MINING AND METALLURGY INSTITUTE BOR
UDK: 622

ISSN: 2334-8836 (Štampano izdanje)
ISSN: 2406-1395 (Online)

UDK: 622.41(045)=111
DOI: 10.5937/mmeb2201001K

Received: 24.02.2022.
Revised: 07.03.2022.
Accepted: 07.04.2022.

Original Scientific Paper
Mining

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DECREASING OF THE AIR HUMIDITY BY THE VENTILATION CONTROL IN THE ST. BARBARA MINE

Abstract

The St. Barbara mine is a visitor mine having a large amount of timbering support which is deteriorating fast due to the high humidity conditions. The air conditioning system of mining is not suitable and also expensive for implementation in a shallow non-productive mine. As there are no usual air contaminants in the visitor mines, ventilation could be powered only when a dew point of outside air is below the strata temperature. Applying this rule would certainly avoid condensation, but also raises a potential for partial dehumidification of mine walls as moisture can evaporate in these conditions. A microclimate analysis, based on one-year data, has showed that these favorable conditions of the outside air occur through the major part of the year. Their availability is mostly 100%, but during summertime there are periods when it drops down to 13%. A real time monitoring system with programable microcontroller allows the automatic ventilation control and adjustment to the psychrometric conditions.

Keywords: *visitor mine, ventilation, dehumidification, automatization, timbering support*

INTRODUCTION

Visitor mines are popular touristic attractions in many places with the past mining activities. There is an increasing trend in restoration the abandoned mines, which must have a large number of visitors to be economically viable and support the needed maintenance costs. One of such mines is the St. Barbara mine in Rude, which has a large amount of timbering support and wooden elements built to achieve the authenticity. Timbering is usually applied as a temporary roof support and deteriorates fast due to a high humidity, so decreasing humidity would aid a service life of timbering. Deep production mines have the ventilation systems with cooling and dehumidification as the most critical needs of air conditioning [1], but these systems are not suitable and expensive for shallow and non-productive mines. On the other hand, the visitor mines do not have to be ventilated all the time because there are no contaminants. Ventilation could be powered on only while the favorable outside air conditions occur, which is an inexpensive way to dehumidify the mine.

ST. BARBARA MINE

The St. Barbara mine is located 30 km southwest of Zagreb in the small village of Rude near the town of Samobor. In the surrounding area, a dozen locations were re-

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corded where various types of ore were mined. The copper ore mining was recorded as early as from 1210 and lasted until 1851. The excavated quantities are estimated at about 2500 tons of copper. The iron ore exploitation was carried out in the period from 1850 to 1859. A total of 26.000 tons of iron ore (siderite) was excavated during this period. The ore was mostly smelted in Rude, and some in Slovenia. Iron ore is bound to the iron sandstones and fine-grained conglomerates of the Paleozoic age, and is spatially and genetically related to the copper ore. The zone of ore occurrence is 1.5 km long. The main mineral is hematite, and siderite appear only in the central part of deposit. During the 20th century, gypsum was also excavated, and mining was abandoned due to the high content of anhydrite (about 15%). Geological exploration in the area has also been carried out on several occasions during the 20th century. Active exploitation in the St. Barbara mine was completed in 1956 when it was abandoned. At the initiative of the local cultural and artistic society, the renovation of deteriorated mine began in 2002 and was completed in 2012. Within that, 350 m of mine headings were renovated with the aim of making the old mine a monument of mining and geological cultural heritage. The mine was opened with three adits (Vlasic, Holy Trinity and Kokel) which portals were collapsed. To date, the St. Trojstvo and Kokel adits have been restored, as well as the old mining faces between them. In order to promote the authenticity, a permanent wooden support was installed along the entire mine at the required locations.

ROOF SUPPORT SYSTEM AND VENTILATION

Excavation of the adit was characterized by the poor engineering-geological characteristics of the rock mass, mostly mullock with the change of finer granulation and large blocks. So that the excavation is completely supported by a wooden trapezoidal base, at a frame spacing that varied from 0 to 0.5 m depending on pressures. The St. Trojstvo adit was supported 167.5 m in total and the Kokel adit 51.5 m. The oak logs about 20 cm in diameter were used for columns and beams. The spaces behind the frame are also closed by the oak boards. Out of the 350 meters of the Mine currently available for visitors, 219 m is supported by the wooden frames. In total, more than 600 wooden frames were used for support.

Mine ventilation is achieved by an axial pressure fan installed on the portal of the St. Trojstvo [2]. The fan is mounted on an air channel, made of 80 mm diameter concrete pipe. A 8.0 m long air channel joins the side of the St. Trojstvo. The incoming fresh air current flows through the adit St. Trojstvo (elevation +306.9 m) by the excavation sites to the adit Kokel and exits on the portal Kokel (elevation +330.6). Due to the elevation difference of 23.7 m between the inlet and outlet of the air current and relatively small resistance of the mine, the natural potential of air flow is also present for most of the year. In the winter months, the natural air flow moves from the lower adit to the higher one, while in the summer months it moves inversely (Fig. 1).

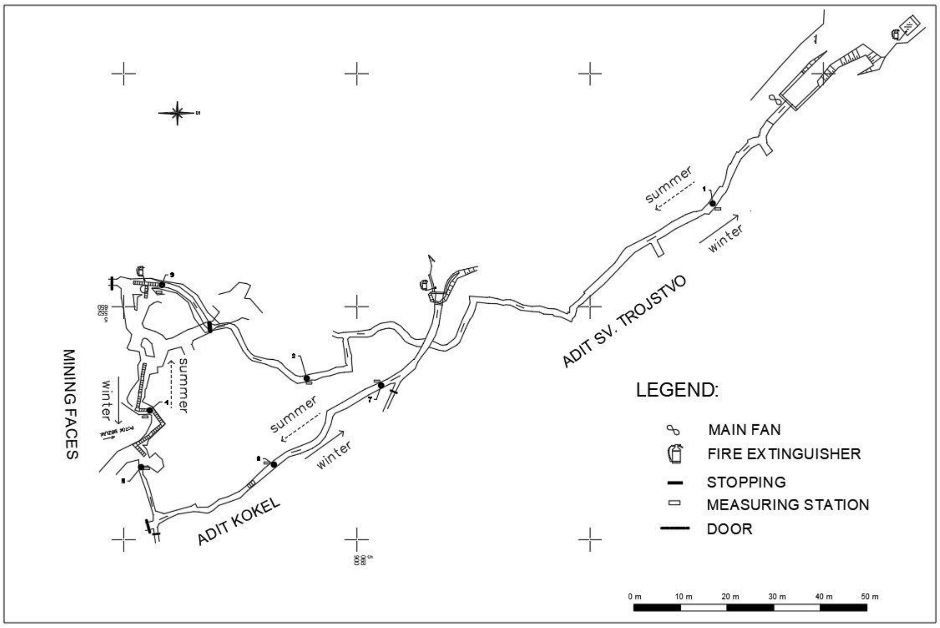

Figure 1 *Mine map*

HUMIDITY CONTROL

The basic idea is that outside fresh air always has some capacity to receive water vapor, as it is practically never saturated to 100%. How much water vapor it can accept depends upon humidity and temperature, but also psychrometric changes undergoing during entrance and flow through the mine. Theoretically, we can highlight three possible psychrometric processes (Fig. 2): 1 – Outside air has higher temperature than mine strata, and high relative humidity, where dew point is above strata temperature. As fresh air enters the mine it cools down to the dew point, when condensation of water vapor occurs. This is unfavourable condition and ventilation should be off. 2 – Outside air is higher in temperature than mine strata and has low relative humidity, thus dew point is below strata temperature. Entering the mine, air is cooled down to the strata temperature, relative humidity raises but not to the saturation point so air can still accept some water vapor, and moisture from walls can evaporate to the air. 3 – Outside air temperature is lower than strata temperature. As air enters the mine it is heated, and relative humidity drops drastically. Air can accept large amount of water vapor before saturation occurs. This is the most favourable condition as heating the air increases its capacity for water vapor no matter how humid the outside air is.

Overall, the two important states of the air can be distinguished. One, where a dew point is above the strata temperature, in which the condition mine should not be ventilated because condensation will certainly occur.

The other one is a dew point below the strata temperature, where it is safe to ventilate without condensation, but the amount of moisture evaporated from the walls will depend upon the psychrometric state of the outside air.

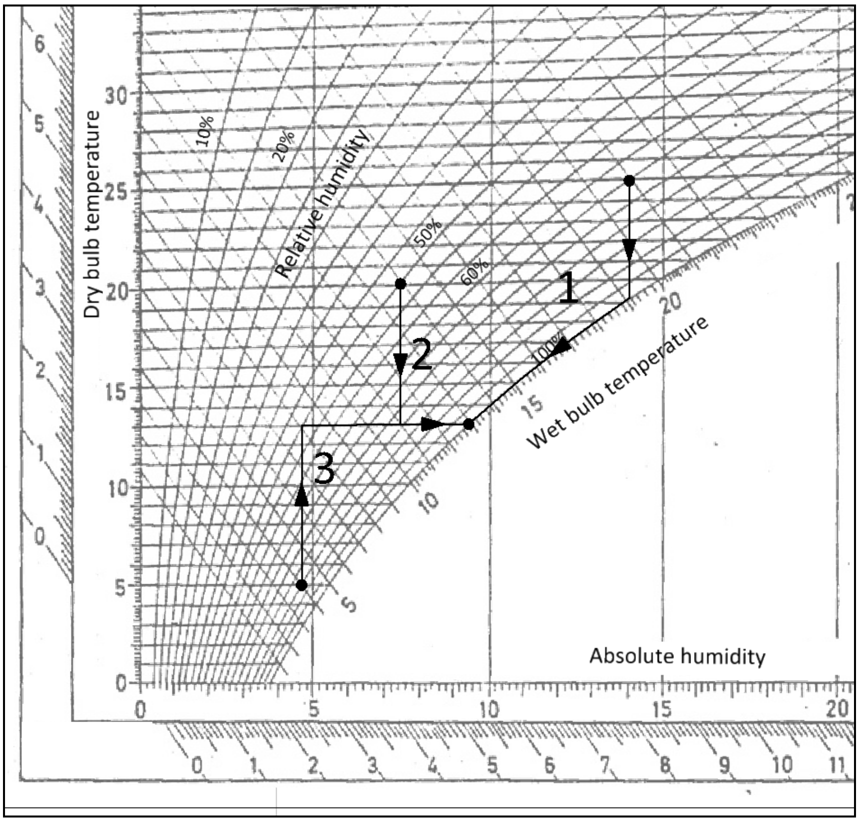

Figure 2 *Mollier diagram processes*

MICROCLIMATE ANALYSIS AND VENTILATION CONTROL

Slow seasonal changes and annual medians [3] show potential for the above-mentioned humidity control, but to exploit daily changes, the higher sample rate data needs to be observed. In order to estimate a possibility of ventilation without condensation, an analysis was done on the basis of one-year data with hourly interval of temperature and humidity recorded [4]. By this way, the season and daily variations in a dew point temperature were considered. Hourly temperatures and humidity were averaged on monthly basis. The resulting trendlines (Fig. 3) show a daily repeating pattern where increasing temperature during the daylight causes relative humidity to drop, and the opposite effect takes place during the night. A dew point was then calculated using the well-known equations (Eq 1-Eq 2) that utilize a dry bulb temperature and relative humidity as the input parameters [5].

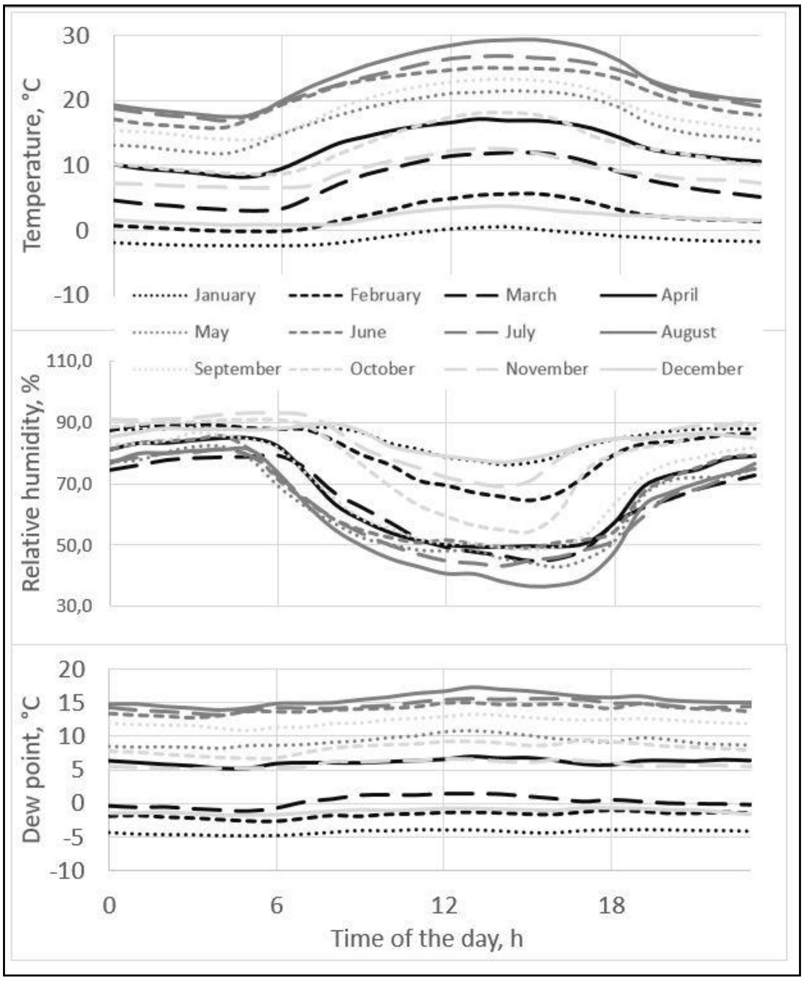

Figure 3 *Dew point analysis*

Given results show that the daily variations in a dew point are negligible and hardly usable, but the seasonal changes show a large drop of dew point below the strata temperature, what could be exploited for dehumidification.

$$e = \varphi \cdot 611 \cdot 10^{\frac{7,5t}{237,7+t}} \quad [eq\ 1]$$

$$t_d = \frac{237,7\ log\frac{e}{611}}{7,5\ -\ log\frac{e}{611}} \quad [eq\ 2]$$

where:

- e – water vapor pressure,
- t – air temperature,
- φ – relative humidity,
- t_d – dew point temperature.

Considering that the average strata temperature is 13°C [6], Fig. 4 shows a percenttage of available time when a dew point is below the strata temperature. It evident that most part of a year this condition is true, with some transition period in June and September, while the least occurrence of this condition can be expected in August.

	0h	1h	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
January	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
February	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
March	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
April	100	100	100	100	100	100	100	100	100	100	97	97	100	100	97	97	97	93	93	97	97	93	97	97
May	100	94	90	94	94	94	90	87	87	84	81	77	71	68	74	77	81	77	81	81	84	87	84	87
June	40	37	43	47	47	23	33	33	40	33	33	30	23	27	27	27	27	27	33	23	27	33	30	30
July	29	32	39	39	42	35	32	29	29	29	23	23	26	23	23	23	23	23	26	26	26	23	26	29
August	19	19	29	29	29	26	23	23	26	26	23	19	16	13	13	13	16	16	19	13	16	19	23	19
September	60	67	67	63	73	73	70	67	60	53	43	47	43	37	40	40	47	50	53	50	57	57	60	57
October	97	94	94	94	97	97	100	100	100	100	97	94	94	97	97	100	94	87	90	100	97	94	94	94
November	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
December	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Figure 4 *Availability of favorable conditions (%)*

In order to reduce humidity, the mine should be ventilated only when a dew point of the fresh outside air is below the strata temperature. How much of moisture from the walls will be evaporated indirectly depends on a dew point. Lower it is – the air has more capacity for water vapor. Additionally, the temperatures could be used for a fan reversal to enhance the airflow by the natural ventilation. The basic algorithm for fan control (Fig. 5) would compare the outside and strata temperature to decide whether reverse the fan airflow. By comparison a dew point to the strata temperature, a decision to power on or off the fan is made. Today's advances in control technology enable a continuous parameter monitoring of the mine microclimate [7]. By knowing these parameters in real-time, it is possible to automatically control the ventilation systems using a PID controller. [8]

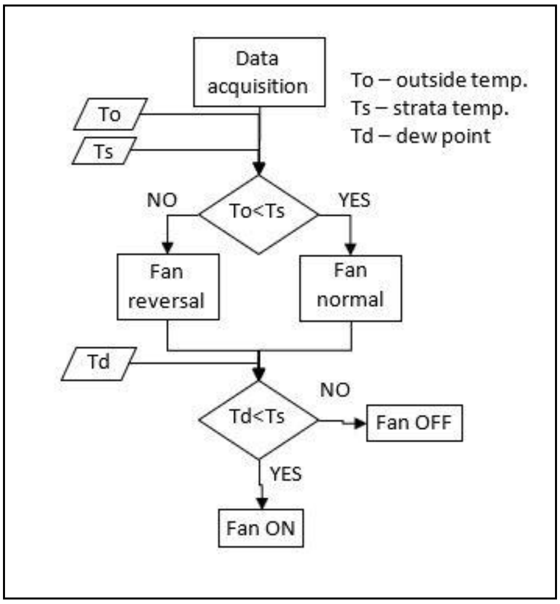

Figure 5 *Fan control flowchart*

CONCLUSION

Service life of a timbering inside the mine can be extended if the air moisture on its surface is reduced. Expensive mining systems for the air conditioning are not suitable for small visitor mines because of their cost and complexity. One way to partially dehumidify the mine is to exploit the outside fresh air capacity to absorb water vapor. This can be only done if right psychrometric conditions are met, whose occurrence is proved by the analysis to exist for most part of the year. The highest affinity to absorb water vapor will occur in winter, while summertime contains periods where the full saturation and even condensation can occur. Visitor mines are not polluted by the production process and if safety allows, the ventilation can be merely controlled by the psychrometric state of the outside air.

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