before it is supplied to the working area.

In the first case, there are unjustified energy costs for the HVU, which is one of the main energy consumers of the oil mine. At the same time, it should be considered that the HVU resources are not unlimited, and it will be impossible to achieve continuous capacity improvement. In addition, there are limitations on the maximum air speed in mine openings.

In the second case, the effectiveness of the proposed activities is also questionable. This is related to the fact that after surface air cooling in the air conditioning system (ACS), it passes quite a
long distance through the mine openings. As a result, the air temperature becomes equal to that of the rocks. Therefore, the operation of the ACS in this case will not achieve the desired effect.

The third way is to reduce the air temperature in the working area, but it has a significant drawback. When cooling the air, the oil reservoir in the working area is simultaneously cooled, which, as mentioned above, must be heated. And since the difference between the air heated to high temperatures (can reach 70-75°C [4]) and the air cooled to the required values will be significant, the cost of ACS operation will increase dramatically. Since the ACS consumes a significant amount of power [5], its use in such a variant will also be low effective.

In view of the fact that it is impossible to eliminate both problems using traditional methods, nowadays alternative ways of problem solution are offered [4, 6-11]. The given methods have advantages. However, each of them allows ensuring either only energy saving during airing or only improvement of hygiene and sanitary working conditions in the working area. In this connection, it is necessary to develop a method of airing the oil mine production unit, which allows solving both these tasks simultaneously.

For the joint solution of problems to improve the working conditions of miners while reducing energy costs (compared with existing methods), the following method of airing the oil mine production unit has been proposed.

To provide the required hygiene and sanitary working conditions in the working area (working area of the production unit) in the method under consideration, it is supposed to use the ACS. However, in this case, the drawbacks related to the rock massif cooling and unnecessarily high power consumption for air cooling system operation will be eliminated.

Since the ACS consists of an evaporator, in which the incoming air is cooled, and a condenser, in which the refrigerant is cooled, resulting in a flow of heated air at its outlet, both of these flows should be separated [12]. For this purpose, the section of the heated reservoir in the production unit is separated with a thermal barrier (figure 1). At the same time, the thermal barrier prevents the heated air from entering the working area and the outgoing mine openings. All the heated air is removed through the air hole to the surface (figure 2) due to the natural draught [13-17] - the phenomenon of convective heat exchange, when warm air tends to go up. To reduce the volume flow rate of air removed through the air hole to the surface (not participating in the airing of the working area), an automatically controlled air gate is provided between the mine opening and the thermal barrier. The natural draught arising, in this case, contributes to the air inflow into the production unit, but at the expense of the air gate, the main part of it flows through the ACS evaporator into the working area.

Another ACS can be used in the method, which will cool the air directly in the working area (figure 1). In this case, the condenser of the above-mentioned ACS will be located at the mouth of the air hole (figure 2). As warm air is "discharged" from the condenser, its natural draught will increase, and therefore the volume flow of fresh air into the production unit will increase.

2. Algorithm for calculating the amount of natural draught that occurs in the oil mine production unit

In the proposed airing scheme, the air flows are divided into two directions, one of which has an outlet to the surface, i.e. the connection with the production unit will be through the daylight surface, shafts, and mine openings. Since such a scheme is a complex extensive network, it is impossible to calculate the air distribution in it separately from the whole oil mine. Therefore, an algorithm described in [9] is adopted for calculations, in which it is possible to determine the value of natural draught at known parameters of mine openings and then calculate the air distribution in a separate unit.

Airing scheme is initially presented as a ventilation network (figure 3). In the scheme, the circuit bypass direction is absolutely random. Without consideration of the directions of air flows in the branches, the sequence of the circuit bypass is determined. For figure 2, the bypass sequence will be as follows: 2, 4, 6, 5, 3, 1, where the digits are the designation of the branch number.

For the ventilation network of the oil mine production unit, the following branches are marked: 1 – intake opening of the production unit; 2 – the area between the oil reservoir and the thermal barrier; 3
– working area; 4 – ventilation pipe; 5 – return opening. Digit 6 designates a reference branch, which includes the oil mine section from the place of exit of the ventilation pipe to the daylight surface to the place of air inlet into the intake opening of the production unit.

Figure 1. The proposed method of airing the oil mine production unit (top view): 1 – intake opening of the production unit; 2 – fresh air; 3 – evaporator of the first air conditioning system; 4 – cooled air; 5 – working area; 6 – heated air; 7 – condenser of the first air conditioning system; 8 – refrigerant pipeline; 9 – regulating device in the pipeline 8; 10 – thermal barrier; 11 – air hole; 12 – return opening; 13 – outgoing air; 14 – air temperature sensor installed in the intake opening; 15 – air flow sensor installed in the intake opening; 16 – evaporator of the second air conditioning system; 17 – condenser of the second air conditioning system; 18 – air cooled in the evaporator 16; 19 – regulating device in the pipeline with the refrigerant 20; 20 – refrigerant pipeline; 21 – section between the oil reservoir and the thermal barrier 10; 22 – controlled air gate; 23 – air gate 22 controller; 24 – air temperature sensor installed in the return opening; 25 – air flow sensor installed in the return opening.
Figure 2. Proposed method of airing the oil mine production unit (air hole section): 1 – thermal barrier; 2 – return opening; 3 – condenser of the second air conditioning system; 4 – heated air; 5 – air hole; 6 – ventilation pipe.

Figure 3. Ventilation network of the production unit according to the proposed scheme: $h_{\text{evap}}$ – pressure developed by the ACS evaporator; $h_{\text{cond}}$ – pressure developed by the ACS condenser; $h_{\text{e}}$ – natural draught in the circuit.
At the beginning of any $i$-th branch, the airflow inlet point is taken, and the outlet point is considered the end of that branch. Variables $P$ and $H$ are used to designate, respectively, the absolute atmospheric pressure and the altitude mark of a branch, i.e. at the beginning of the $i$-th branch the air pressure will be designated as $P_{1(i)}$, and the altitude mark of this point will be designated with the use of $H_{1(i)}$. At the end of this branch, the parameters will be marked as $P_{2(i)}$ and $H_{2(i)}$. The entire ventilation network (or part of it) will be represented as a vertical plane projection (Figure 3). Once the bypass direction is selected, the positions of air inlet into and outlet from the branches will be recorded. According to the selected bypass direction, the initial branch will be branch 2 in which air movement is conditionally accepted to be from the point $(P_{1(2)}, H_{1(2)})$ to the point $(P_{2(2)}, H_{2(2)})$. All branches in the circuit bypass direction are considered in the same way. After the circuit ("conditional branch") is closed, the value of natural draught in it may be determined as algebraic sum of masses of vertical or inclined air columns according to the formula:

$$h_{ej} = 9.81 \sum_{j=1}^{n} \rho_{(i)} \cdot H_{(i)}$$

(1)

where $h_{ej}$ is the natural draft in the $j$-th circuit, Pa; $\rho_{(i)}$ - average air density in the $i$-th branch included in the $j$-th circuit, kg/m$^3$; $H_{(i)}$ is the vertical length of the branch, m, which can be determined as a difference in elevation marks.

$$H_{(i)} = H_{1(i)} - H_{2(i)}$$

(2)

where $n$ is the number of branches in the $j$-th circuit.

According to Fig. 2, expression (2) will be written for each branch of the circuit:

- for branch 2
  \[ H_{(2)} = H_{1(2)} - H_{2(2)}; \]
- for branch 4
  \[ H_{(4)} = H_{1(4)} - H_{2(4)}; \]
- for branch 5
  \[ H_{(5)} = H_{1(5)} - H_{2(5)} \text{ etc.}, \]

the sign of expression (2) will be defined as the difference in elevation marks. When moving from top to bottom in a branch, expression (2) will always be negative, and when moving from bottom to top - positive.

In [9], in the case of the known numerical value of $h_{es}$, it is proposed to represent it as an additional source of draught, for example, a fan. In this case, the second law of ventilation networks is written as follows

$$\sum R_{i} \cdot Q_{i}^2 \cdot \text{sign}(Q_{i}) + \sum G_{i} \cdot \text{sign}(H_{i}) + \sum h_{vent,i} \cdot \text{sign}(h_{vent,i}) + h_{el} \cdot \text{sign}(h_{el}) = 0,$$

(3)

where $R_{i}, Q_{i}$ – aerodynamic resistance (Н∙с$^2$/м$^8$) and air flow (м$^3$/с) in the $i$-th branch included in the $j$-th circuit; $G_{i}$ – mass impact of vertical air column in each $i$-th branch, kg/m$^2$; $h_{vent,i}$ – depression (pressure) of draught sources (fans), Pa;

\[ \text{sign}(Q_{i}) \quad \begin{cases} +, & \text{if the direction of air flow in the branch coincides with the direction of the circuit bypass (route),} \\ - , & \text{if the direction of the air flow in the branches is opposite to the direction of the circuit bypass (route);} \end{cases} \]

\[ \text{sign}(H_{i}) \quad \begin{cases} +, & \text{if the beginning of the opening is above the end of the opening,} \\ - , & \text{if the start of the opening is below the end of the opening;} \end{cases} \]

\[ \text{sign}(h_{vent,i}) \quad \begin{cases} +, & \text{if the direction of the draught source is opposite to the direction of the circuit bypass (route);} \\ - , & \text{if the direction of the draught source coincides with the direction of the circuit bypass (route);} \end{cases} \]
3. Results of calculation of air distribution in the oil mine production unit including the action of the natural draught arising in it

For calculations, we used actual parameters of mine openings of the production unit T-2 of oil mine No. 1 of the Oil shaft Department of Yareganeft (OOO LUKOIL-Komi), shown in Table 1 [9].

The difference in altitude marks between the beginning of the production unit (the highest altitude mark of the intake opening) and the working area is 15 meters, and the depth of the air hole with the pipe is assumed to be 180 meters [9].

Table 1. Parameters of openings of the dip-working unit T-2 of oil mine No. 1 of the Oil shaft Department of Yareganeft (OOO LUKOIL-Komi).

| Parameter | Value |
|-----------|-------|
| Length of inclined workings (intake and return), m | 312.0 |
| Internal cross section of inclined workings, m² | 5.1 |
| Working area length, m | 100.0 |
| Internal cross section of the working area (after separating with a thermal barrier), m² | 8.0 |
| Volume flow rate required for ventilation of the production unit, m³/s | 20.5 |

The calculations accept that 10 production units are simultaneously in work and also that all air entering into the oil mine is used to air them (without losses on leaks), i.e. 205 m³/s.

At the given air velocity and the area of heat-exchange surfaces according to [18-21], the heat exchange between the thermal barrier covered on both sides and the air in the working area will be no more than 6°C. Taking into account the heat exchange with the walls of the intake opening of the production unit, to provide the required hygiene and sanitary working conditions according to mathematical dependencies [22], it is established that it will be necessary to spend 804 kWh of power for moving the whole volume of air (205 m³/s) to the required temperature of the ACS.

Due to the natural draught $h_e$ (because of a difference in temperatures of external air and air in the working area), the total volume of air arriving in the oil mine increases, resulting in a lower capacity of the HVU. In this case, it becomes possible to reduce expenses of the electric power for airing [23].

Table 2 shows the results of the calculation of the electric power ($N$) spent by the HVU when its capacity became low, considering the action of the natural draughts operating in the production units. Table 2 also shows the value of electric power saved in case of adjusting the operating modes of the HVU ($\Delta N$, kWh) and the value of this saved electric power in comparison with the costs of the HVU operation ($\Delta N$, %), i.e. from 804 kWh.

Table 2. Costs of electric power spent to air the oil mine when adjusting the operating modes of the HVU, taking into account the action of natural draughts.

| Outdoor air parameters $t_{out}$, °C | 0  | 2  | 4  | 6  | 8  | 10 | 12 | 14 | 16 | 18 | 20  |
|-------------------------------------|----|----|----|----|----|----|----|----|----|----|-----|
| $N$, kWh                            | 837.9 | 882.2 | 923.6 | 961.8 | 996.6 | 1027.0 | 1054.0 | 1077.0 | 1094.9 | 1107.8 | 1115.4 |
| $\Delta N$, kWh                     | 279.6 | 235.3 | 193.9 | 155.7 | 120.9 | 90.0 | 63.0 | 40.0 | 22.6 | 9.7 | 2.1 |
| $\Delta N$, %                       | 34.8 | 29.3 | 24.1 | 19.4 | 15.0 | 11.2 | 7.8 | 5.0 | 2.8 | 1.2 | 0.3 |

4. Conclusion

In warm seasons, the natural draught has practically no effect on the airing process and it makes no sense to adjust the operation of the HVU with regard to its action. However, when the temperature decreases, the natural draft increases, and it becomes possible to reduce expenses of the electric power due to the change of the HVU operation rather considerably.
Taking into account the fact that the Yaregskoe oil titanium field is located in the Far North, where climatic parameters of external air have low and negative temperatures for a long time, adjustment of the HVU operating mode bearing in mind the natural draught action while using the proposed method of airing the production unit will allow saving considerably expenses for airing. In this case, it is necessary to develop a system for automating the airing of production units when the outdoor air parameters change.

At the same time, due to the separation of air flows with a thermal barrier in the working area, the required hygiene, and sanitary working conditions will be provided with the minimum power consumption for the ACS operation, which can be partially compensated by reducing the HVU capacity.

Calculations for each specific oil mine should be performed individually, depending on the required air volume, the number of production units, reservoir heating temperature, etc., but it is obvious that the above assumptions about the method efficiency are confirmed, even if one ACS is used in the production unit.

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