Thermal conditions of the underground town collector tunnel

Aleksandr Galkin

D.Sc. in engineering
Saint-Petersburg, National Mineral Resources University,
E-mail: afgalkin@mail.ru

Abstract
The analysis of data on operation of the underground collector tunnel located in frozen aqueous soil was carried out. It is established that misuse and design errors caused accident conditions of the tunnel due to the progressing thawing of frozen soil. The new scheme of tunnel aeration during the winter period of year was suggested. The optimum air flow rate providing the optimum thermal conditions in a tunnel excluding progressive thawing of frozen soil in a zone of thermal influence was determined.
Key words: DESIGNING, OPERATION, TUNNEL, COLLECTOR, THERMAL CONDITIONS, FROZEN SOIL, THAWING, VENTILATION

Tunnels of underground town collectors of a cryolithic zone are designed on the basis of preservation principle of a frozen condition of surrounding rocks during the entire period of operation. Basically, it is caused by significant dependence of frozen dispersive rocks strength on temperature and humidity. It is known that for characteristic types of dispersive rocks, their strength and coupling are reduced when significant temperature increasing. It is also noted that at certain humidity, many dispersive rocks completely lose the coupling and become running after thawing. The adverse effect of properties change of dispersive sedimentary rocks, which often causes the total fall of openings and emergency situations (sudden fall, caving formation, mud accumulation, etc.), are rather well-known in mining engineering, in particular, when developing of placer gold deposits using the underground method [1]. At the same time, by means of rocks frost-bounding, it is possible to achieve the improving stability of mine openings of various applications, as during the period of construction as well as operation [2, 3, 4].

When openings (tunnel) design of Yakutsk underground collector, it was provided the year-round preservation of frozen condition of the rocks surrounding massif within an opening active layer. In order to avoid the freezing of the water in opening collector pipe, its thermal insulation was provided. During the winter period, it was supposed the additional cooling of rocks (frost-bounding) by cold air delivery in the opening through the ventilating vertical openings located along the entire collector road on average through 500 m. They were connected with the main development by horizontal holing-through from 5 to 22 m long. The opening was fixed by solid wooden support of an incomplete framed timber in the site of about 1 km long and by precast concrete slab in other sites. Temperature of rocks at a depth of opening is minus 3÷ 4°C, and volume humidity of surrounding openings rocks changed for sands within 20–30%, and for sandy loams of 25 - 50%. As the analysis of archival materials showed, the design conditions of operation of a collector tunnel were violated immediately after the beginning of its work. Because of the storm water drain absence in the city, ground waters began to pass to the tunnel, and emergency stops of the main station pumps caused sewage flooding of a tunnel. For example, when thermal discharge from high-level networks of heat supply, water temperature in a tunnel reached + 30°C.

All of this led to violation of the thermal conditions in the openings of a collector and caused the rocks progressing thawing. According to the conducted researches, the depth of rocks thawing halo in a doorhead reaches a surface active layer in particular areas during the autumn period, i.e. the solid thawed zone, through which surface waters pass to the openings, washing away the soil and mudding off the tunnel, is formed. Temperature of rocks in a thawed zone is +4÷ +5°C. In some parts of the back, the dome forming caverns were formed, the rocks completely lost competence, the timber was damaged and the opening was mudded off. On separate sections the section of framing decreased more than twice. In some spots, the opening section decreased more than twice. The earth surface subsided and the roadway holes were recorded in some areas; this caused the closure of vehicle traffic on principal traffic roads of the city.

According to the experimental studies, the air temperature changed along the opening length, for example, in December from -13 °C at the beginning to +4.5 °C at the end of the field in case of the air flow rate from 5.1 m^3/s to 1.2 m^3/s. Thus, the air circulation is not generally observed on some parts, and the air flow was layered throughout the opening height, and in one section, the air is moved in another direction on other parts. The existing diagram of tunnel ventilation is shown in Fig. 1, where the characteristic results of measurements of temperature and air motion rate in December, when the average temperature of atmospheric air was - 40^0C, are also given.

It is important to note that the mode of tunnel ventilation is extremely unstable. Periodically, the dead-air spaces and unspecified reversing of ventilating current appear.

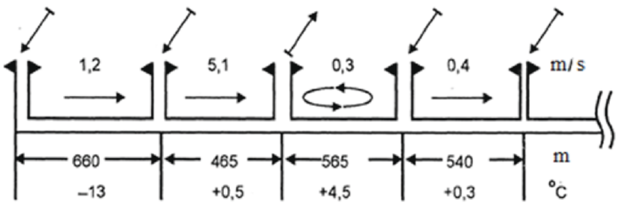

Figure 1. Diagram of ventilation of an initial section of city collector

It is important to note that the mode of tunnel ventilation is extremely unstable. Periodically, the dead-air spaces and unspecified reversing of ventilating current appear. It is a consequence of the active heat and mass exchange processes in the mine opening. Contacting to warm water, the cold air passing to a tunnel is heated and moistened then mixed up with part of the cold flow, which is given through the ventilation opening. It causes the intensive condensation of water vapors and formation of hoarfrost on walls. With the course of time, the “ice links” are formed. They cover the opening section almost completely changing the aerodynamic characteristic that leads to change of the ventilating mode in a collector tunnel, formation of the dead zones with the positive air temperature, which value does not depend on the atmospheric air temperature. The field studies showed that the positive air temperature is maintained almost on the entire length of the opening most of the time even during the winter period. First of all, the assessment of capability for achieving of the rocks frozen condition recovery round the opening, and also an assessment of energetic efficiency of this action and the selection of optimum method of the purpose achievement are of interest.

The mathematical model was developed for process of heat exchange modeling in a collector and surrounding rocks massif. It posed the variant of earlier created and supplemented model of air heat exchange with rocks in the openings [5].

The field studies data on the thermal mode of opening surrounding the rocks and also the pipelines are used as basic data.

The frost-bounding possibility of the existing thawed zone round the opening (tunnel) was evaluated by means of alternative calculations for the developed model. Results of calculations are shown in Figures 2 and 3.

Apparently from diagrams, the frost-bounding depth depends significantly on the air flow rate during the winter period: the depth of freezing is almost twice lower in case of the rate of 1 m^3/s, than in case

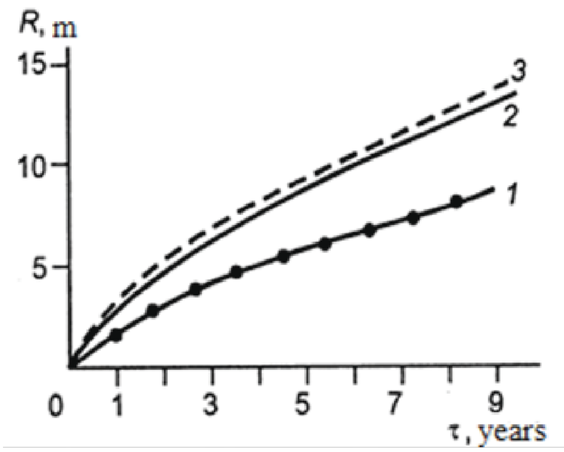

Figure 2. Change of rocks thawing depth in time depending on the air flow rate during the winter period 1 - δ

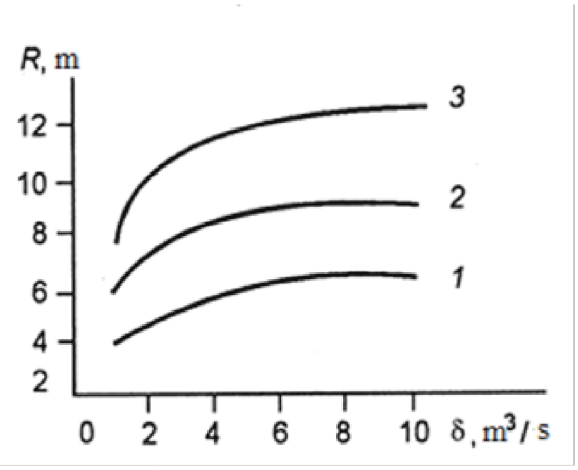

Figure 3. Influence of the air flow rate in the opening during the winter period on the depth of rocks freezing 1 – 3 years; 2 – 5 years; 3 – 8 years.

than in case of rates of 5 and 10 m^3/s; at that, the increase in the air flow rate of 5 to 10 m^3/s leads to the insignificant growth of the frost-bounding depth. As energy costs of the opening aeration are proportional to the air flow rate cubed, these results allowed proving of reasonability of air supply in the openings, close to 5 m^3/s. It significantly reduces the required energetic costs of the frozen massif recovery round the opening of a collector. The evaluating calculations show that the freezing halo equal to 13 m can be reached at the beginning of the opening on up to 200 m in depth section approximately in 10 years in the case of the air flow rate of 5 m^3/s. Further, along the length of the opening, the depth decreases, and it is almost twice less, for example, on a mark of 500 m.

The analysis of numerical calculations results showed that the frost-bounding efficiency in case of the straight-through arrangement of ventilation is not really high. Even in case of high-quality heat insulation of the pipeline, it will be possible to provide the rocks frozen conditions only on a section approximately equal to 200 m in 10 years. Change of the pattern of ventilation of an underground collector can be a way out of this situation, in particular, transition to zonal aeration during the winter period with a periodic reverse of a ventilating stream. Earlier, it was proved that reverse aeration is most effective [6] if there is a task to achieve the necessary value of the frost-bounding depth of rocks round the opening in the case of the constant air flow rate for the given period. The numerical calculations, which results are presented in the form of diagrams in Fig. 4, were carried out in order to evaluate the efficiency of rocks frost-bounding in case of reverse aeration.

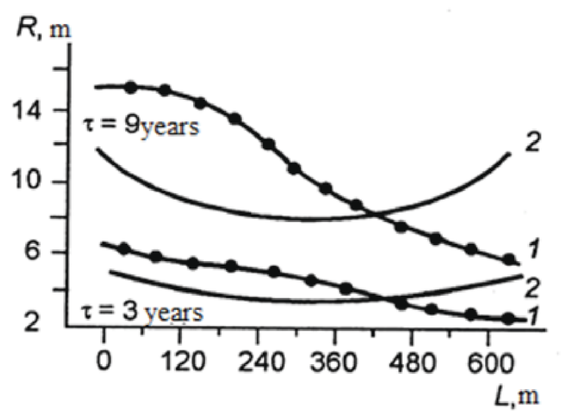

Figure 4. Change of rocks freezing depth along the opening length depending on the aeration method in case of the air flow rate of 5 m^3/s
1 – the direct-flow; 2 – the reverse.

From diagrams, it is seen that the reverse aeration allows more uniform freezing of rocks along the length of the opening. And, the minimum frost-bounding depth is observed in the middle of a section of opening and its value exceeds the minimum depth of a frost-bounding by 1.7 times in case of direct-flow aeration observed at the end of an opening section for the third year of a frost-bounding, and by 1.6 times after 9 years of frost-bounding. I.e. there is a pronounced tendency to depth growth of freezing of soil round a tunnel in case of reverse aeration in comparison with direct-flow aeration.

The energy estimation of reasonability of use of a ventilating stream reversion was carried out by comparing of the electric power costs in case of two aeration methods in order to achieve the given criterion of quality (in the case under consideration, a minimum of depth of rocks thawing at the end of the summer period). The calculation results showed that, for example, ventilating stream reversing with an interval of 360 hours allows lowering of energy costs on a section of 600 m long almost twice, and on a section of 400 m long almost five times, due to reduction of amount of air, which is required for the opening during the winter period. The effective pattern of ventilation of different sections of a city collector tunnel is suggested, and optimum air flow rate, which ranges from 4.3 to 5.7 m^3/s, is selected. It allows achieving of necessary results in case of minimum energy costs.

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