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Alternative fog removal methods in mine ramps

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ABSTRACT: Fog forms in mine ramps when warm and humid exhaust air moves upwards the ramp and temperature decreases. As fogging is a fairly common problem, many different fog removal alternatives are known. For example, heating, cooling, scrubbing, chemically drying the air, and increasing air velocity are used to remove fog.

In this study fogging problems of some Finnish mines are reviewed. Furthermore, possible fog removal methods are compared to identify most feasible and sensible solutions. The most common fog removal methods in subarctic countries are air heating and increasing air velocity, so the main interest is directed for comparison of these methods. In cases where there have already been attempts for fog removal, user experiences of the used fog removal methods are presented.

To enable comparison of the methods tests were conducted and measurements taken. Results of the comparison indicate that increasing air velocity by air rerouting is not a satisfactory fog removal method. Installing an additional fan to increase the air velocity yielded better results, but calculations showed that the resulting changes in temperature and humidity are directly proportional with the heating capacity of the fan. Best fog removal results were achieved with air heaters.

1 INTRODUCTION

As fogging is often a seasonal problem, it is considered in many mines more of a nuisance than a safety hazard. Only when visibility is decreased to extremely low or fogging becomes a continuous problem, corrective measures are taken. Even then it is not easy to decide, how to deal with the problem, as every alternative approach has its drawbacks.

In Finland as well as in other subarctic or arctic countries another thing to consider is the cool climate that prohibits use of fog removal methods designed for warmer climates. The drastic seasonal changes of weather conditions and thus fogging should be taken into account. Also the occurrence of fog mainly or only in the decline of the mine is typical for countries with an aforementioned climate. This restricts also fog removal method selection.

Earlier studies have indicated problems in fog removal by increasing air velocity. Now this issue is addressed in a greater detail. More thorough field research with measurements is completed concerning both air velocity increasing methods and heating. Obtained results are then presented and analysed.

2 FOGGING AND REMOVAL ALTERNATIVES

2.1 *Fogging problems in Finnish mines*

Fogging occurs mainly in the declines of the mines in Finland. As the declines are often used as haulage roads, fogging comprise a potential for a safety hazard. In ventilation point of view the declines are used mainly as secondary exhausts. As the exhaust air typically carries high particle concentration, gaseous pollutants and plenty of water, it is not easy to avoid fogging.

Weather influences fogging especially in shallow underground mines. If the weather is humid or the outside temperature changes rapidly, fogging is more probable. Thus thickest fogs are observed during spring and autumn in most mines in Finland.

Choosing a fog removal method in subarctic countries is difficult, as the fogging problem is usually seasonal, and thus fog removal is only required part-time. Also methods developed for warm climates are seldom practical. Another thing to consider is the individual character of fogging in a mine. In some mines fogging occurs because of the high humidity of air, in some other mines the main influencing factor is the high particle concentration. Thus the same fog removal method may not be the most effective in every mine even in a region with similar weather conditions.

2.2 *Comparison of fog removal alternatives*

Fog removal alternatives used worldwide are heating, cooling, scrubbing, increasing air velocity and chemical drying of air. Sometimes two or even more of these methods are used in a combination. Usually best fog removal results are achieved by these combinations.

The fog removing effect of increasing air velocity is said to be based on air mass mixing and promoting evaporation from fog droplets. In addition, an increase in airflow velocity creates a psychrometrically uniform air mass and diminishes the number of potential condensation points. Economically this method is suggested to be the most plausible solution. (Tien 1999) Increasing air velocity is currently one of the most popular ways for fog removal, but its efficiency is questioned. (Martikainen 2005, Calizaya et al. 2001)

Centrifugal scrubbers work well in level workings according to literature, but they are not necessarily suitable for clearing declines. Their effectiveness in fog removal is based on their multiple function characteristics. They increase air velocity, reduce particle concentration as well as humidity.

Heating is often criticized because of the added heat to the mine environment, but in cool climates with cool or temperate underground temperatures increasing temperature does not cause problems. Heating is unfortunately quite expensive as it consumes a lot of energy. It does not reduce the amount of particles, either.

Cooling by refrigeration is the most expensive fog removal method and in a cool climate it may also cause difficulties as the temperatures are already low and freezing is definitely not recommended.

Chemical drying is considered impractical in mining industry because the amount of drying material needed is huge. Spreading the material and gathering it is also extremely troublesome.

Removing humidity by preventing leakages is not mentioned in literature as a fog removal method, but can also be used as such to some extent. Unfortunately treating a long ramp is costly. As there are also open ditches and pumping stations along the decline, preventing leakages may not be enough for fog removal.

3 FOG REMOVAL ATTEMPTS AND USER EXPERIENCES

3.1 *Fog removal trials and errors in Finland*

In most Finnish underground mines fog removal by means of rerouting air in order to obtain higher air velocity in the decline has been tried out in some decree. The results vary, but it can be concluded, that fogging problems have not disappeared. In some mines the fog has moved further up along the ramp or long fog fronts have been split to shorter ones. Fog removal has not been accomplished.

In a paper by (Martikainen 2005) fogging problems of three Finnish mines have been analyzed and results obtained from increasing air velocity by rerouting were presented. As high velocity as 2.5 m/s was not able to scatter fog, even if the literature value suggested enough to greatly reduce the widespread occurrence of the underground fog is only one tenth of this.

Best air rerouting results were obtained accidentally at the Pyhäsalmi mine as most of the humid air escaped from the decline to the old workings and thus took the fog away from the ramp entirely. Unfortunately the air velocity in the decline dropped close to zero, which was not appreciated. The air reentered the decline some hundred meters above with lower humidity. It was concluded that either the filling of the old workings was adsorbent or water condensed on the cool surfaces of the filling material and rock surfaces while working its way through.

Because increasing air velocity is one of the most popular fog removal methods, further studies were conducted. An additional fan was installed to the decline-level crossroad of the Louhi mine on level +130 m. Measurements covered both operating mode and the situation in the ramp with the fan turned off. Measurements for comparison purposes were taken with full operation and after the shift. Results are presented in Tables 1 and 2. After the shift the main fan operated only with 80 % capacity and the level working fans were turned off. This can be seen from the velocity values.

Table 1. Measurement results with full operation.

Depth *m*	Particles *mg/m^3*	Air velocity *m/s*	Temperature *˚C*	Relative humidity *%*	Dew point *˚C*	Fogginess *estimate*
230	0.314	0.95	9.1	84.4	6.6	no
222	0.319	1.1	8.7	87.2	6.7	no
206	0.505	1.2	9	86.7	7.2	light fog
175	0.176	1.3	8	89.8	6.5	fog
155	0.197	1.2	8	90	6.5	fog
130	0.273	1.7	8.7	89	7	light fog
110	0.296	3.1	8.9	88.7	7.2	no
70	0.366	1.5	8.9	88.6	7.2	light fog
40	0.427	1.1	8	90.8	6.7	fog

Table 2. Measurement results after the shift.

Depth *m*	Particles *mg/m³*	Air velocity *m/s*	Temperature *˚C*	Relative humidity *%*	Dew point *˚C*	Fogginess *estimate*
230	0.314	0.5	8.7	86.7	6.8	no
222	0.319	0.8	8.4	88.1	6.7	no
206	0.505	1	8.2	89.3	6.4	light fog
175	0.176	0.6	8.3	88.1	6.5	ligth fog
155	0.197	0.9	8.4	88.6	6.5	light fog
130	0.273	1.8	8.3	88.5	6.5	light fog
110	0.296	1.7	8.5	88.1	6.8	light fog
70	0.366	1.6	8.4	88.4	6.7	light fog
40	0.427	1.2	8	89.6	6.5	fog

The fan installation and the fan itself are shown in Figures 2 and 1. The idea was to take fresh air from the level and direct it through the ventilation wall to the decline with a duct. Airflow direction is presented with arrows in Figure 2.

Figure 1. An additional fan installed on level +130 m.

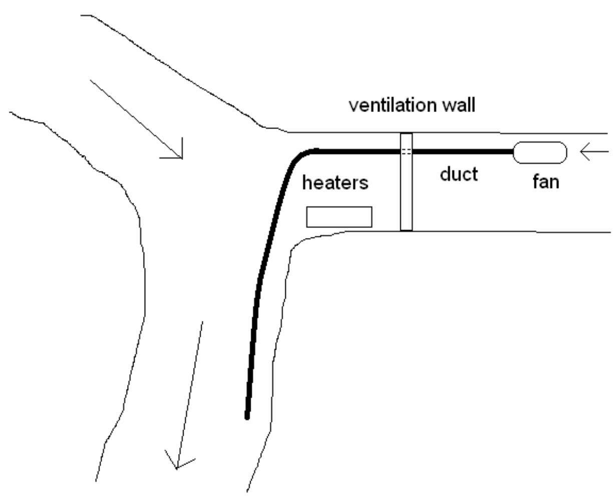

Figure 2. Fan and heater installation on level +130 m

Analysis of results showed most noticeable change in the depth of 110 m. The temperature rise was only 0.3 ˚C, but humidity decrease was more pronounced 3.4 %. The increase in air velocity was somewhat less than 1 m/s.

As the air was taken from a level, also the characteristics of the air there were considered important and thus measured. Furthermore, the effect of the fan to the airflow was studied. The results showed that in passing the fan the airflow dried considerably and was heated. The temperature increased by 1.3 ˚C and the decrease of relative humidity was as high as 5 %. Results are presented in Table 3.

Table 3. The effect of fan to the airflow.

Depth *m*	Particles *mg/m³*	Air velocity *m/s*	Temperature *˚C*	Relative humidity *%*	Dew point *˚C*	Fogginess *estimate*
Fan on						
110	0.243	2.8	8.8	87.6	6.7	no
130	0.197	1.2	8.4	89.8	7	no
Fan off						
110	0.336	2	8.5	91	7.3	fog
130	0.281	2.2	8.1	90.7	6.6	fog
Duct						
Duct end			9.3	82.7	6.5	no
Fan inlet	0.039	1.7	8	87.7	6.1	no

Calculations showed that the changes in humidity and temperature with the fan on corresponded exactly with the heating capacity of the fan. The calculated temperature of the united airflows of 14 m^3/s from the fan and of 46.8 m^3/s from lower levels on level +130 m was 8.376 ˚C when the measured value was 8.4 ˚C. The correspondence was similar for the humidity.

Also air heating in combination with the fan was studied. The installation of the heaters is shown in Figure 2. Air heating was already evaluated to be suitable for fog removal of this mine earlier. (Martikainen & Särkkä 2004) The heaters were not tested without fans on during operation, because satisfactory results were received with the fan and turning it off would have had a negative effect on ore transport. Heaters were installed close to the fan. The overall heating capacity of these heaters was 94 kW, which was slightly lower than anticipated from the calculations, which are presented later. With heating a temperature rise of 2 ˚C was sought after.

On the installation location measured increase in temperature was 1.4 ˚C. Unfortunately in the depth of 110 it was already decreased to only 0.6 ˚C. A slight increase in temperature was observed all over the decline. This was not, however, enough for complete fog removal. On the other hand the effect of heating on the measured relative humidity values was drastic. On the crossroad of +130 m the decrease of relative humidity was over 7 %. The smallest difference in relative humidity was measured near the surface, but even there relative humidity decreased over 1 %. These measurement results are shown in Table 4.

Table 4. Measurement results with heaters on and off.

Depth	Particles	Air velocity	Tempe-rature	Relative humidity	Dew point	Fogginess
m	*mg/m^3*	*m/s*	*˚C*	*%*	*˚C*	*estimate*
Heaters on						
230	0.678	0.9	9.3	82.9	6.5	no
222	0.69	1	9.2	83.7	6.6	no
206	0.667	1	9	86	6.5	no
185	0.509	1.4	8.6	88.4	6.6	light fog
130	0.338	1.4	9.6	84.9	6.8	no
110	0.299	2.3	9	87.2	6.9	no
70	0.244	2.3	8.7	89.1	6.7	no
40	0.336	1.2	8	91.6	6.8	light fog
Heaters off						
230	0.577	0.8	9	87.8	7.2	no
222	0.678	1	8.3	90.6	7	no
206	0.543	0.7	8.3	91.2	7.1	light fog
185	0.592	1.4	8	91.8	6.9	light fog
130	0.413	1.7	8.2	92	7.1	no
110	0.334	2.2	8.4	89.3	6.9	light fog
70	0.211	2.4	8.4	93	7.4	fog
40	0.265	1.3	7.8	92.7	6.9	fog

The reason for failure to remove fog completely was that the calculations for the heater dimensioning were very basic and did not take into account all factors that affect the temperature. Two sets of calculations were done and both of these gave similar results. The first set of formulas was meant for interior climate design of houses. It is presented with Equations 1 and 2:

$$\phi = \varphi q_v (h_2 - h_1) \quad (1)$$

where *Ø* represents the required heater capacity in kW, φ represents air density, q_v airflow and h_1 and h_2 air enthalpies. Enthalpies are calculated by:

$$h = 1.006t + x(2501 + 1.85t) \quad (2)$$

in which h is the enthalpy in kJ/kg, t is the temperature of humid air and x is the absolute humidity of air. (Seppänen 1996) With these formulas obtained required heater capacity was 115 kW.

The other calculation way is presented as Equation 3.

$$\frac{BTU}{hour} = 0.24 \times 0.0746 \times CFH \times \Delta T \quad (3)$$

In this equation BTU is British thermal unit, 0.24 is the specific heat of air, 0.0746 is the weight of one cubic foot of air, CFH is the volume of air to be heated and T is the number of degrees rise desired. (Kennedy 1996) After converting all units to SI units, a value of 106 kW was obtained.

For example leakages, rock thermal conductivity and virgin rock temperature were not taken into account at all in any of the formulas. As all these effectively decrease the temperature, it is easy to understand why the heater capacity was not sufficient.

The worst leakages were observed between the measurement points of 40 m and 70 m, where the smallest decrease of relative humidity was measured. Also other measurement results correspond well with the observations.

If dimensioning for complete fog removal was made, more complicated analysis of the relevant parameters is required. It would probably be best to use a computer program designed for this purpose. As an example a mine climate simulation program CLIMSIM can be mentioned. The program distributor, Mine Ventilation Services, states that this program takes into account geothermal gradient, rock thermal conductivity and diffusivity, airflow, air quality, age of the excavation, wetness of the rock surfaces and the siting and capacity of machinery, heat exchangers or other local or disseminated sources of heat and humidity. (Mine Ventilation Services 2003)

3.2 *User experiences*

Increasing air velocity by air rerouting has not been able to solve fogging problems anywhere. Information concerning changed fog movement patterns and fogging locations have been obtained from personnel, but actual improvements have not been observed. So it can be concluded that increasing air velocity by air rerouting is not a sensible fog removal method.

Increasing air velocity by installing a booster fan at the Louhi mine had a positive effect on the situation. The personnel of the mine were pleased as the fog got lighter near the fan. Air velocity increased about 1 m/s upstream of the fan and humidity values changed locally.

Installing heaters also gave positive results. Fogginess decreased noticeably upstream from the installation. Measurement results showed conditions less favourable for fogging also downstream, but unfortunately the personnel did not respond accordingly. The feedback contained comments about better visibility in the upper part of the decline, but also complaints about decreased visibility below the heater installation location.

It was obvious that the capacity of the heater installation was not enough to treat the long decline. Even if the temperature was higher in every measurement point, it was still not high enough to prevent fogging completely.

The reason for the feedback was not obvious, so it was questioned whether it originated from the improved conditions of the upper section of the decline or changes below the heaters. When the visibility upstream the heaters increased noticeably, could it be possible that the almost unchanged situation downwards of the heaters was considered worse? As the eye adjusts to the better visibility light fog that was not even observed earlier after driving through a heavily fogged part surprises the eye and seems worse than before.

Leakage prevention used at the Pyhäsalmi mine prevents fog formation, but the situation was already quite good in the treated part of the incline before these measures were taken. As the temperature there was well above the dew point the worst problems were likely to occur in the upper parts of the ramp anyway. In there the fog situation did not change. (Pulkkinen & Martikainen 2004) Personnel are almost completely working in the deep section of the mine where fogging does not occur, so they are quite happy with the results. In the upper part of the decline, from about depth of 1050 m upwards, however, fogging is still a nuisance.

4 CONCLUSIONS

Increasing air velocity by rerouting is highly unlikely to solve fogging problems. This method has been tested in many mines with similar results. The only observed changes were location changes of the fog fronts as well as some fog movement variations even if the achieved air velocities reached 2 m/s and above. No fog removal actualized.

Air rerouting may give positive results if foggy air is rerouted through absorbent material or through tunnels with cold walls in which water condenses. As the humidity of the air decreases, probability of fogging also decreases. This method is, however, not well tested.

Increasing air velocity in one of the mines with an additional fan installation gave slightly different results when compared to increasing air velocity by rerouting. Local fog removal was observed. Calculations showed that the measured temperature and humidity decreases were directly proportional to the heating capacity of the fan. Thus it can be concluded that the fog removal effect of a fan is due to its effect as a heater.

Altogether it can be concluded that increasing air velocity does not give acceptable results in removing fog from a mine. If fans are used for fog removal, their effect is not based on the air velocity increase, but rather on their heating capacity.

Heater installation gave fair results. It decreased relative humidity and increased temperatures all around the decline. This was by far the most satisfactory of the tested methods.

Unfortunately the dimensioning of the heaters was not enough for complete fog removal in the test case. Formulas used for the capacity dimensioning were straightforward and did not take into account every parameter that affects temperature in a mine climate. More refined numerical modelling is suggested whenever a detailed quantitative understanding is required.

5 ACKNOWLEDGEMENTS

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