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Comparative Evaluation of Fogging Phenomenon in the Ramp of Three Mines in Finland

A Martikainen[1]

ABSTRACT

In Finland fogging in mine ramps is a common problem. Fog forms when warm and humid exhaust air moves upwards the ramp, where the skin temperature of surrounding wallrock decreases to about 10°C. Changes in fog thickness and lengths of fog-filled parts of the ramp depend at least on climatic conditions outside, diesel equipment usage in the mine, and the length of working sequence at a time.

In this study fogging problems in three different mines, namely Orivesi mine, Louhi mine and Pyhäsalmi mine, with different ore types, different layouts, and different depths are presented and compared. All these mines use diesel equipment and the ramp is used as an exhaust air route. In two of these mines the ramp is used as a haulage road and in the other for supply and repairing, checking, and surveying purposes.

Measurements of humidity, temperature, air velocity, and dust content were performed in these mines. The measurement results, as well as field observations are presented, compared, and discussed. The results show that fog is observed in areas with high relative humidity values when air temperature and dew point temperature are less than 3°C apart from each other. Air velocity values were high in many areas. In addition, measured particle concentration values were mainly high in areas, where fog was observed.

A short literature review of recent fog formation studies is also presented. It demonstrates the complicacy of the fog formation process.

Similarities and differences concerning fog problems in the ramps are found and presented. As already a lot of new information is gained, the continuation of research is considered plausible to find more economical ways of solving and preventing this problem in the future.

INTRODUCTION

Fogging is a common problem in northern mining countries with a cool or temperate climate as well as in tropical countries. Fog prohibits visibility, and is thus considered a safety hazard. Many different fog removal alternatives are known. To date heating, cooling, scrubbing, chemically drying the air, and increasing air velocity have been used to remove fog in mines. Unfortunately most of these options are fairly expensive and not always effective.

At present air heating and increasing air velocity in the area of fogging are considered the best solutions to the problem. The air velocity value of 0.25 m/s is suggested in literature to be mostly enough for fog dissolution. This does not seem however, to be the cure in the case studies describing the situation in ramps of three mines in Finland.

Some case studies concerning fogging have been made, but there is still not much material about user experiences. Also information from miners working in underground mines having fogging problems has not been gathered, or published.

Research concerning fog formation and behaviour of fog has been hectic in the fields of meteorology and physics especially during the 1990s. This interest has been partly motivated by the need to understand the principles of pollution-related climate change. More detailed understanding about fog formation processes has recently been published. These new research achievements may give us the opportunity to find new approaches to fog prevention and removal in the underground mining industry. Also, the new technical developments, for example the more sophisticated measurement devices, facilitate the application of the research material.

The basics of fog formation and recent published results concerning the topic are discussed as well as case studies and worker experiences from three different Finnish mines.

PHYSICS OF FOG FORMATION

Fog is essentially a cloud having its base at the ground, so cloud formation mechanisms are similar to those of the fog formation. The Meteorological Observer's Handbook (1982) says that fog is:

> *A suspension of very small, usually microscopic, water droplets in the air, reducing visibility at the earth's surface to less than 1000 m. When sufficiently illuminated, individual fog droplets are frequently visible to the naked eye; they are often seen moving in a turbulent manner. In general, the relative humidity is, or is close to, 100 per cent.*

Relative humidity is a measure of water vapour content in the air, in comparison with the water bearing capacity of that air. Relative humidity depends on the temperature and vapour content of the air. Dew point is a temperature in which relative humidity reaches 100 per cent. So a small temperature dew point spread in the air mass as well as condensation nuclei acting as droplet centres are essential in activating fog formation.

In meteorology four different types of fogs are classified, namely radiation fog, advection fog, upslope fog, and precipitation fog. In some references, eg Stimac (2004), a fifth fog type, steam fog, is introduced. Only two main processes, cooling air to its dew point or adding moisture to the air, however, lead to fog formation; Parsons (2003). This means that all fog types are based on either one or both of these principles.

Radiation fog forms almost always at night, near daybreak, or in the morning. Then the radiating heat escapes the ground surface and cools it. Consequently cooled ground surface then cools the air above it to the dew point. This form of fog is usually shallow and does not last long. Advection fog forms when moist air moves over colder ground or water. Advection fog on the surface gets thicker as wind speed increases up to about 7.5 m/s, after which stronger wind lifts the fog layer to stratus or stratocumulus clouds. Upslope fog occurs when air is forced to rise up a large slope and cools adiabatically to its dew point. Precipitation fog forms when raindrops fall into unsaturated cooler air and evaporate thus causing an increase in the amount of water vapour. This vapour then condenses into droplets.

So fog is formed as the water in the cooling air condenses into droplets. This cooling is either due to a temperature drop or to evaporation caused by radiation. When more water is condensed into the droplet than is evaporated from it, droplet grows. These droplets form around condensation nuclei that can be either particles or aerosols. Common condensation nuclei include salt and soil particles, dust and pollutants. The diameter of condensation nuclei is typically about 0.2 micrometres, but ranges considerably. The role of condensation nuclei in fog formation has been explained thoroughly in many references like in Hudson (1993), and also in a mining related article by Gillies and Schimmelpfennig (1983). They found that large

1. Rock Engineering, Helsinki University of Technology, PL 6200, Hut 02015, Finland. Email: anu.martikainen@hut.fi

condensation nuclei of size 0.1 - 1 µm and giant condensation nuclei of size 1 - 10 µm form the major source of condensation surfaces for fog forming moisture droplets.

The rate of droplet formation is determined by the number of condensation nuclei present. Results by Bott (1991) show delayed fog layer formation for small aerosol concentrations. High concentration of aerosols and particles in the air yield the highest vertical extent of fog above the ground and also the highest fog water content.

When the air contains a lot of small water droplets, droplets grow also due to collision-coalescence process. In this process bigger water droplets fall with a higher speed than smaller ones. They then collide with the small droplets and sometimes merge together. Also turbulence and mixing of air enhance fog formation. In favourable conditions the fog droplets grow to their typical size of about 20 µm.

It has been observed that a relative humidity of 100 per cent is not always necessary for fog formation. Fog may form with a relative humidity as low as 70 per cent. The main reason for fog formation with such low relative humidity is the existence of hygroscopic particles gathering water vapour and acting as condensation nuclei in the air. This is known to reduce the equilibrium vapour pressure, and is called the solute effect.

Mattila, Kulmala and Vesala (1997) studied the behaviour of simultaneous condensation in vapour mixture. They concluded that multicomponent condensation enhances significantly the growth rate of the aerosol droplet. The droplet grows faster due to two reasons. The first reason is the existence of other condensing substances and the second is the increased mole fluxes of each species. These results indicate that the problem of droplet growth, and thus fog formation, is even more complicated than earlier believed. Therefore, it is also more difficult to prohibit fogging in a mining environment.

Thus saturation conditions can occur even with lower relative humidity than expected, due to the presence of soluble particles and multicomponent condensation. Also saturation fluctuations influence droplet growth. Kulmala *et al* (1997) found that some droplets are able to form and grow in unsaturated conditions with mean saturation ratio less than unity. This is due to saturation fluctuations, in which turbulent fluctuations result in some droplets experiencing saturations that initiate droplet growth.

FOGGING CONDITIONS IN MINE RAMPS

McPherson (1993) concludes that fogging in subsurface ventilation systems occurs in two situations. First, when the stratum is cooler than the dew point temperature of the incoming air and, secondly, due to decompression (autoexpansion) of humid return air.

As the air mass moves up the ramp, fog starts to form in the upper levels. The rock surrounding the ramp is cooler near the surface and causes the air to cool down as well. Therefore, the situation is similar to formation of advection fog above the ground with the only exception that warm, humid air moves through a tunnel with cold rock surfaces all around, not just over one cold surface. Also similarities with the upslope fog are evident.

CASE STUDIES

All three of the mines surveyed have a main or primary exhaust air route that consists of raises or shafts or a combination of both. The ramp is used as a secondary exhaust air route removing part of the humid return air. The velocity of air, relative humidity, and temperature vary along the ramp. For example water seepage, pumping stations, level connections and shaft connections affect these parameters. Changes in fog thickness, fog front length and location of fog depend at least on the climatic conditions outside, diesel equipment usage in the mine, and the length of a working sequence at a time.

In the mines surveyed fogging occurs mainly or only in the ramp throughout the year. Thickness of the fog varies, and the problem is most severe, usually during spring and autumn. Also during the summer, especially after heavy, warm rainfall, fog gets thick. In the wintertime air is usually quite dry, and the visibility is better since the fog is lighter.

It is also typical that thickness of the fog increases during the workday and also during the working week. This is due to machinery usage and traffic, which increase the amount of the particles and aerosols that act as condensation nuclei in the air.

Pyhäsalmi mine

The Pyhäsalmi mine is a zinc-copper mine located in central Finland. The depth of the mine is 1445 m making it the deepest operating metal mine in Europe. Ventilation system of the Pyhäsalmi mine is discussed thoroughly in the paper presented by Pulkkinen and Martikainen (2004).

This is the only surveyed mine, which has also some areas and levels susceptible to fogging. Fog in these areas is however, not a problem, since the levels have been long abandoned. Fog in the ramp is also not considered a serious problem, since the ramp is not used as a haulage road. Only a supply truck uses the ramp regularly and it has no strict schedule. Other vehicles use the ramp occasionally, mainly for repairing, checking, and surveying purposes. The speed limit in the ramp is 25 km/h, but sometimes the fog has been reported too thick to enable driving according to the limit. In the Pyhäsalmi mine, however, there have been no accidents caused by fogging.

Fogging has been more of a nuisance than a problem in the Pyhäsalmi mine. Attempts to get rid of the fog include increasing air velocity in the ramp and prohibiting water flow down the ramp. Also the possibility of heating has been discussed, but not too seriously. In the working areas, where the water flow to the ramp has been limited, and the area is dryer by nature, there is no fogging. In the upper parts of the ramp where the air velocity has been increased, the results were not as efficient in fog removal as expected.

Appearance of fog in the ramp is not continuous, and there is usually no exact fog front in the Pyhäsalmi mine. Several sections of the ramp are foggy, but in between there are also clear parts. In some parts of the ramp fog clouds of different sizes move upwards.

Louhi mine

The Louhi mine is a limestone mine whose orebody is a steeply dipping limestone layer, with a thickness of about 100 m. The mine depth is 230 m and mining method is longitudinal sublevel stoping. A description of the ventilation system of the Louhi mine is presented in Martikainen and Särkkä (2004). Fresh air entering the mine is about 55 m^3/s and about 60 per cent of this is exhausted through the ramp.

In the Louhi mine fog in the ramp is a safety issue. According to the personnel, one accident has been probably caused by fog reducing visibility. Fog also affects haulage speed, but has not been taken into account in schedules.

Fog in the Louhi mine occurs in an almost stable front from the surface to level +155. The length of this fog front is thus about 850 m. Thickness of fog is also quite constant through this whole length.

Orivesi mine

The Orivesi mine is a gold mine located in southern Finland. The mine depth is about 720 m. The Orivesi mine is currently in a standby mode, but a feasibility study is being prepared concerning the Sarvisuo orebody close by. If mining of Sarvisuo starts it will be carried out through the old facilities with an underground connection tunnel between the old mine and the Sarvisuo ore deposit. Measurements in the Orivesi mine were performed when the mine was still in full production during the 2003 autumn.

The primary ventilation system of the Orivesi mine consists of two intake shafts and one exhaust shaft. The main fresh air shaft reaches 700 m depth. The upper part of it to the level +235 is a full profile raise of a diameter of 1.8 m, other parts are long-hole raises of about 2 m × 2 m. The other fresh-air shaft and the exhaust shaft consist of a series of long-hole raises going down to level +665. Part of the exhaust air moves up along the ramp. The amount of exhaust air travelling through the ramp is about half of the total airflow.

The amount of fresh air entering the Orivesi mine is about 90 m^3/s. Air is distributed to the working areas using auxiliary fans and flexible ducts. Also ventilation walls are used to control the air distribution. These walls are mainly of concrete, and equipped with either doors or openings for fans and flexible ducts.

In the Orivesi mine air velocity in the ramp is high due to the collapse of an exhaust shaft, so all exhaust air moves up the ramp past the collapsed part of the shaft. The high air velocity in the ramp is inconvenient, since dump trucks cause a disturbing pumping movement of the air. This part of the ramp is, however, free of fog.

The worst fogging period in the Orivesi mine is the summer. Fog is sometimes thick enough to prevent visibility of the rock walls surrounding the ramp and thus slows down haulage speed. No accidents caused by fog have been recorded.

Ventilation system changes have been attempted in order to prevent fogging, but these changes have not produced the anticipated results. Fogging has been noticed mainly between surface and level +235 as a steady fog front. During winters fog appears in a clearly narrower range.

MEASUREMENTS

The same protocol and procedures for taking measurements was performed in all three mines surveyed. In the Orivesi mine and in the Louhi mine one set of measurements was taken. In the Pyhäsalmi mine however, two measurement sets were taken. The first set of measurements was taken in 2003 in connection with a ventilation study. Another set of measurements was taken in 2004, when some of the upper level connections were sealed off to keep the air velocity in the ramp more stable and to ensure the flow of air up the ramp. The results of the second measurement set were expected to be a lot more informative about fog related parameters than the first measurement results.

The measurement set consists of air velocity, humidity, temperature, and dust content measurements. Air velocity measurements were performed with a thermo-anemometer. Humidity and temperature measurements were done with a hygrograph and thermometer, which measures relative humidity of 0 - 100 per cent and temperatures from -10°C to +80°C. An aerosol metre with a maximum particle size range of 0.1 - 10 µm was used in large and giant-sized particle measurements. The aerosol metre has a measuring range of 0.001 mg/m^3 to 100 mg/m^3 and a resolution of one per cent of the measuring range.

In the Pyhäsalmi mine first observations showed fog in between levels +300 and +780 as an almost continuous front. Upwards from level +300 also a couple of moving clouds of fog were noticed. The measured relative humidity values in the foggy area ranged from 75 to 81 per cent. Both particle and air velocity values changed considerably throughout the ramp. Highest particle values were observed in working levels of +1100 and +1300. A complete listing of measurement results is presented in Table 1.

In the foggy area, air velocities ranged from 0.3 m/s to 1.3 m/s and the particle concentration from about 0.4 mg/m^3 to 1 mg/m^3. The air velocity of the ramp was found to vary, due to leakage into the worked out areas. Temperature decreased from +21.5°C in level +780 to 15°C in level +300. Humidity, air velocity, particle values, and an estimate of observed fogginess are presented in Figure 1. The measurements were taken in the spring when outside temperature ranged from 0°C to 10°C in the course of the measurements. Relative humidity ranged then from 17 per cent to 33 per cent. The amount of air entering the mine during the measuring period was roughly 90 m^3/s.

The first measurements were performed during the weekend with little traffic movement. The weekend air is fresher and less humid than during the weekdays. This shows in the measurement results. The second set of measurements took place on a Tuesday afternoon shift. The results of the second measurements in the Pyhäsalmi mine are shown in Table 2.

The second set of measurements in the Pyhäsalmi mine was performed in winter with a temperature outside ranging from about -6°C to -8.5°C, and the relative humidity ranging from 39 per cent to 67 per cent. On this occasion, the number of measurement points was increased to ease figuring out trends along the ramp. Surprisingly, the reading indicated very high relative humidity values in the mine, despite the surface

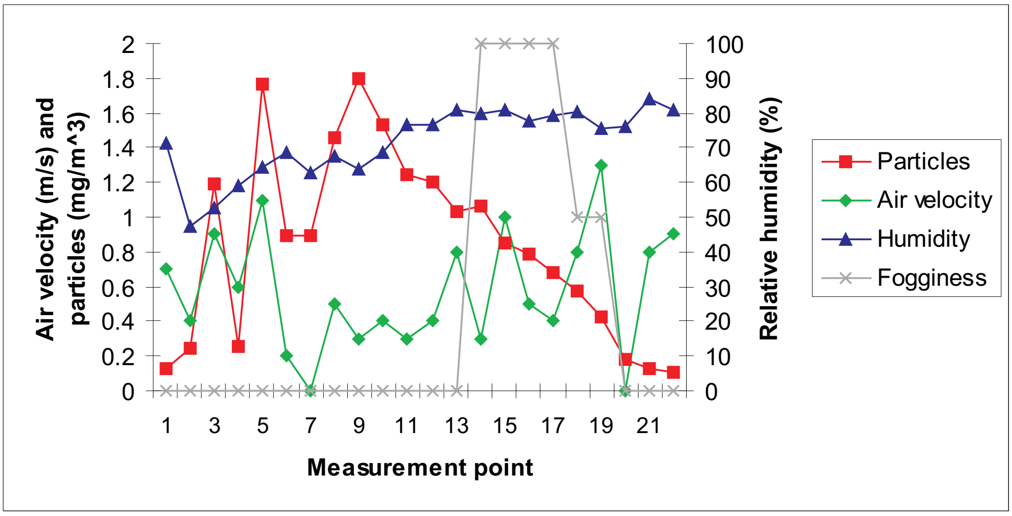

FIG 1 - Measurement results from the first measurements at the Pyhäsalmi mine.

TABLE 1

Complete set of measurement results of set one from the Pyhäsalmi mine.

Measurement point	Depth (m)	Particle concentration (mg/m^3)	Velocity (m/s)	Temperature (°C)	Relative humidity (%)	Dew point (°C)	Fogginess (estimate)
1	1425	0.129	0.7	21.0	71.5	16.2	no
2	1400	0.250	0.4	23.2	47.3	11.4	no
3	1375	1.190	0.9	21.2	52.7	11.7	no
4	1350	0.252	0.6	21.4	58.8	13.6	no
5	1300	1.763	1.1	20.4	64.6	14.1	no
6	1250	0.898	0.2	20.1	68.7	14.7	no
7	1200	0.892	0.0	22.6	62.6	15.4	no
8	1125	1.454	0.5	21.8	67.7	15.9	no
9	1100	1.802	0.3	21.6	63.8	15.1	no
10	1080	1.530	0.4	21.9	68.7	16.4	no
11	1010	1.241	0.3	20.8	76.7	16.8	no
12	930	1.202	0.4	21.8	76.7	17.4	no
13	850	1.036	0.8	21.7	80.6	18.3	no
14	780	1.060	0.3	21.5	79.9	17.9	fog
15	680	0.848	1.0	20.5	81.0	17.5	fog
16	600	0.785	0.5	21.3	77.8	17.6	fog
17	425	0.681	0.4	18.8	79.2	15.8	fog
18	360	0.570	0.8	13.1	80.4	10.2	some fog
19	300	0.429	1.3	15.1	75.5	11.4	some fog
20	160	0.183	0.0	14.8	76.0	11.2	no
21	140	0.129	0.8	13.9	84.1	11.9	no
22	100	0.103	0.9	13.6	80.6	10.9	no

temperature being below 0°C. There was fog in two different fog fronts, between levels +1010 to level +500 and from level +160 almost to the surface. Thickest fog was observed between levels +500 and +780 as well as between levels +970 and +1010. Relative humidity values in these foggy areas ranged from 74 per cent to almost 93 per cent. Particle concentration was also surprisingly high in the foggy areas, in many places exceeding the values measured in the active mining area, even when there was no traffic above level +1100. Air velocity values were between 1 - 1.5 m/s in the foggy parts of the ramp. From level +500 a lot of air leakage from the ramp to old workings was attributed to causing the fog to disperse and the lowering the air velocity to near zero. Humidity, air velocity, particle values and observed fogginess are shown in Figure 2.

In the Louhi mine fog in the ramp was observed between measurement points 5 and 11, from the surface to about level +175. There fog got lighter and disappeared quickly. Relative humidity in the foggy part of the ramp ranged from 80 per cent to 85 per cent. Highest particle measurement values were observed in the foggy area. Air velocities upwards the ramp ranged there from 1.1 m/s to 1.7 m/s. Temperature ranged only a little around +9°C. The weather outside during the autumn measurement day was rather stable with a temperature of about 15.5°C and a relative humidity of 72.5 per cent. The measurement results achieved from the Louhi mine are presented in Table 3 and humidity, air velocity and particle values as well as observed fogginess in Figure 3.

The Orivesi mine had the highest values of relative humidity. These high values were found in the foggy area and ranged from 92 per cent to 93.5 per cent. The air velocity ranged from 0.7 m/s to 2 m/s and the temperature in the foggy part of the ramp decreased as one approached the surface from +16.5°C to a bit over +14°C. The thickest fog was observed between points 10 and 12, where the air velocity was about 1.5 m/s. The foggy area reached from the surface to about level +310, disappearing then slowly when going deeper so that level +375 was completely clear. The complete measurement results are shown in Table 4.

Particle concentrations were the highest where the fog was the thickest and also close to the ramp portal. Probable causes for the high particle concentration near the surface were the brisk wind outside and a few passing dump trucks, which seemed to affect other measurement results in measurement point 16 as well, and scatter the fog close to the ramp exit. Humidity, air velocity, particle values and observed fogginess are shown also in Figure 4. Conditions outside were warm with a temperature of about 22°C and a relative humidity of about 50 per cent during the measurements.

EVALUATION OF RESULTS

From the measurement results it can be seen that a difference of about 3°C between the measured temperature and the dew point temperature is enough to prohibit fog formation in the climate of these mines. Furthermore, it is also clear that the fog is thickest when the relative humidity is the highest.

Fog needs condensation nuclei to form. So the large and giant sized particle concentration values observed in the foggy areas are as high as expected. An interesting observation is, however, that particle concentration values are much higher in the foggy areas than in the areas with no fogging, even without the influence of traffic or any other particle sources. This indicates that fog actually hinders particle movement to the areas with unfavourable conditions for fog formation and that way prevents fog from scattering. At least the studied large and giant condensation nuclei tend to stay in the air of the foggy area. This way fog there continues to form easily, even if there are minor changes in other influencing parameters.

TABLE 2

Complete set of measurement results of set two from the Pyhäsalmi mine.

Measurement point	Depth (m)	Particle concentration (mg/m^3)	Velocity (m/s)	Temperature (°C)	Relative humidity (%)	Dew point (°C)	Fogginess (estimate)
1	1425	0.228	0.8	20.5	72.2	15.8	no
2	1405	0.475	0.6	21.7	53.3	15.2	no
3	1375	0.730	1.8	22.1	71.0	15.2	no
4	1350	0.693	1.3	20.8	74.2	15.9	no
5	1300	0.982	0.1	21.2	70.6	16.8	no
6	1250	1.123	0.9	21.6	74.1	16.3	no
7	1200	0.901	0.9	21.7	79.9	17.0	no
8	1125	0.877	1.1	20.5	81.0	17.0	no
9	1100	1.158	0.4	20.4	81.1	17.3	no
10	1080	1.273	1.1	20.5	81.6	17.3	no
11	1010	1.532	0.8	20.6	74.2	17.5	some fog
12	930	3.027	0.9	22.2	76.0	17.5	some fog
13	850	2.171	1.0	22.5	85.3	17.8	some fog
14	780	4.547	1.1	20.6	85.0	18.0	some fog
15	680	4.643	1.4	20.2	85.0	17.8	some fog
16	620	4.603	1.6	19.8	87.3	17.6	fog
17	600	4.650	1.5	19.8	86.3	17.6	fog
18	520	7.755	1.3	17.6	92.8	16.7	fog
19	500	5.018	1.5	18.9	85.5	16.8	fog
20	425	0.246	0.1	17.9	75.9	14.5	no
21	400	0.161	0.3	15.2	82.0	12.6	no
22	360	0.162	0.8	14.2	80.1	11.2	no
23	300	0.196	0.9	14.9	74.7	10.9	no
24	240	0.173	1.2	13.5	85.1	11.1	no
25	160	0.662	0.9	11.5	88.5	10.3	fog
26	150	1.093	1.3	12.3	88.0	10.9	fog
27	140	0.844	1.5	11.3	92.6	10.9	fog
28	130	0.588	1.2	10.8	89.6	9.7	fog
29	75	0.879	1.0	9.4	91.1	9.1	fog
30	70	0.334	1.5	9.0	89.9	8.9	fog
31	50	0.149	1.7	9.2	85.0	8.7	some fog

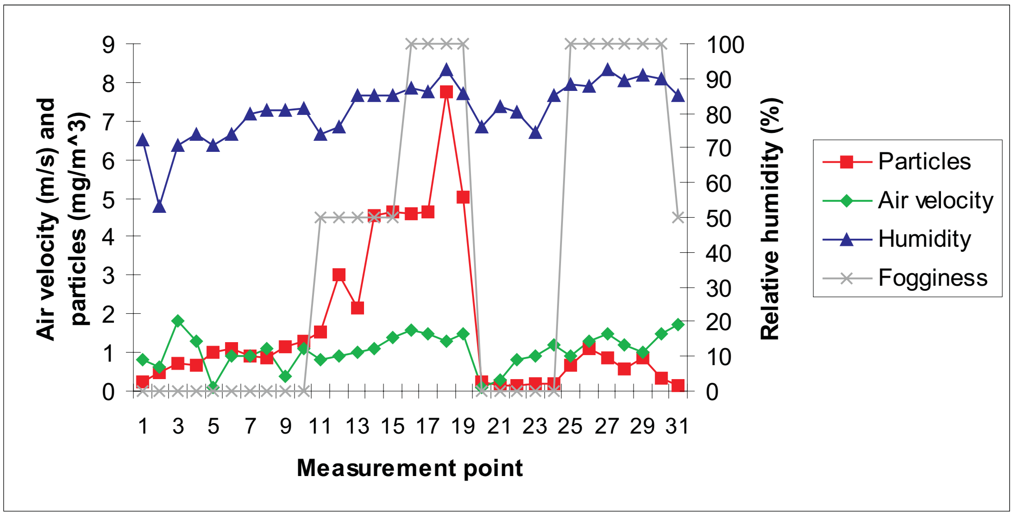

FIG 2 - Measurement results from the second measurements at the Pyhäsalmi mine.

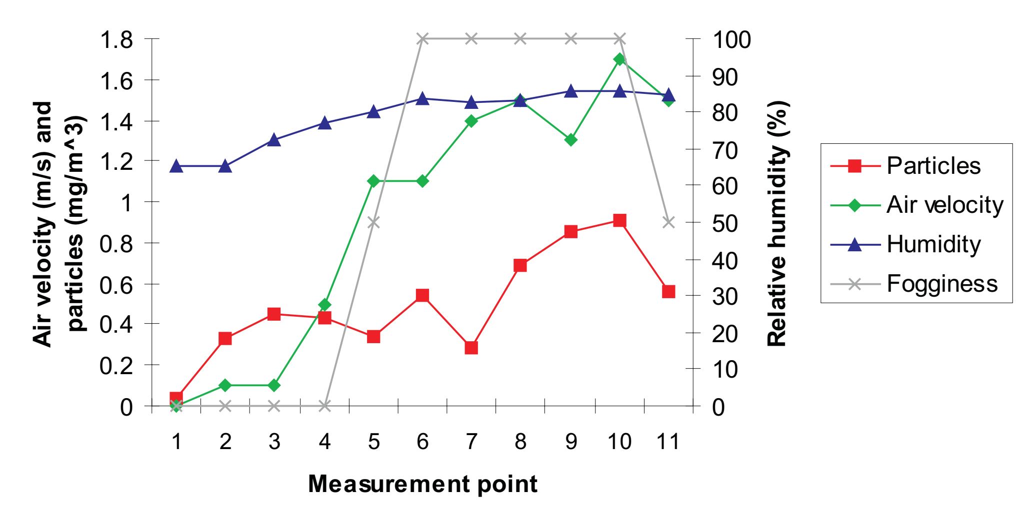

FIG 3 - Measurement results from the Louhi mine.

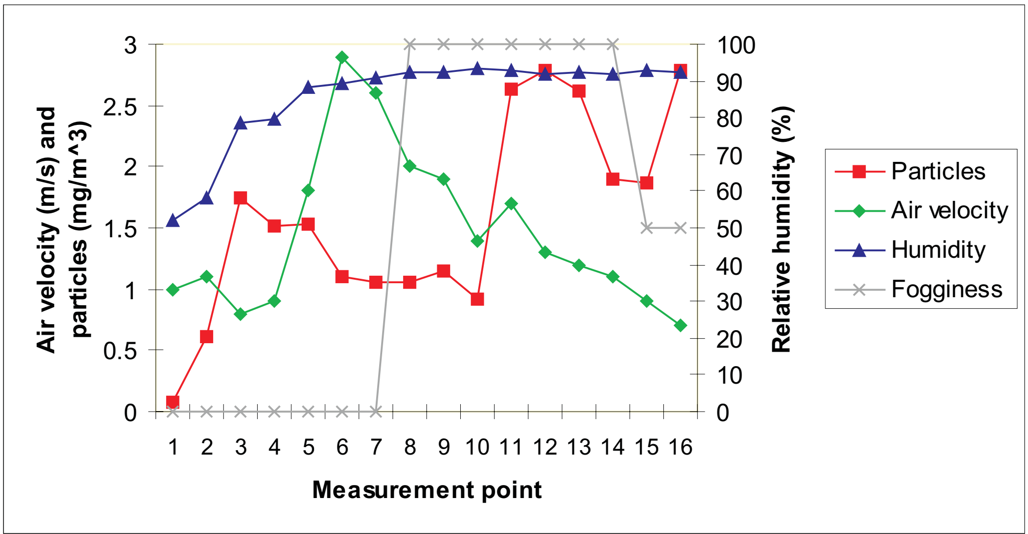

FIG 4 - Measurement results from the Orivesi mine.

TABLE 3

Complete set of measurement results from the Louhi mine.

Measurement point	Depth (m)	Particle concentration (mg/m^3)	Velocity (m/s)	Temperature (°C)	Relative humidity (%)	Dew point (°C)	Fogginess (estimate)
1	230	0.035	0.0	12.7	65.4	6.3	no
2	222	0.327	0.1	12.9	65.3	6.4	no
3	206	0.454	0.1	11.2	72.5	6.3	no
4	185	0.430	0.5	11.2	76.8	7.4	no
5	175	0.336	1.1	9.8	80.2	6.4	some fog
6	155	0.541	1.1	8.8	83.8	6.4	fog
7	130	0.282	1.4	9.3	82.6	6.5	fog
8	110	0.691	1.5	9.3	83.4	6.5	fog
9	70	0.857	1.3	8.7	85.6	6.2	fog
10	40	0.912	1.7	8.8	85.9	6.5	fog
11	15	0.557	1.5	8.9	84.7	6.6	some fog

TABLE 4

Complete set of measurement results from the Orivesi mine.

Measurement point	Depth (m)	Particle concentration (mg/m^3)	Velocity (m/s)	Temperature (°C)	Relative humidity (%)	Dew point (°C)	Fogginess (estimate)
1	700	0.082	1.0	23.2	51.8	13.0	no
2	665	0.609	1.1	23.4	58.1	14.8	no
3	610	1.739	0.8	19.5	78.6	16.3	no
4	550	1.521	0.9	19.0	79.8	15.8	no
5	490	1.529	1.8	17.6	88.2	16.3	no
6	430	1.101	2.9	17.4	89.4	16.1	no
7	375	1.054	2.6	17.0	90.6	16.1	no
8	310	1.057	2.0	16.5	92.4	16.0	fog
9	276	1.145	1.9	16.2	92.3	15.7	fog
10	235	0.924	1.4	15.8	93.5	15.4	thick fog
11	202	2.633	1.7	15.6	92.8	15.0	thick fog
12	164	2.792	1.3	15.4	92.0	14.9	thick fog
13	132	2.623	1.2	15.1	92.1	14.5	fog
14	97	1.901	1.1	14.8	92.0	14.2	fog
15	66	1.863	0.9	14.3	92.7	14.0	some fog
16	35	2.791	0.7	14.2	92.2	13.6	some fog

In some areas, even if the results do not show exactly favourable fogging conditions, some fog was still observed. This may be because of the earlier mentioned soluble aerosol actions, as well as small turbulent changes in saturation conditions. Air velocities are also so high in many parts of the ramps in question, that fog in some places moves quickly away from the point of formation. This complicates the result analysis.

Air velocity of 0.25 m/s is not enough in the ramps of the surveyed mines to scatter the fog, or to prohibit fogging. This value is suggested to be typically sufficient for fog dissolving by many authors like Gillies and Schimmelpfennig (1983) and Tien (1999). Air velocities as high as 2 m/s were measured in areas filled with thick fog. The measurement results obtained from the Orivesi mine show that with a temperature dew point spread, of only about 1°C, no fog is observed with air velocities above 2.5 m/s. In this situation, the air velocity in the ramp is nevertheless so high that pumping effect caused by moving vehicles becomes problematic.

Calizaya, Karmawan and Wallace (2002), on the other hand, say that the results of improving visibility with installing additional fans in a foggy ramp did not reach the desired level. They suggested the main reason for this was that the fans did not contribute enough heat to the air to eliminate fogging upstream of the fans. If this is considered further, maybe the real reason for fog removing effect of additional fans is not a consequence of the air velocity increase, but follows from a characteristic heating effect of a fan motor. This idea would support the results received from two mines in Finland, where higher air velocities in ramps, obtained by air re-routing, have not been able to reduce fogginess.

Heating the air would most probably solve the fog problems in these ramps, but it is not considered economically feasible. As the temperature decreases, when one moves upwards, the ramp closer to the surface, energy requirements become often too high.

In the Louhi mine the temperature difference over the fog front was at the time of the measurements only about 1°C, so heating may be a feasible option there. The situation at the Pyhäsalmi mine was the worst, when considering heating as a solution for fog removal, because the temperature difference there over the two observed fog fronts was over 11°C.

Controlling humidity by limiting water leakage to the ramp, where it was possible, gave the best results in fog prevention. Unfortunately this method cleared up only the treated part of the ramp. It is thought, however, that the active areas are free of fog already by nature mainly because of higher temperature and less ground water ingress from the surrounding rock, and the effective ventilation of the Pyhäsalmi mine.

CONCLUSIONS

Recent research shows that fog formation process is even more complicated than initially believed. In the underground mining environment, where diesel equipment, explosives, crushers, and road graders are used, high production of aerosols and particles ensures favourable conditions for fog formation, during working periods.

As the measurement results show, the large and giant condensation nuclei tend to stay airborne in the foggy areas. It is also clear however, that small changes in other fogging parameters are not necessarily enough to prohibit fog formation. Especially increasing air velocity does not always scatter the fog as expected. In the ramps, fog was observed even in areas with air velocities of about 2 m/s. With air velocity raised above 2.5 m/s no fog was observed, but the increased velocity had the effect of causing the dump trucks to give a problematic pumping effect of air in the ramp.

Probably a method of simultaneously attacking as many sources of fog as possible would be the best in preventing fog formation in the ramps used as secondary exhaust routes. Air heating in combination with removing aerosols and particles as well as water leakage prevention may also lead to good results. As this would however, be costly, more research is needed to identify new methods of providing the desired results within a reasonable price.

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