The influence of changes in humidity and temperature of air on the rock salt mine museum

N. Szlazak, D. Obracaj, M. Borowski

University of Mining & Metallurgy, Department of Underground Mining,
al. Mickiewicza 30, 30-059 Cracow, Poland

Changes in humidity and temperature of air affect processes on the surface of opened walls in rock salt mine. Solution and recrystalisation are the results of these processes on salt surface. In the case of a working salt mine these processes are unfavourable but do not affect the safety of mining works. In the case of an underground salt museum the changes in humidity and temperature of air affect unfavourably the condition of salt exhibits. The article presents an impact of changes in humidity and temperature of air in the museum part of Salt Mine "Wieliczka" in Poland.

INTRODUCTION

The main natural hazard in an underground salt mine is water. The reasons for water hazards are: both the inflow of water from rock strata surrounding a salt deposit and water coming into a mine together with air. For many years a lot of research on methods and ways of overcoming these hazards has been conducted, usually with positive results. Controlling this hazard is a part of "everyday life" of a mine. However, a hazard that is due to water vapour contained in mining air is not hazardous while mining a salt deposit.

During airflow along an excavation drilled in a salt deposit the content of water vapour changes due to the exchange of heat and moisture between hygroscopic salt and air. The effect of the exchange of moisture between airflow and walls of galleries drilled in a salt deposit is well known and was described in works [1, 2, 3, 4, 6].

The content of moisture in the air affects unfavourably the condition of machinery and mining equipment in a mine. Changes in temperature and moisture of air in time are the reasons for the process of the exchange of moisture between air and salt walls. This process causes salt lixiviation on walls and may influence resistance parameters of walls; at the same time influencing stability of excavations.

Despite a harmful effect of changeable content of moisture in the air there is also a positive aspect of this phenomenon. High content of moisture in the air can be used e.g. to affect parameters of working conditions by means of overcoming concentration of salt dust [5, 6, 7]. Changes in parameters of the air and its ionisation are used for healing purposes, i.e. in a convalescent house in an underground salt mine [4].

Generally speaking, in an operating salt mine the processes of the exchange of heat and moisture can be burdensome; however, they do not affect greatly technological processes of mining salt. In the case of the underground salt mine museum these processes are to a large extent responsible for the condition and protection of museum exhibits. It is a tough problem to protect such a museum, as there are some periodic changes in parameters of atmospheric air.

THE PROCESS OF EXCHANGE OF HEAT AND MOISTURE

Drilling underground excavations in a rock salt deposit is connected with disturbances in the original geothermal equilibrium. At the same time a gradient of temperature and moisture appears in the solid surrounding an excavation. Therefore, during airflow along an excavation the exchange of temperature and moisture between rock mass and airflow occurs, depending on kinds of parameters of intake air.

Processes of exchange of temperature and moisture are connected on the one hand with hygroscopic qualities of salt and on the other hand with periodic changes in temperature and moisture of intake air. The temperature of atmospheric air changes periodically, both during a day and during a year. To the depth of approximately 30m from the surface the temperature of rock is changeable and depends on the temperature of atmospheric air. Below this depth temperature of rock remains steady.

The difference in temperatures of air and salt walls results in the exchange of heat. In summer heat from the air is absorbed and in winter heat is emitted into atmospheric air, i.e. there is an inflow of heat from salt walls. The exchange of heat takes the form of conduction and convection. During the exchange of heat also relative humidity of air changes, which makes the exchange of moisture possible as well.

The inflow of moisture into airflow in a mining excavation can take either a liquid or gaseous form. In the case of dry rocks, whose representative is rock salt, the inflow of moisture is connected with the exchange of water vapour. Therefore, the exchange of moisture takes the form of convection and diffusion. Diffusive exchange of moisture is connected with the heat of vaporisation or condensation of moisture on the surface of a salt solid.

In summer, when the content of moisture in the air is high, the lixiviation of excavation walls takes place, and in winter the dehumidification of walls can be observed. In shallow mines this effect is most visible at midday, when "slippery" roadway walls and floor can be observed [3, 4, 5].

While drilling excavations on the surface of salt, the exchange of surface energy takes place, which is the reason for processes of sorption of gas particles and vapours. Water vapour pressure physically or chemically connected with sorbent is lower than partial water vapour pressure in a saturated state for a given temperature. If this value is lower than partial water vapour pressure in unsaturated air, the process of water vapour sorption takes place. This process begins when partial water vapour pressure in the air equals partial vapour over a sorbent.

For every mineral of salt there is only one definite partial pressure of saturated water vapour over a saturated brine [1, 2, 4]. The ratio of saturated water vapour pressure over brine to saturated water vapour pressure over water surface is called critical humidity, which in the case of halite amounts to approximately 75%. When relative humidity of air is lower than 75%, salt emits moisture into the air, and when it is higher than 75%, salt absorbs moisture from the air. The process of dehumidification on the surface of a solid can reduce the temperature of air and rocks from which it absorbs heat necessary for this process.

The intensity of these processes depends on:

- chemical constitution of a salt deposit,
- deposit impurity,
- temperature of excavation walls,
- temperature, pressure and humidity of air.

Air is the mixture of water vapour and dry air. Air with the same content of water vapour has a greater capacity to absorb moisture at higher temperature.

The other essential reason for changes in parameters of air is a changeable character of parameters of airflow into a mine. The influence of changes in temperature and humidity of atmospheric air explains the changeable character of processes of the exchange of heat and moisture between salt and air.

This effect can be observed best in shallow mines when the seasons of the year change; winter to spring and autumn to winter. In summer the temperature of atmospheric air is higher than the temperature of salt walls. Heat flows towards rock mass cooling the air and increasing its humidity. If humidity of air exceeds 75%, absorption of moisture takes place on the surface of salt walls, where brine forms. Brine absorbs moisture from the air until water vapour pressure of air equals vapour pressure over brine.

In winter the temperature of salt walls is higher than the temperature of airflow; therefore heat is released into air. Moisture condensed in winter can evaporate and be conducive to salt recrystallisation and absorption of other particles, depending on partial water vapour pressure in the air.

According to the conducted research changes in temperature and humidity can be described by the following dependence:

$$t = A_0 \sin(\omega\tau + \varepsilon_0) + t_{0a}$$

where:

- A_0 – amplitude of periodic changes in temperature, [°C],
- t_{0a} – average yearly temperature of air, [°C],
- ω - frequency of yearly atmospheric fluctuations, [1/s],
- ε_0 - phase shift of periodic fluctuations of temperature, [rad].

Amplitude of changes in temperature of air decreases while the distance of the airflow from a mine entry increases. It also decreases more quickly when a diameter of an excavation is greater or airflow rate increases and a co-efficient of thermal conductivity of rocks λ_s [W/mK] is small. A phase shift of changes in temperature of air during a year in relation to temperature of atmospheric air increases when the depth increases linearly. The shift is greater when a co-efficient of thermal conductivity λ_s is of a great value and volumetric flow rate is small.

THE EFFECTS OF PROCESSES OF THE EXCHANGE OF HEAT AND MOISTURE IN SALT MINES

Heat exchange in airways is the reason for which the range of periodic changes in temperature of air is greatest in downcast shafts and main airways of intake airflows. Therefore, this process has the greatest force in these sectors. It is confirmed by measurements of parameters of air in two rock salt mines [4].

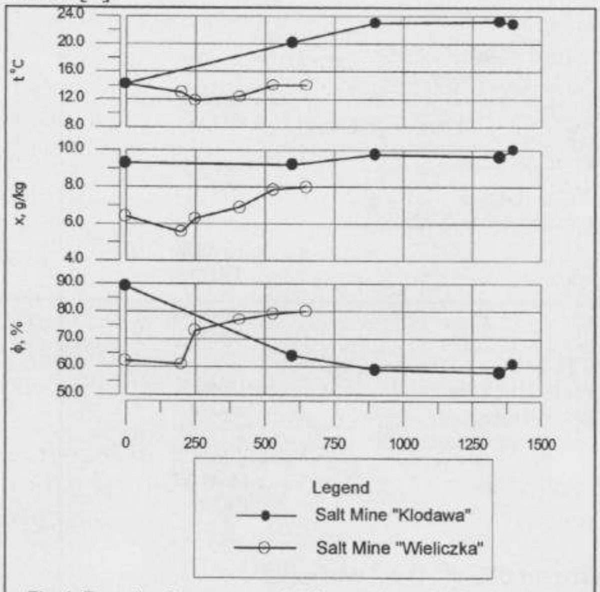

Fig. 1. Reasults of measurements of parameters of airflow in a function of the distance from the entry to a mine

Figure 1 presents the results of measurements of parameters of air taken in spring in Salt Mine "Wieliczka" at level 200m and in Salt Mine "Klodawa" at level 600m. In Mine "Klodawa" this process did not take the same form as in a shallow Mine "Wieliczka". A significant decrease in relative humidity in a downcast shaft in Mine "Klodawa" is the result of an increase in temperature of air. In Mine "Wieliczka" both a decrease in a downcast shaft and an increase in content of moisture in further airways were observed.

In Mine "Klodawa" the research into parameters of air was conducted during the whole year in different workplaces in various parts of the mine [5, 6]. The results of averages of relative humidity of air, temperature and moisture as absolute humidity during a working shift are presented in figure 2.

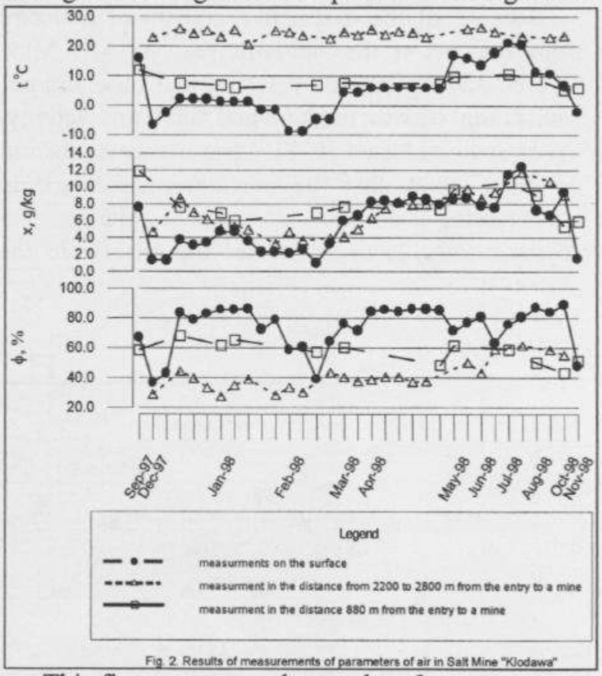

Fig. 2. Results of measurements of parameters of air in Salt Mine "Klodawa"

This figure presents the results of measurements of parameters of air on the surface and in the distance of 850m and 2200-2800m from the entry to the mine. The results presented confirm that lengths of airways through excavations in a salt deposit affect the process of exchange of heat and moisture. The greater the airway from the surface the weaker the effect of exchange of moisture.

Fluctuations of relative humidity of air along a big distance during a year are smaller. Processes taking place on walls of excavations drilled in rock salt deposits, depending on parameters of atmospheric air, are more obvious in excavations located closer to air inflow into a mine. The influence of these processes is most obvious in a rock salt mine – museum.

Salt Mine "Wieliczka", which was opened 700 years ago and registered in1978 on the first List of World Cultural and Natural Heritage by UNESCO, for a long time has been experiencing a bad influence of changes in humidity of airflow. Despite many organisational and ventilation attempts to distribute airflow, slow, but systematic deterioration of salt monuments, mainly salt sculptures, relieves and columns could not be avoided. For many centuries artists and miners –amateur sculptors created a great number of sculptures, relieves, monuments in natural size, at the same time setting up an art museum unique in Europe.

Because of the destructive activity of moisture from the air in the museum part of Salt Mine "Wieliczka", systematic research and observations, whose aim was to identify and limit this activity, have been conducted [4, 8]. Measurements taken in the mine show that the maximum difference in temperatures during a year amounts to approximately 13^{0}C. In winter the airflow in the mine gets heated by approximately 12^{0}C and in summer it gets cooled by about 14^{0}C. Such a difference, when absolute humidity is small, results in considerable fluctuations of relative humidity when air pressure is steady. Assuming that the exchange of heat is not the result of processes of exchange of moisture, such differences of temperature cause considerable fluctuations of relative humidity of air.

In winter, when relative humidity fell maximally, the amount of water vapour absorbed by air amounted even to 6 g/m^3 of air. The amount of vapour precipitating from about 1200 m^3/min of airflow was several thousand litres per week in summer.

On hot days the difference in moisture of intake and return air into the mine was even 7g/m^3.

Figure 3 presents a simplified schematic diagram of ventilating the museum part of Salt Mine "Wieliczka". Intake air enters the mine through "Danilowicz" Shaft to levels 64m, 170m and 240m and later on it is distributed to the chambers of the Convalescent House, chambers of the Museum, Chamber "Haluszka", St. Kinga's Chapel and St. Anthony's Chapel.

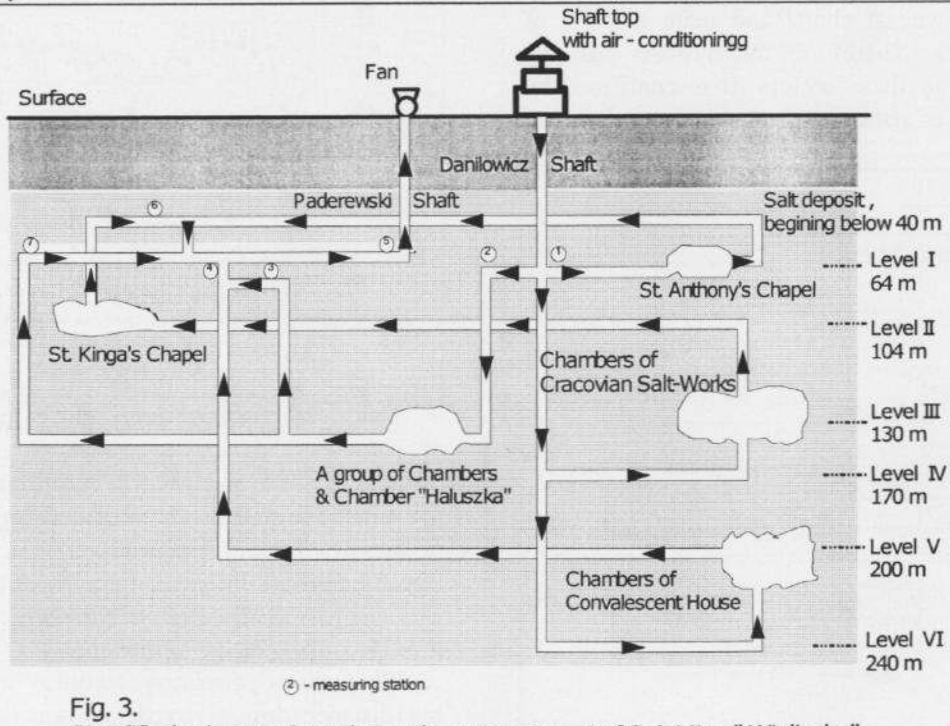

Fig. 3.
Simplified scheme of ventilating the museum part of Salt Mine " Wieliczka"

The maximum depth of excavations in the museum part of the mine is 327m. The air from these areas is carried away to ventilation shaft "Paderewski". The air flows along six levels at different depths. The greatest noticeable destructive effect of the exchange of moisture and heat was observed in St. Anthony's Chapel and in adjoining chambers at level 64m. Salt sculptures in this chamber were considerably destroyed, their features were erased and often original form was lost; therefore this part of the museum cannot be visited any longer.

During many years of the destructive activity of airflow the other hazardous region was a group of chambers at level 130m adjoining a small ventilation shaft "Antonia".

Because of greater distances of airflow in other chambers there was no effect of the exchange of moisture, which would be hazardous to unique monuments.

The results of monitoring relative humidity of air over a period of a week in April and in June in three museum chambers of Salt Mine "Wieliczka" are presented in figures 4 and 5.

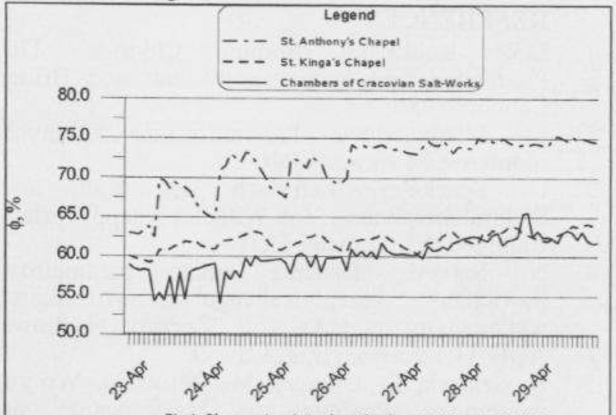

Fig 4. Changes in relative humidity from 18th June to 24 th June in the museum part of Salt Mine "Wieliczka "

In St. Anthony's Chapel situated at level I adjoining a downcast shaft relative humidity on the first days of taking measurements was below 75%. At the end of the first week humidity was approaching this value, so the effect of precipitating moisture from the air was started. In other chambers in a much greater distance humidity did not exceed 65%. In June the effect of intensive dehumidification of airflow in this chamber could be observed while relative humidity in other chambers was reaching only 70%.

In the periods when measurements were taken relative humidity of atmospheric air ranged from 70 to 85%.

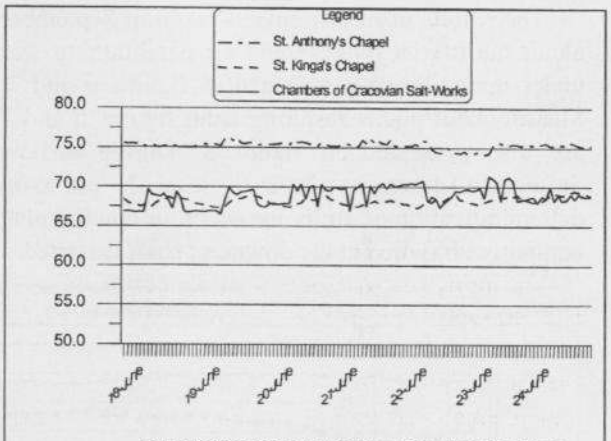

Fig 5. Changes in relative humidity from 23 rd June to 29 th June in the museum part of Salt Mine "Wieliczka "

THE PROTECTION OF THE MUSEUM PART OF THE MINE

The destructive influence of changes in parameters of air on museum salt chambers and exhibits in museum parts f the salt mine should be limited. First of all, the range of changes in temperature and humidity of air during the whole year should be identified. It is necessary to determine the amount of heat and moisture exchanged in all seasons of the year. Monitoring parameters of air along the main airways makes it possible.

Keeping up the same parameters of intake air into a mine during the whole year by means of air conditioning equipment, which was done in Salt Mine "Wieliczka", prevents salt mines from moisture hazard. Such equipment should keep parameters of air down to below 75% of relative humidity. It was decided to use air conditioning from York Company [8] in the museum part of "Wieliczka". As the amount of intake air in this mine was 1200 m^3/min, it was decided to air condition the whole airflow by means of installing a piece of equipment at the entry to downcast shaft "Danilowicz". It consists of a cooler, a condenser, a heater and a fan. The air is cooled and dehumidified in a cooler, then it is heated in a heater in order to ensure proper parameters of intake air. In winter the air is heated and humidified to obtain proper parameters. Parameters of conditioned air are steady in summer and winter and they amount to 13^{0}C and 6 gH_2O per each kg of dry air. The system is fully automated; it switches off when specific humidity of air falls below 6 g/kg and switches on when specific humidity of air is above 8 g/kg.

The results of measurements taken in September along the tourist route, while air conditioning was under operation, are presented in figures 6 and 7. Measurement points resulting from figures 6 and 7 are also presented in figure 3. During airflow through a downcast shaft to level I, i.e. 64m dehumidification of air by means of air conditioning equipment installed at the downcast shaft is started.

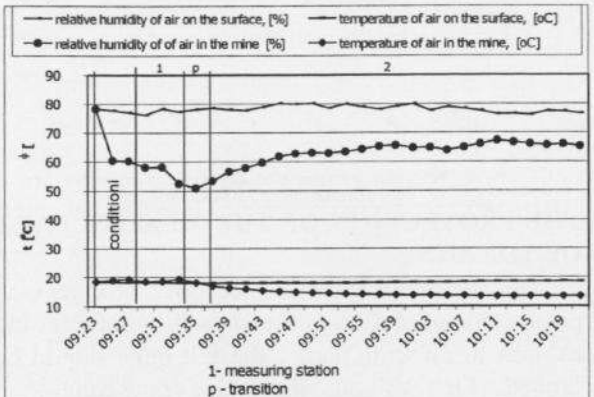

Fig 6. Changes in relative humidity & temperature in intake air at a Level I in S.M. "Wieliczka"

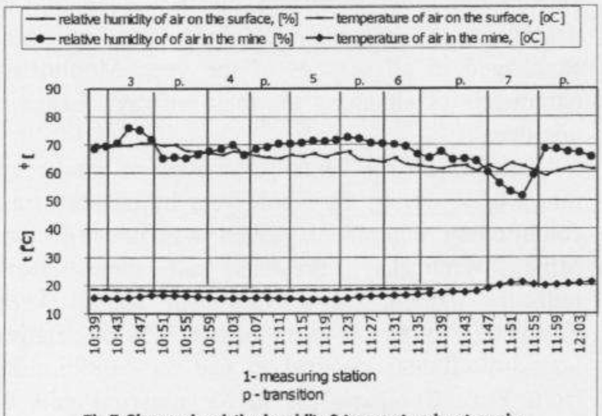

Fig 7. Changes in relative humidity & temperature in return air in S.M. "Wieliczka"

Relative humidity of air was reduced by 18%. Along airways of intake air relative humidity was approximately 65%. About 4g of moisture per each kg of dry air was taken away from airflow. Along return airways relative humidity is similar or slightly greater than relative humidity on the surface. An increase in relative humidity to approximately 70% is the result of the fall in temperature of the air. In points of measurements of parameters in return airflow relative humidity reached maximally 72% near an upcast shaft. An increase in specific humidity of air in the whole mine did not exceed 2 g/kg. It was only slightly humidified along a tourist route due to tourists visiting the mine.

Conducted measurements prove that installed air conditioning equipment is effective.

CONCLUSIONS

Periodic changes in humidity of intake air into a mine do not affect significantly the safety of mining rock salt by means of "dry" method. In the case of shallow underground salt mines, which have a monumental character, changes in humidity of atmospheric air are hazardous to museum exhibits.

In summer absorption of moisture from mining air takes place. In shallow mines this effect can be observed in dog headings. In deep mines this effect can be observed in a downcast shaft and in pit bottom workings. In a greater distance this process may take the opposite direction during the change of winter into spring and summer to autumn.

Artificial keeping the parameters of intake air down below 75% of relative humidity can be a method for reducing this influence.

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