Chapter 9

VENTILATION DESIGN ALTERNATIVES FOR UNDERGROUND PLACER MINES IN THE ARCTIC

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ABSTRACT

The method of mine ventilation involving heated air, which is frequently used in mines in cold regions, does not correspond to the natural conditions prevailing in permafrost regions; it is not economical and leads to a series of complications which can be prevented or greatly reduced by lowering the temperature of the air stream entering the mine until it is equal to or very close to the temperature of the frozen ground.

This paper presents ventilation design approaches which can be engineered to provide the required micro-climate and thus ensure the stability of the ground for placer mines in permafrost. Specifically three ventilation design approaches are presented: 1) design based on minimum thermal impact; 2) design based on positive/negative heat accumulation in the existing mine airways; and 3) design based on heat exchanging devices such as thermosyphons placed above ground.

INTRODUCTION

During excavation of a mine opening and subsequent exploitation of mineral resources, intensive ventilation is required. In cold region, large seasonal variations in the temperature of the ventilating air cause changes in the original thermal field around a mine airway, through heat and mass exchange between the air and the surrounding medium. This is especially true in the summer, when the temperature of the air entering the mine is far above the freezing point of water, causing thawing of the ice contained in the surrounding rock. In the winter, in order to avoid icing up of the intake airways and to protect mine workers from the cold air, the intake air must be often heated, and the velocity of the heated air must be kept fairly high. These thermal interactions have major influence on the climate and the stability of mine openings.

The nature and intensity of heat exchange between the air and the walls of an underground working are functions of a number of independent variables, including the thermal properties of the permafrost and air, the velocity and distribution of the air stream, the size, shape and cross-section of the airways, the ice content and temperature of the ventilation air and time. Because the main component of the heat balance in a mine is the heat exchange between the ventilating air and the surrounding rockmass, it is of critical importance to make an accurate estimation of the mine thermal regime. An analysis of mine thermal regime allows engineering of ventilation design layouts to provide for the control of the micro-climate. In most cases, uncontrolled thermal regimes in arctic mines do not permit maintenance of tolerable minimum temperatures in the working area.

This paper examines three ventilation design approaches that can be engineered to provide the required micro-climate and thus ensure the stability of the ground for placer mines in permafrost.

MINE THERMAL REGIME IN THE ARCTIC

Changes in the thermal regime are related to the heat and volume of the air stream passing through the mine airways. A relationship between the deformation of the airway and the temperature can be determined based on the thermodynamic considerations (Bandopadhyay, et al., 1996).

A physical model of heat transfer processes between ventilating air and the frozen rockmass around a mine opening that undergoes freezing and thawing can be described as follows: temperature of the ventilating air, T_A, changes along the length of the airway, Z, and with time, t, as a result of heat and mass exchange with the frozen rockmass. The heat exchange between the ventilating air and the rockmass takes place at changing rate and periodically alternates its direction. The temperature of the rockmass, Tg, changes with time and with increasing distance from the surface of the mine opening, and as well as along the airway length.

Bandopadhyay, et al. (1995) developed a two-dimensional heat transfer model that takes into account heat conductance not only by the mutual exchange in air and rockmass temperatures, but also by the phase change of water, and solved the problem by using a finite difference approach. Their research indicated that heat exchange between the air and the rockmass would at least result in weakening of the roof and walls, and could even lead to a total loss of the ice-cement bond in the surrounding rockmass. Thus regulation of the mine thermal regime is extremely important to assure the stability of mine openings.

Without any thermal control, there will be a constant decrease in air temperatures along the ventilation path (Figures 1 and 2). To prevent such changes, the air entering the mine is often refrigerated when outside air temperature is above freezing. The need for thermal control to ensure stability, including refrigeration of intake air if necessary, was also emphasized by Bandopadhyay and Zhang (1990).

VENTILATION DESIGN BASED ON MINIMUM THERMAL IMPACT: RECIRCULATION OF AIR

A number of Canadian mines are located in areas with winter temperatures of -30 to -40°C. In order to avoid icing up of the intake airway and to protect the mine workers from the cold air, the intake air is often heated, and the velocity of heated air must be kept fairly high. The method of ventilation involving heated air does not correspond to the natural conditions prevailing in permafrost regions; it is not economical. Mchaina and Hall (1992) estimated that annual heating cost in a number of Canadian mines could be as high as $2000 per cubic meter per second of intake mine air. Passage of heated air through the mine airways leads to a series of complications which can be prevented or greatly reduced by lowering (increasing) the temperature of the air stream entering the mine until it is equal to or very close to the temperature of the frozen ground.

It can be seen from Figures 1 and 2, that as the ventilation air passes through the mine working, it warms up or cools down, and a thermal equilibrium is reached between the ventilating air and the rockmass. The distance within which temperature equilibrium is reached depends, among other things, on initial rock temperature and on the velocity and temperature of the air.

Ventilation air in thermal equilibrium can be recirculated as much as possible and reduced the intake volume of a mine until the maximum desirable contaminant levels prevail. Recirculation of air would not have adverse impact on the mine thermal regime.

Controlled recirculation can operate in either an on/off system or a variable quantity mode. According to Hall (1985), variable quantity recirculation systems are much more complex than fixed quantity systems, and fan types and positions are critical if the system is to be practical.

In a mining panel recirculation system the objective is to increase the airflow through a small part of the mine while maintaining the overall flow through the whole mine at the same quantity. The effect of this is to prevent any excessive build-up of gas and dust beyond the levels existing prior to the introduction of recirculation.

Overall control of containment gases and dust can actually be reduced by controlled recirculation. Contaminant concentration of respirable dust reach predictable, maximum levels in a system of controlled recirculation (McPherson, 1991), and may be reduced significantly by the use of filters. The greater volume of air being filtered results in more dust being removed.

Figure 3 shows a simplified schematic illustrating the fan locations in a mine panel recirculating system. A major consideration in all designs of controlled partial recirculation is that in conditions of an emergency or plant stoppage, the system must be fail-safe and revert to a conventional, non-recirculating configuration. If the recirculating crosscut fan fails, then doors in the crosscut must close automatically. The airflows must then remain sufficient to allow personnel to evacuate the area safely and for the necessary corrective measures to be taken.

Recently introduced on line ventilation monitoring and control systems, many of which are fail-safe, allows monitoring of the concentrations of gases, airflows, and temperature of the ventilating air at strategic locations, as well as operating conditions of fans. The main ventilating fan and the recirculating fan can be interlinked electrically to eliminate the possibility of uncontrolled recirculation. Should any monitoring parameter fall outside prescribed limits, the system will automatically revert to a conventional non-recirculating system.

The climatic conditions within a system of controlled, partial recirculation depend not only the airflows, and positions and duties of the fans but also upon the highly interactive and variable nature of heat transfer between the frozen rockmass and the ventilating air streams. The only practicable means of handling the large number of variables is through a computer program that simulate the interacting physical processes (Figure 4). Such analyses (Bandopadhyay, et al., 1996) together with practical observations, indicate that increased air velocities within the recirculation zone enhance the climatic condition in frozen ground placer mines.

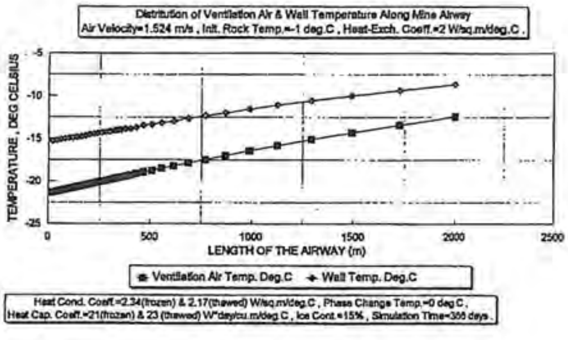

Figure 1. Profile of ventilation air temperature and wall temperature (winter).

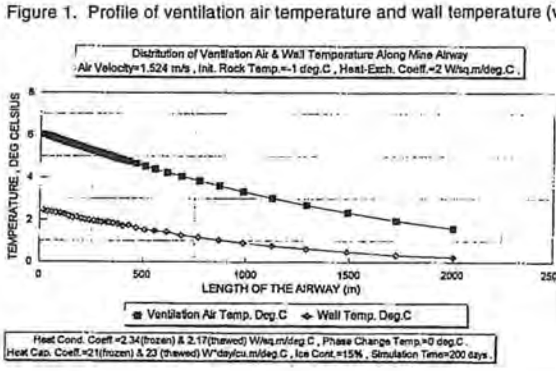

Figure 2. Profile of ventilation air temperature and wall temperature (summer).

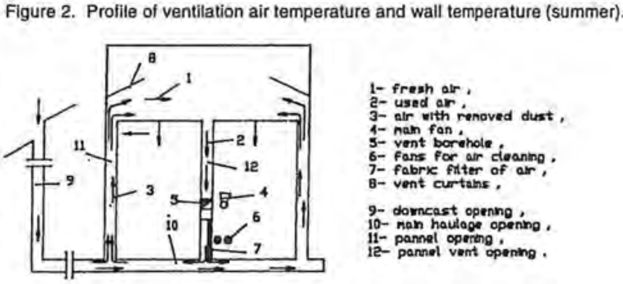

Figure 3. A schematic of ventilation layout in a mine panel recirculating system.

VENTILATION DESIGN BASED ON POSITIVE/NEGATIVE HEAT ACCUMULATION IN THE EXISTING MINE AIRWAYS

Utilization of heat accumulating airways is based on the fact that the ventilating air, when circulated through mined out openings, will lower the incoming air temperature during summer months (Figure 5) or increase the air temperature during winter months (Figure 6) to permafrost temperature, due to the heat exchange between the rockmass and the ventilating air. With this approach, the heat-sink capacity of rockmass can be used to counteract the effects of seasonal air temperature variations.

Such temperature control can be achieved by periodically shifting the direction of air movement in special openings, by using ventilation doors. The flow direction of return air remains unchanged in the ventilation circuit. The major deficiency of the system is the increased airflow resistance with time, as the extent of mine workings increases

Lupin Mine, located 90 kilometer south of the Arctic Circle, has no air heating plants. The ventilation system relies mainly on heat exchange with diesel equipment and on rock heat transfer. The total fresh air volume is downcasted through the borehole raises directly to the 250 meter level and upcasted through the ramp,

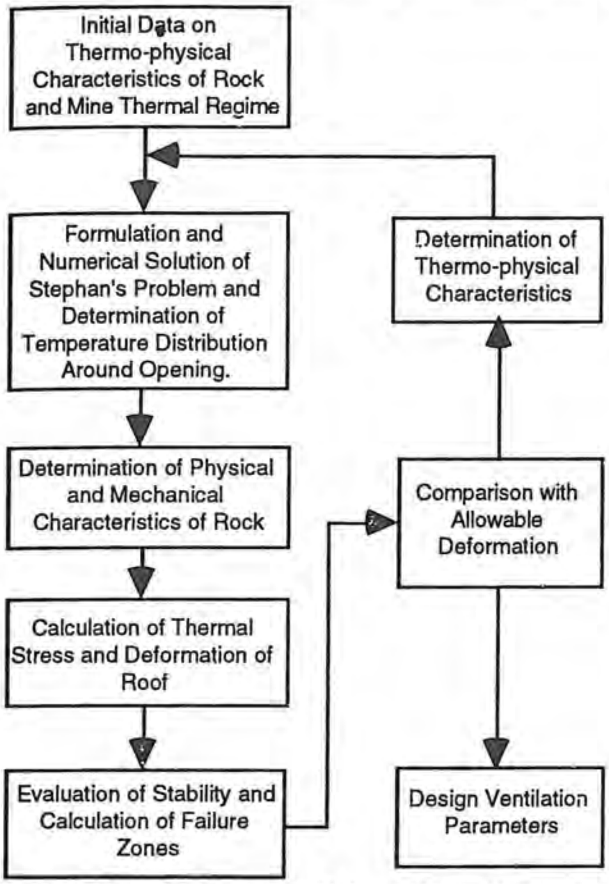

Figure 4. Ventilation Systems Design for Underground Placer Mines in the Arctic.

thus increasing air temperatures mainly because of air retention time and higher rockmass temperature (Cullen, 1985).

Ventilation Design Based on Heat Exchanging Devices

The stability of frozen ground is affected by thawing, which is usually due to the passing of warm ventilation air through the underground workings. This leads to a gradual increase in the temperature of the frozen ground and to a decrease in its ice content (Figures 1 and 2).

If cooling of ventilation air is neither feasible nor economical, subcooling of permafrost can greatly increase the bearing capacity of the rockmass. The use of heat exchanging devices, such as thermosyphons, has proven very useful in stabilizing frozen ground throughout Alaska and at many locations in Canada. During the Arctic winter season, thermosyphons can remove large quantities of heat from the soil, and reject that heat to the air. In the summer, when the air and the environment are warmer than rockmass, the device becomes inactive to minimize heat input to the ground.

A thermosyphon is a device with a very high thermal conductance due to the continued cycle of evaporation and condensation in its working fluid. The heat transfer processes that occur in a thermosyphon are shown in Figure 7. Heat transfer to the liquid in the evaporator section causes the liquid to evaporate. This vapor flows from the evaporator section to the condenser section driven by a pressure gradient. This pressure gradient is set up by the decrease in saturation vapor pressure of the liquid in the condenser section, due to the lower temperature of the condenser section. The vapor comes in contract with the cold surface of the condenser section and forms a condensate film that returns to the evaporator by gravitational force. The latent heat of vaporization, required to evaporate the liquid and subsequently released during condensation of the vapor, gives rise to the extremely high heat transfer conductance characteristics of the thermosyphon.

A similar device, referred to as a heat pipe (Feldman, 1967; Dunn and Reay, 1976), has a wick structure so that the condensate may return to the evaporator by capillary forces. This allows the heat pipe to transfer heat in the absence of gravity or to transfer heat against gravity, having the condensate section below the evaporative section so that the liquid flows upward through the wick. A wickless heat pipe is generally called a thermosyphon (Heuer, et al., 1985).

The choice of working fluid for a thermosyphon is based on several parameters. The working fluid must have an adequate vapor pressure at low operating temperatures, high thermal conductivity, high density, and low viscosity to enhance flow return and turbulent flow (Heuer, et al., 1985). The nature and intensity of the heat removal in permafrost rock by thermosyphons are functions of a number of independent variables, including the thermal properties of the permafrost and air, the velocity and distribution of the ventilation air stream, the size, shape and cross-

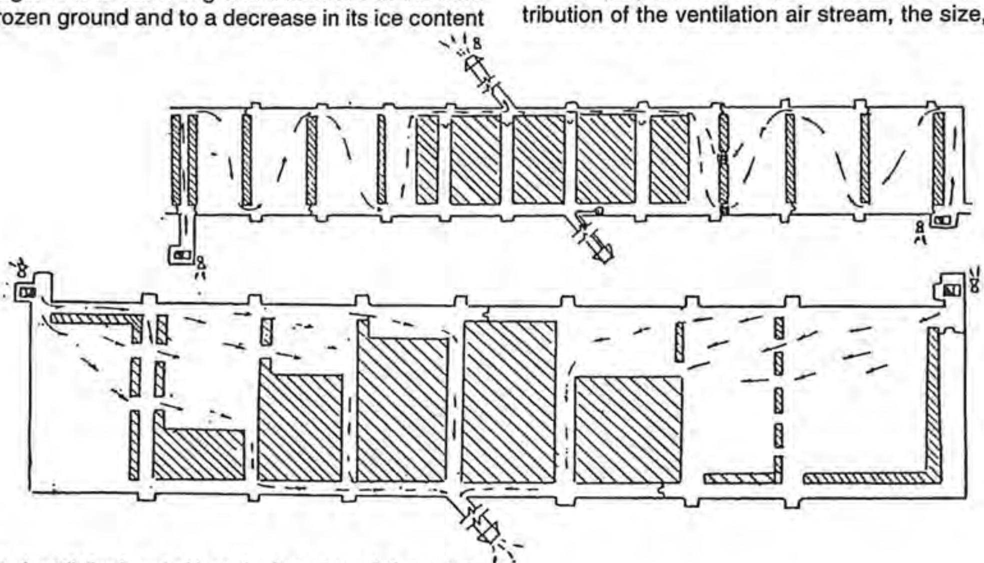

Figure 5. A schematic of ventilation layout with postive heat accumulation entries.

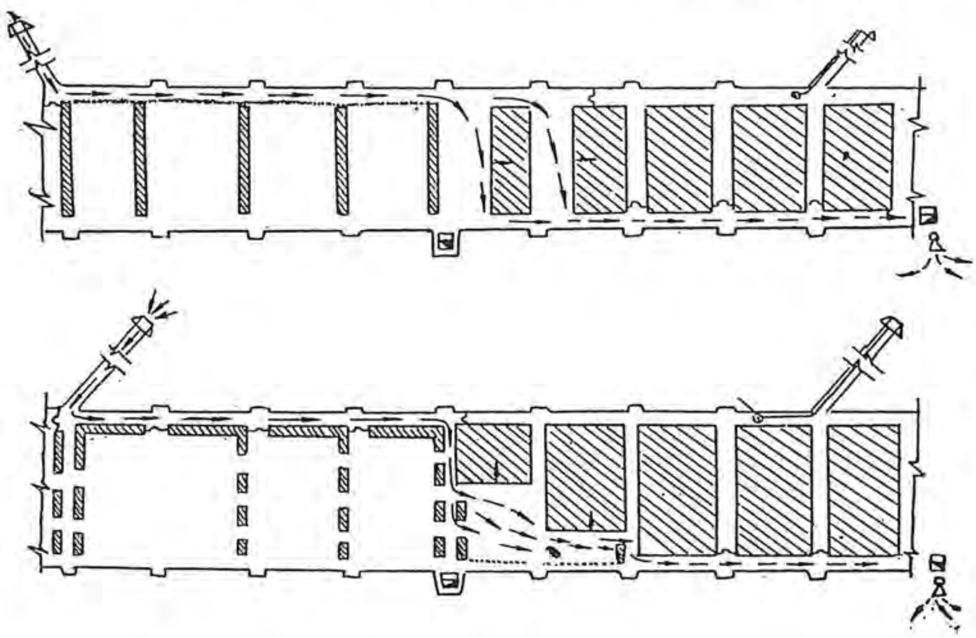

Figure 6. A schematic of ventilation layout with negative heat accumulation entries.

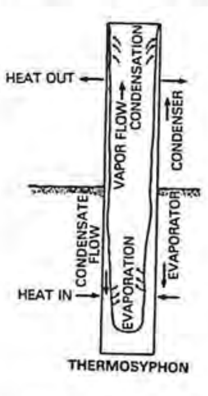

Figure 7. A simplified sketch of thermosyphon.

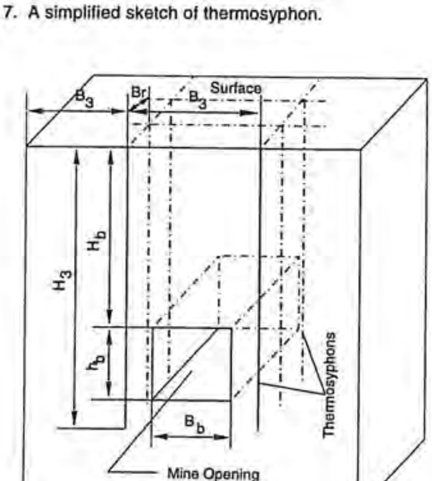

Figure 8. A sketch of mine development opening with thermosyphon.

section of the air ways, the ice content and temperature of the permafrost, the thermal properties in the freezing fluid of the thermosyphon, and time. In an average frozen ground situation, thermosyphon condenser surface temperatures below that of the frozen ground initiate cycling. The amount of heat removed will depend on the thermal conductance of the unit and the temperature difference between radiators and soil. Convective cooling is improved by increased air flow across the fin surfaces (Heuer, et al., 1985). Soil cooling through the thermosyphon occurs throughout the winter and into the spring. As long as the condensor surface temperature is lower than the soil temperature, heat is extracted directly to the air. Thermosyphons are only effective if they are installed in sufficient density. Depending on the geometry of the mine opening, the material characteristics and the seasonal air temperature, installation of a series of thermosyphons in rows seems reasonable. In such an installation, the distance between rows, the length of the thermosyphons, the geometry of the installation, and the spacing of the thermosyphons in the rows are important considerations.

Bandopadhyay, et al. (1996), developed a model of heat removal process by thermosyphons in a mine development opening (h_B x B_B), shown in Figure 8, located at a depth of H_B in frozen ground. Two rows of thermosyphons are installed in holes drilled from the surface towards the mine opening at right angle to the axis of the development opening, as shown in Figure 8. The length of the thermosyphons is H_3, the spacing between the thermosyphons in the same row is B_r, and the distance between the rows of thermosyphons is given as B_3.

Using the modeling technique and the physical system described previously, Bandopadhyay et al. (1996) computed the temperature distributions around a thermosyphon as a function of time of the year. A sinusodial relationship was used to model the variation of ambient temperature throughout the year. The thermosyphons, in thermal equilibrium with the ambient air, were assumed to be placed in the ground during early spring. The thermosyphons function during the first 270 days, from April to December, when the average surface air temperature is approxi-

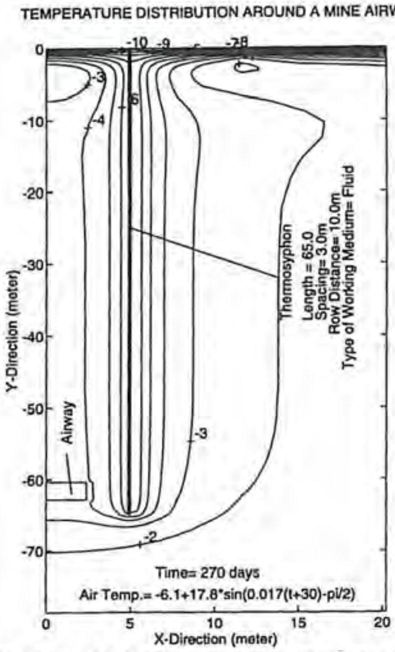

Figure 9. Subcooling effects of two rows of thermosyphons after 270 days in operation.

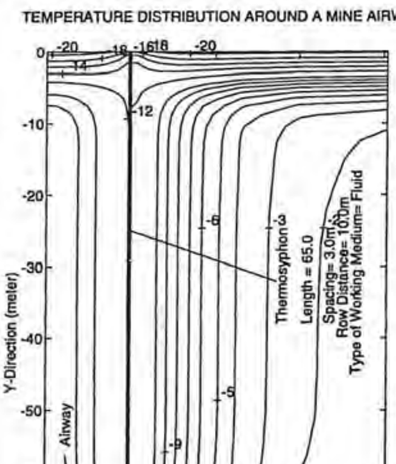

Figure 10. Subcooling effects of two rows of thermosyphons after 366 days in operation.

mately -5°C.

Figures 9 and 10 show the effect of placing two rows of thermosyphons, 65 m long, on a 3 m x 10 m grid, after 270 days and 366 days of operation, respectively. Both figures show a large volume of subcooled rockmass surrounding the unit, with the rockmass temperature around the mine airway is significantly lower than the phase change temperature. The temperature of the soil surrounding the thermosyphon decreases, roughly paralleling the air temperature. This would help the rockmass maintain its stability during summer months, when the temperature of the ventilation air is above the phase change temperature.

CONCLUSION

Regulation of mine thermal regime is extremely important in ventilation design for frozen, underground placer mines in the Arctic. In many cases, the correct engineering approach includes not only overcoming the problems associated with permafrost, but also using its unique properties whenever possible. Arctic mine ventilation and frozen rockmass stability problems are resolved by maintaining the frozen state of the ground and by controlling the ground thermal regime within acceptable limits. Heat exchanging devices such as thermosyphons can be employed to modify ground temperature before mine development, and to maintain it during the extraction of the mineral resources.

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