Headframe, intake shaft and intake portal design issues for heated mine air

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For underground mines with extended periods of surface temperatures below freezing, there are a range of potential impacts on the ventilation design, as well as the overall general mine design. The ventilation-related impacts vary depending on the type of surface intake (equipped or unequipped, travelway or not, shaft or ramp), the type of services in the shaft or ramp, implications of frost/ice build-up, whether there is permafrost (frozen ground) to protect for ground stability reasons, whether there are associated headframes to be heated, the need for surface attached buildings to be under positive pressure (so heat leaks out), the allowable pressures across headframe or building walls and the push-pull systems needed to keep this within design limits, the availability of energy sources/fuels for heating, the duration of the heating season and other factors. This paper describes from practical experience how these factors need to be assessed to develop a suitable integrated ventilation strategy and heating strategy for a modern mine. With respect to headframe design issues, most of the guidelines are equally relevant to mines needing to introduce chilled rather than heated air.

Do the mine intakes need to be heated?

Without heating, most intake airways at mines that have extended periods of surface (dry bulb) temperatures below freezing will needing heating for one or more of the following problems:

- To protect the health and safety of personnel while travelling or working;
- To prevent freezing of service water and discharge lines;
- To ensure reliable operation and maintenance of hoisting and conveying equipment and other mechanical or electrical equipment in the intakes;
- To maintain safe, ice-free roadways for traffic and travel;
- To prevent rock surfaces or shotcrete linings from damage due to cyclical expansion and contraction from freezing and thawing;
- To prevent ice build-up reducing the effective cross-sectional area of airways which in turn can restrict airflows.

Mines where the surface temperatures only drop intermittently below freezing and where the average daily (i.e. 24-hour average) temperature generally exceeds freezing should not need heating.

In some cases, the evaporation of water from the walls of wet shafts can depress the intake air temperature below the freezing point triggering the need for heating even when surface temperatures are at or just above freezing.

Where the intake airway is empty and very dry and frost build-up is acceptable (e.g. due to the presence of other intake airways of sufficient capacity), then no heating might be required, and the resulting frost and ground freezing might even be used to advantage by providing “free” cooling of the hot, humid summer intake air. [1]

At what time of year does heating need to be turned on?

Usually the mine heating system needs to be turned on when 24-hour average daily temperatures become persistently below freezing. The “usual” week of the year that this occurs can usually be interpolated from monthly long-term climate records. In the lead-up to winter, the heating system might only be turned on during night or particularly cold periods and then turned off at other times, depending on how practical it is to turn it on and off for relatively short periods and its overall “turn down” ability (between maximum and minimum output).

Appropriate design value for intake air supply temperature

A very conservative position would be to choose the coldest temperature historically recorded at or near the site; a less conservative position would be to choose the 99th percentile, i.e. the temperature which is exceeded 99% of the hours each year, based on long term (minimum 7 year) statistical analysis of hourly surface temperatures. Where the mine has significant thermal damping in the intakes, then a warmer surface design condition could be used at least in unequipped, non-travelling intakes, e.g. 95%.

The design value for the intake air supply temperature mainly affects the size and capital cost of the heating system. This is because the number of hours per year colder than (say) the 99% condition is small, so the additional energy (principally the fuel) requirement to heat the air from this lower temperature is also small. In many cases, the capital cost of the heating system, especially direct-fired systems (see below), is also small compared to the life-of-mine operating cost of the system, so the choice of a conservative design value for the intake air supply temperature can be justified.

Appropriate design value for intake air delivery temperature

Intake airways that have services in them (cables, pipes, mechanical plant, etc.) as well as intake airways in which personnel work or travel generally need to be heated to about $+5^0$C. Empty intake airways (i.e. dedicated intakes without services) can be heated a little lower, typically about $+2^0$C.

Where the mine is very deep and frost formation in the intake is less of a concern, then autocompression (adiabatic self-heating of the intake air, which is roughly 10^0C per vertical km) may allow lower surface design heater temperatures.

Mines with extensive depths of permafrost (ground whose temperature has been below freezing for at least two years, [2] principally but not exclusively in arctic regions) may choose to keep the entire mine environment below freezing to avoid ground control problems. Heating is still required but the intake air delivery temperature will remain below freezing.

In some cases, there are also legislated minimum requirements for intake air temperatures depending on the purpose of the intake.

Choice of fuels and heating systems

The availability and economics of potential fuels for heating is frequently the most important consideration in the choice of heating system. The issues are well described by Terkovics and Kwant. [3]

The appropriate choice of heating system depends on factors such as:

- Accessibility to the site for fuel and equipment;
- Fuel options in terms of transport and “reserve” (backup or emergency resupply);
- Noise and environmental restrictions;
- Legislation (e.g. banning the use of direct fired heaters of any type).

Most mine heating systems use propane or natural gas or diesel or fuel oil. Other fuel sources for mine heating less frequently used include:

- Waste heat, e.g. steam from geothermal sources or smelters;
- Central heating, e.g. glycol produced by burning coal and distributed site-wide including to the mine heaters
- Electric heating although it is rarely viable for large heaters, not only due to operating costs, but also the very large switchgear and cabling required.

In terms of burning fossil fuels, the key choice in heating systems is between direct fired and indirect fired.

- Direct heaters locate the burners in the intake air so all the products of combustion (POCs) from the fuel enter the intake air. Indirect heaters use a heat exchanger so the burners are outside the intake and the POCs never enter the intake air;
- Direct heating is much more efficient in terms of converting the calorific value of the fuel into useful heat, compared to indirect heating (almost 100% rather than 80% efficient). Higher efficiencies than 80% are possible for indirect heating systems but result in condensation of the exhaust products in the heat exchanger. This condensate is acidic and this creates maintenance issues. So, in practical terms, indirect fired heating is limited to about 80% efficiency;
- Direct heating is much cheaper in capital cost, has a smaller footprint, and has lower operating costs including maintenance costs compared to indirect heating (due to more moving parts and more skilled technicians being required with most indirect heating). In general, direct heating also has much better turndown ratio and is therefore much better suited to variable intake air flow rates than indirect heating and is easier to cycle on and off during any warmer periods at the start or end of winter;
- Indirect heaters need an effective exhaust so that POCs are discharged away from the heater house intake points.

An important caveat is that direct heating must always use a clean-burning fuel such as propane or natural gas (or electric heating elements). Diesel or fuel oil cannot be used for direct heating as it is too “dirty” in terms of carbon monoxide and nitrogen dioxide standards. Note that the products of combustion of natural gas depend on the composition of the gas which depends on its source and any treatment given to the gas prior to sale. The suitability of a particular natural gas supply for direct heating should therefore be carefully checked prior to commitment.

Indirect heating is therefore generally only used there is:

- Inexpensive waste heat or central heating via a solid fuel such as coal, or
- Where the only practical fuel sources are diesel or fuel oil, typically the case in very remote mine sites where there is no propane used on site but lots of diesel for mobile equipment. In this case, construction of the major storage facility required for propane cannot be justified especially if all fuels must come in on winter roads which may be open for only a few months of the year. In this case, if the mine does run short on heating fuel (diesel) then it is possible to fly diesel to site (e.g. if there is a really cold winter where more fuel than predicted is consumed) but propane cannot be transported by air.

Equipment lead times and “drop dead” dates?

The need for heating adds another dimension and complication to the requirements to commission the ventilation system, and some styles of heating system have long lead times to site. The issue is further complicated by the need for the heating system to be fully commissioned and operating by the time freezing conditions are experienced, or severe consequences for the underground workings can eventuate. This is unlike most other mine equipment where “slippage” of a few weeks may impact on various matters but not to the same extent.

How much heating/fuel is required?

In terms of the expected heating energy/fuel requirement (or kg of propane or natural gas or kg (or liters) of diesel), and hence the annual heating cost, this is usually determined by:

- Calculating the ambient surface “degree-hours” of heating between the ambient air temperature during the year and the targeted heated air temperature (from local weather records). An example where the target intake air (heated) temperature is to be 3.3^{0}C (38^{0}F or 6^{0}F above freezing) is shown in Table 1;
- Calculating the energy required to provide this number of degree-hours of heating. This will depend on the energy content of the heating method or fuel and the efficiency of the conversion process. An example for indirect diesel-fired heating for a mine at this location which has a surface ramp (portal, on intake) and two intake ventilation shafts is shown in Table 2;

- Calculating the maximum heater duty. In this case, the design minimum temperature was -43⁰C and the design intake supply temperature was +3.3⁰C, so the required temperature increase was 46.3⁰C.

Month	Average Monthly temperature, ⁰C	Average required increase in temperature, ⁰C	Degree-Hrs (⁰C) below 3.3⁰C
Jan	-18.5	21.8	16 244
Feb	-18.3	21.6	14 538
Mar	-12.3	15.6	11 631
Apr	-4.9	8.2	5 928
May	1.0	2.3	1 736
Oct	1.1	2.2	1 662
Nov	-5.1	8.4	6 072
Dec	-12.8	16.1	12 003
Total			69 814

Table 1 Degree-hours (⁰C) of heating for a particular location (heating not required Jun-Sep inclusive)—heating to +3.3⁰C

The heat of combustion of diesel fuel is about 45 MJ/kg with diesel having a specific gravity of 0.8 kg/liter and hence a heat of combustion of about 36 MJ/liter.

The heat of combustion of natural gas is generally taken to be about 54 MJ/kg. This is the so-called “Higher heating value” (HHV) which takes into account the extra (latent) heat produced when the water vapor in the combustion gas re-condenses as the gas is cooled to 25⁰C (which will occur since the mine intake air is only heated to a few degrees above freezing). The heat of combustion excluding this condensation is called the “Lower heating value” (LLV) and assumes the water vapor is only cooled to 150⁰C.

	Airflow, m^3/s	Heater peak** duty, kW	Diesel consumption/ yr*, litres
Portal intake raise	170	10 301	1 898 377
North intake raise	375	23 366	4 306 075
South intake raise	350	21 859	4 028 264

* At 80% efficiency for indirect fired diesel heater, heat content of diesel of 34 000 kJ/l, an extreme minimum of -43⁰C and temperature increase to +3.3⁰C (an increase of 46.3⁰C rounded to 50⁰C)

** Effective peak requirement (i.e. net heat input into the air not gross heat produced)

Table 2 Summary of heater duties and heating energy requirements. All flows m^3/s at 1.20 kg/m^3.

Headframe and heater-house design principles

Unequipped intake shafts in cold climates can have vertical (blowing) axial fans on them with heaters on top of the fans, and effectively operate at any pressure required.

Equipped “intake” (hoisting and/or man-riding) shafts are usually operated using one of three strategies:

- Upcasting fresh air (e.g. an adjacent surface intake provides heated air to the bottom of the equipped shaft, which then upcasts to surface where the air is discharged). This is especially the case for timbered shafts where there is the potential for a fire in the shaft;
- Used as a neutral intake, which means heated air downcasts in the shaft, but the flowrate is only sufficient for the shaft operation itself and the air is then discharged into a return. Any fire in the intake then has minimal impact on underground operations;

- If the risk of fire in the intake is low, and there are also suitable and effective fire management and egress and entrapment controls in place, then the intake may be designed to operate as a full intake, i.e. feeding heated fresh air into the main body of the mine using offtakes on one or more levels of the shaft.

Important design and operating practice principles for equipped shafts needing heated air and where the shaft is acting as a mine intake includes the following:

- The surface "push" (heater house) fans must not contribute to overcoming *any* of the mine resistance, including the below-collar surface shaft itself;
- The pressure on the headframe with the heating system operating should be positive (so heated air leaks out not cold air leaking in) with a maximum pressure of about 50 to 100 Pa across the heater house walls. This is to avoid frost build-up in the heater house. The rest of the heater house fan pressure is absorbed in the heater house inlet and the air transfer tunnel and the shock loss at the discharge from the air transfer tunnel into the shaft;
- These fans should only have sufficient pressure capability to overcome the pressure loss in the heater house and the air transfer duct to the shaft, i.e. must be low pressure fans. Fans with pressure capability substantially greater than the safe operating limit on the headframe cladding, windows and doors should be avoided;
- Headframes typically need to leak outwards about 10 to 15 m^3/s of heated air to avoid frost formation inside and this airflow needs an outlet from the headframe, either by way of leakage (most older headframes easily leaked this amount) or using a design outlet (for modern energy efficient building construction techniques and materials). Headframes should *not* be completely sealed off from the atmosphere with no pressure relief. In many headframe designs, there are already openings for dump points, access doors and rope-ways that provide such relief. Note that to achieve a flow of 10 m^3/s through a wall while maintaining 50 Pa across that same wall requires an outlet area of about 1.7 m^2;
- This heated air should be vented near the top of the headframe to ensure effective heating of the entire headframe volume;
- This heated air will be very dry and produces negligible frost at the outlet due to condensation;
- The design needs to take into account the cyclical pressure variation due to the skips operating in the shaft. The headframe needs to remain under positive pressure over the full cycle of skip movements;
- The heater house fan must have a volume capacity greater than the maximum demand down the shaft, including the headframe air discharge. If there is a booster fan underground in the shaft, then the volume capacity of the heater house fan should be greater than the booster fan. This avoids any potential for the heater house fan to be forced to operate in its "4th quadrant"; [4]
- The system must be able to accommodate changes in the mine airflow demand over time, especially through that intake;
- It is particularly important to note the following:
    - The heater house fan cannot contribute to overcoming the overall mine system resistance or even any portion of the below-collar intake shaft resistance. If it does, then it will put the headframe under unacceptable pressures, typically resulting in damage to or failure of the cladding on the headframe and/or unacceptable opening pressures on doors into the headframe;
    - The heater house fan must have sufficient flow capacity to not move into the 4th quadrant under all credible operating scenarios.

Heating systems for surface ramps on intake

In below freezing temperatures, outcasting a surface ramp (i.e. using the ramp as a mine exhaust) usually results in poor visibility both outside the portal and for some distance inside the portal due to the warm, moist air in the ramp meeting the very cold, dry air on surface resulting in thick fog. This can make travel in this area quite hazardous.

However, putting a heater house directly over the portal and driving equipment through the heater house (incasting the portal) is usually impractical.

An alternative is to have a short vertical raise from surface intersect the ramp a short ramp distance inside the portal. The vertical raise has a heater house on top of it. The raise delivers heated, fresh air to the intersection with the ramp. A small split of heated air is then outcast to the portal, which keeps the portal area with good visibility and ice-free. The majority of the heated air from the raise proceeds down the ramp to the working areas. The heater house fan(s) have variable speed drives to ensure neither too much nor too little air outcasts from the portal.

A further alternative to the use of a short vertical raise is to use a second dedicated portal/ramp that joins the main ramp just inside the first ramp as before. This option is more likely where the portals are inside a discontinued open pit or where both portals are located in the same box cut.

Summary and Conclusions

The optimal design of the heating system for a mine requires an integrated multi-disciplinary approach from the mine ventilation engineer, heater design specialists, environmental engineers and others. If an integrated approach where the deliverables and the constraints are carefully reviewed and agreed is not used, then a range of problems can develop, which can create serious operational difficulties, or require expensive retrofits (with potential downtime), or incur unnecessary ongoing operating costs. In addition, the design and supply of some heating equipment, as well as the heating fuels themselves, can have long lead-times in terms of delivery to site and commissioning, and late commissioning as the mine enters winter can have major impacts on the underground environment, development and construction activities.

References

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