JOURNAL OF MULTIDISCIPLINARY SCIENCES AND INNOVATIONS
VOLUME 04, ISSUE 11
MOPNTHLY JOURNALS
ISSN NUMBER: 2751-4390
IMPACT FACTOR: 9,08

VENTILATING THE OPEN-PIT MINE USING THE ENERGY OF THERMAL FORCES.

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Annotation: The document examines the effects of thermal forces and wind flow on the ventilation of open-pit mines. It discusses convective and inversion ventilation schemes, their formation conditions, and air movement characteristics within the pit. The text explains how heating of pit walls, wind speed, and additional heat sources influence convective flows, including air velocity distribution along pit benches. It also describes the formation of inversion layers due to radiational cooling of pit walls and low wind energy, and the consequences for air exchange and pollution distribution. The study highlights that convective flows enhance ventilation and pollutant removal, whereas inversion flows are laminar, causing accumulation of dust and gases, which worsens sanitary conditions. Key parameters such as temperature gradients, air velocity, and energy coefficients are introduced to quantify the ventilation processes.

Keywords: Open-pit mine ventilation, Thermal forces, Convective air flow, Inversion air flow, Air temperature gradient, Pit wall heating, Air velocity distribution, Turbulent flow, Laminar flow, Pollution, Dust accumulation, Radiational cooling, Wind speed effects, Inversion layer, Sanitary-hygienic conditions, Convective scheme, Inversion scheme

Introduction: When the wind speed on the surface is 2 m/s, thermal forces have a significant effect on ventilating the open-pit mine. When the wind speed is low, the change in the temperature gradient inside the pit causes convective or inversion air movement, resulting in convective or inversion ventilation schemes.

If the surface wind flow is weak and the pit walls are heated, a convective ventilation scheme is formed. The heated pit walls warm the air above them, causing the heated air to rise from the bottom of the pit, while colder air from above flows downward to take its place.

The overall heating of the pit walls causes air movement throughout the entire pit. When the wind speed decreases to about 0.7–0.8 m/s, the convective scheme begins to operate. This corresponds to a specific energy of approximately 0.4 J/m³ created by the wind flow at the surface. As the wind energy decreases, convective air movement inside the pit intensifies. When all points within the pit cavity are heated evenly, the change in air temperature at those points also becomes uniform. As wind energy decreases, the turbulence of the flow also decreases, resulting in weaker air exchange within the pit. As a result, the air layers near heat sources (the pit surface) warm more strongly than the air layers farther from them. This causes the vertical temperature increase in the pit atmosphere to exceed 1° per 100 meters. This fully corresponds to the heat exchange law mentioned above.

The heat flux q in the vertical direction is determined by the following expression.

$$q = C_p \cdot A_q \left(\frac{dt}{dr}\right),$$

Where C_p — heat capacity of air at constant pressure; A_q — turbulent thermal conductivity coefficient; t— air temperature. According to the expression, if $q=const$, an increase in wind-flow energy (which raises A_q) leads to a decrease in the temperature gradient dt/dr.

When ventilating the pit under a convective scheme (Fig. 1), the warm air mass moves along the benches stepwise because it is pushed down by the colder air descending from above (rather than

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rising vertically). As a result, the volume of warm air rising from the pit increases with elevation. High-power convective flows are observed along the pit benches.

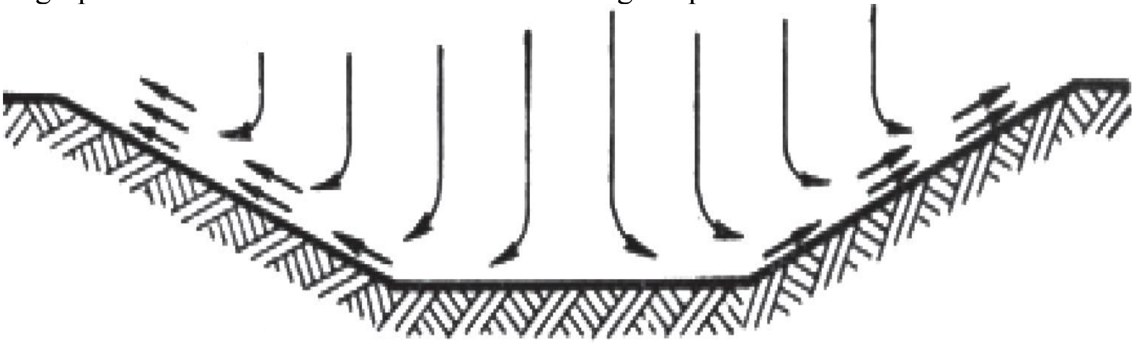

Figure 1. Air movement in the open-pit under the convective ventilation scheme.

If the mass of air rising along the pit walls increases, its velocity also increases with height. At the upper edge of the pit wall, the air movement velocity reaches its maximum. When the pit depth is 100–200 m, the convective air-flow velocity can reach up to 1.5 m/s.

The horizontal velocity of the convective air flow is determined by the following expression:

$$U = 0,55 \cdot K_1 \sqrt{g \cdot \sin\beta \left(H - h\right) \cdot \frac{t_n - t_B}{t_n + 0,01 \cdot \Delta t \cdot H}} \ \text{m/s},$$

Where K_1 is the coefficient accounting for the deceleration of the airflow due to the effect of benches; g is the gravitational acceleration, m/s²; β is the slope angle of the pit wall, degrees; h is the depth at which the convective flow velocity is determined, m; t_n is the temperature of the pit wall surface at depth h, degrees; t_B is the air temperature at the surface, degrees; Δt is the actual temperature gradient, degrees/m.

One of the main reasons for the formation of convective air flow in open pits is the heating of pit walls by solar radiation, which occurs only on sunny days. In this case, the northern wall of the pit heats more than the southern wall. As a result, the volume of air rising along the northern wall and its movement velocity become significantly higher than the convective flow along the southern wall.

If additional heat sources are present in the pit — such as fires or exogenous heating of the walls — convective air movement occurs throughout the entire day.

When the pit is ventilated according to the convective scheme, the aerodynamic regime of air movement is not stable. When the air movement speed is low, the regime is laminar; when it is high, a slight degree of turbulence appears in the flow.

The removal of harmful substances from the pit is carried out by the air flowing upward along the pit walls. As the flow approaches the ground surface, the concentration of harmful substances also increases, because mining operations on the upper benches introduce additional pollutants into the air.

When ventilated under the convective scheme, the pollution of the pit atmosphere is mainly influenced by internal sources (drilling operations, excavator activity, vehicle movement, etc.). On these benches, the concentration of harmful substances becomes higher on the wall opposite to the wind direction — especially when wind speed is low. External sources do not affect pit-air pollution under the convective ventilation scheme.

Due to the cooling of the pit walls and the low energy of the surface wind flow, an inversion air-flow scheme forms in the pit. For such a scheme to occur, the wind speed at the surface must not exceed 0.7–0.8 m/s, because at this speed the specific kinetic energy of the wind flow exceeds 0.4 J/m³.

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An increase in wind-flow energy affects the thermodynamic state of the atmosphere. Turbulent air exchange inside the pit increases, creating additional cooling sources. As a result, the temperature gradient approaches the adiabatic gradient. Thus, conditions are created for the downward movement of cold, denser air masses from the surface into the pit.

Inversion air movement in the pit can occur not only due to cooling of the pit walls but also, in certain cases, due to cold air blowing over the pit. In this case, the cold air enters the pit directly from the ground surface. The air layers near the pit walls cool and become denser more rapidly, sinking down to the pit bottom and displacing the warmer air upwards. As a result, the warm air rises and exits the pit. With the development of inversion, the thickness of the cold air layer increases at the lower levels of the pit (Fig. 2), and eventually, the entire pit becomes filled with cold air.

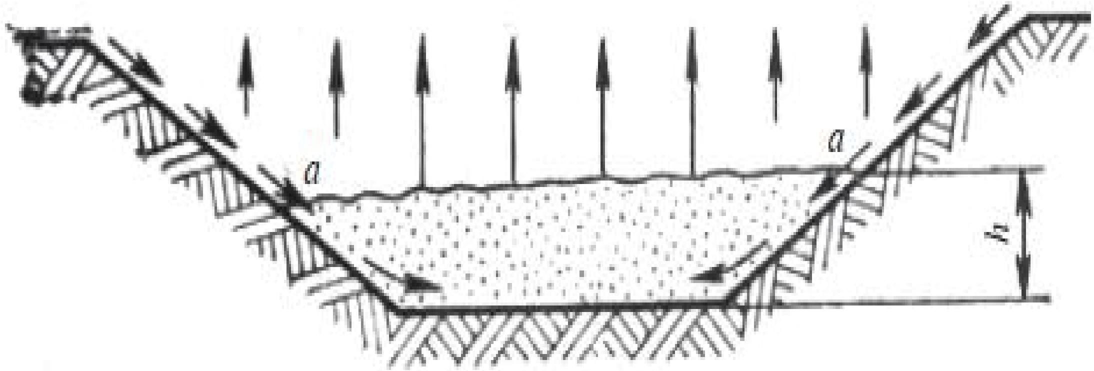

Figure 2. Inversion air-movement scheme in the open-pit mine according to the project.

As a result of inversion, the cold air layer that fills the open-pit is called the inversion layer, and its thickness (height) is denoted by h. Its upper boundary is called the inversion level (Fig. 2). Below this level, the temperature gradient of the air layers becomes negative.

In the inversion air-movement scheme, the maximum velocity of air moving along the pit wall slope does not exceed 1 m/s. As the airflow approaches the inversion layer, its velocity decreases, and below the inversion level the air remains motionless.

The average velocity of the air moving along the pit wall slope under inversion flow conditions is determined by the following expression:

$$U = 1,41 \cdot K_2 \sqrt{H \cdot g \frac{T_k - T}{T}},$$

Where K_2— an experimental coefficient accounting for the reduction of the effect of gravity due to adiabatic heating of air caused by friction along the benches in deep horizons; H — the distance from the ground surface to the motionless air layer or to the bottom of the pit, m; T— the average absolute temperature of the air around the pit, degrees; T_k— the average absolute temperature of the air entering the pit, degrees.

Depending on the duration, inversion can be short-term or long-term.

Short-term inversion lasts for several hours and usually forms at night due to radiational cooling of the pit walls. Therefore, inversion develops on clear nights and disappears with sunrise.

Long-term inversions can last several days, mainly occurring during the cold seasons. If the radiational cooling of the walls exceeds the heat received from the sun, air inversion can occur even during the daytime. As mentioned above, air inversions can also occur when a cold air front passes over the top of the pit.

When ventilating a pit under the inversion scheme, the air flow is laminar or nearly laminar, making air exchange difficult. Over large distances, this leads to increased concentrations of dust and gases in the air. Air moving along the upper edges of the pit walls carries pollutants from sources on the surface into the pit atmosphere. As a result, conditions below the inversion layer become very unfavorable for sanitation and hygiene, with dust and gas concentrations significantly exceeding permissible limits.

Because the flow is laminar under the inversion scheme, the removal of harmful substances from the pit atmosphere is very slow or may not occur at all.

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