Effect of Temperature and Humidity on Salt Mine Environment

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Abstract

The temperature and humidity of intake air changes the temperature and humidity of rock salt mine. The general trend of climate of Jhelum was analyzed to see the general characteristics of meteorological parameters of the region. Hot and humid summers, dry and mild winters, average annual precipitation above 900mm are associated with the climate of Jhelum. In Khewra Salt mines, the rock salt accepts the effects of parameters of influx air and shows the changes with sensitivity immediately. For this reason, the walls of salt mines are deteriorating. Resultantly, the changes in appearance, shape of salt walls, re-crystallization and generation of brine solution was observed in different proportions depending upon the distance from the entry of the mines. In an enclosed chamber of hygroscopic salt, as the temperature fluctuates absolute humidity fluctuates more than the relative humidity. The calamitous effect of changes in parameters of air on salt chambers and manifestation in different parts of salt mines should be limited. It is proposed that to protect the geological layers of the salt inside the salt mines where the destruction is high; ventilators should be erected and regulated in such a way that the levels of temperature and humidity might be maintained for frequent exchange of the parameters of air with the influx air.

Introduction

Moisture is one of the main natural hazards in an underground rock salt mine. The moisture is coming with the air and inflow from rock layers surrounding a salt deposit. Due to exchange of moisture and heat between hygroscopic salt and air, the amount of water vapor changes during air flow near an excavation in a salt deposit. The effect of the exchange of moisture between air flow and walls of galleries drilled in a salt deposit (Kaufmann et al., 1956).

The machinery and mining equipments are affected adversely by the amount of moisture in the air. The reason for the process of exchange of moisture between air and salt walls is the changes in temperature and moisture of the air in time. This process may affect the stability of excavation and causes salt leaching on the walls. There is also a positive side of this event despite of a harmful effect of changeable amount of water vapor in the air. More amount of water vapor in the air affects the parameters of working conditions by means of surmounting aggregation of salt dust. The exchange of heat and moisture is demanding in operating salt mines; however, the technological process of mining salt is not greatly affected by this process. These processes are largely liable for the condition and protection in the case of underground salt mines.

The brine solution is saturated with a fixed percentage of moisture whereas the remaining solid rock salt keeps continue to absorb more moisture from surroundings and generate more brine solution. After generation of moisture saturated brine solution, relative humidity starts rising above equilibrium level of humidity of the salt saturated solution.

According to the kinds of parameters of intake air, shift in temperature and moisture occurs between airflow and rock salt, during airflow along an excavation. A change in temperature and moisture of intake air and hygroscopic qualities of salt affects the processes of exchange of temperature and moisture. The temperature of rock changes to the depth of 30m from the surface and is stable below the depth of approximately 30m but it mainly depends on the parameters of atmospheric air (Szlazak et al., 2000).

The process of leaching of excavation walls takes place when the quantity of moisture in the air is high. At midday, this effect is high in shallow mines where slippery roadway walls and floor can be seen (Szlazak et al., 2000). Exchange of heat also causes the exchange of moisture which in turn changes the relative humidity of air. The influx of moisture is related to the exchange (convection or diffusion) of

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water vapor in case of dry rock. The influx of moisture is affiliated with the exchange of water vapor in rock salt as it is an example of dry rock (Szlazak et al., 2000).

In case of halite, the critical humidity aggregates approximately 75%. If relative humidity is lower than 75% in the air, moisture is released by the salt into the air, and if it is higher than 75%, moisture is absorbed by the salt from the air. It takes the required heat from the air or rock mass for dehumidifying them.

In different shafts of mines the temperature changes time to time because of the intake air. The process of temperature change has a very influential role in these sectors of mines which are under consideration i.e., Wieliczka and Klodawa. At level 200m in Wieliczka and at level 600 m in Klodawa, two things were noted distinctively. 1). a significant decrease in relative humidity is the result of an increase in temperature of air. 2). the increased content of moisture is a result of the increased distance from the mouth of mine. The research into parameters of air in mines Klodawa was conducted for the whole year in different work places in various parts of mine. Measurements of parameters of air on the surface and in the distance of 850 m and 2200-2800 m from the entry of the mines confirms the lengths of airways through excavations in a salt deposit that are affected by the processes of exchange of heat and moisture. The weaker effect of exchange of moisture is because of the greater airways from the surface. At large distances in different periods of the year; relative humidity shows smaller fluctuations in it (Szlazak et al., 2000).

The hazardous effects of exchange of moisture are seen in “St. Anthony’s Chapel” and in small ventilation shaft “Antonia”. But in distant chambers where the exchange of moisture is less, many hazardous effects are observed.

This study analyzed the meteorological parameters of Jhelum district to see the general trend of temperature and humidity where the study area falls and that of inside the Khewra salt mines. As the salt range is comparatively cooler in the summers as compared to the adjoining areas in foot hills and the plains, this study compared the difference among them to see how the outer environment influenced the mines’ inner environment and salt. The range of humidity and temperature was calculated for mines to preserve the salt layers which were disturbed due to the different behaviors of meteorological parameters. The climatic analysis of the region and effect of intake air in the mines as in the case of underground salt mines, the changes in humidity and temperature of air affects unfavorably the condition of salt exhibits.

The results were used to chalk out wide-ranging recommendations to know the range of meteorological parameters which can be used during a particular season to protect the salt layers from disturbances and to preserve this geological heritage.

Study Area

Jhelum

District Jhelum is in the north east of Punjab and is bounded by Rawalpindi District in the north and Gujrat and Sargodha in the south, Azad Jammu and Kashmir in the east and District Chakwal in the west. In the west it is separated from District Chakwal by Kohistan-e-Nimak. The river flows eastern and southern parts of the District Jhelum. Jhelum District contains four tehsils. These are Dina, Jhelum, P.D. Khan, Sohawa. The total area of Jhelum District is 3785 Sq. Km and population is 936,957 according to the census of 1998.

Jhelum is hot and humid in summer, dry and mild in winter. The maximum mean temperature is 30.4 °C, whereas the minimum mean temperature is 16.6 °C. Average precipitation is greater than 900 mm per annum. In the rainy season from July to September, the water torrents flow from North to the river Jhelum with a very fast speed due to less penetration and more runoff and cause damages to the crops, bridges, roads and are responsible for the soil erosion in the district.

Table 1: Climatic Data for Jhelum

Climatic Data for Jhelum													
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average max °C	19.3	21.5	26.3	33.0	38.4	40.2	35.6	34.4	34.7	32.7	27.7	21.5	30.4
Average min 0° C	5.5	7.9	12.5	17.8	22.6	25.7	25.9	25.3	23.1	16.6	10.4	6.3	16.6
Precipitation mm	37.4	52.8	68.8	36.0	27.3	57.1	263.2	251.6	74.5	18.5	10.0	26.6	923.9
Relative Humidity (%)	68.7	61.9	55.3	44	34.2	39.3	65.4	72.7	65.0	59.6	66.7	71.7	58.7

Khewra Salt Mines

Salt mines located in Khewra, Jhelum District, Punjab in Pakistan, about 160 kilometers from Islamabad. Khewra Gorge is called the 'Museum of Geology' in the world as it contains the rocks of Precambrian to the Quaternary age. Room and Pillar mining method is a popular underground mining method used for mining in the Khewra salt mines. The mines' building has 19 stories, with 11 below ground. Only 50% salt is extracted and 50% is left as pillars to keep the mountain. The salt-mine is 288 meters above sea level and extends around 2438.42 meters inside the mountain from the mines entry (Iftekhar, 1991).

There are different shades of salt. It is transparent, white, reddish to beef red, pink, milky white and dull white etc. There are beautiful alternate bands of red and white color salt. There are faults, joints, burrows, folds, stalactites, and stalagmites observed inside the salt mine.

There are 64 chambers excavated north south for various lengths. Each chamber has been developed nearly north south across the east west striking salt seams. Width of the each chamber is 40 ft (as taken by Asrarullah 1967) and pillar as 30ft up to chamber-36. Therefore strike length of all chambers and pillars (36 normal chambers plus A, B, C and D chambers) is: 853.60 m, from chamber-37 to chamber-64 each chamber and pillar if 52 ft in width. Total length of all chambers is 1,008.00 m and total length of all pillars is 851.77 m (Iftekhar, 1991).

Inside the mine there are certain chambers filled with saturated brine solution. The water seeps through mines' wall and roof and collects into these chambers overtime. The density of these ponds is approximately 2.6.

The main entry to the Khewra Gorge is Low Level Tunnel (LLT) (10×12) ft, R.L 835 ft.

The area for this study is a part of Khewra Gorge and starts from the entry of the Khewra Salt Mines to 1500m inside the tunnel. The temperature and humidity inside the mines in different chambers is more or less affected by explosions of low intensity for exploration of salt, the combustion engines which carry the salt to the surface from the mines and other human activity. Jhelum District with geographical coordinates 32° 56' North, 73° 44' East and located in Northern Punjab Province for the climatic analysis.

Data Sampling

Data for temperature and humidity was collected in months of August, 09 through December, 09 inside the salt mines and on the surface, in which summer monsoon and winter season falls. Data was collected twice in a day at 8:00 am and 2:00 pm from different points at different distances from the entry of the salt mines. Data was recorded from chamber # 46 R.L 987 ft, chamber # 37 R.L 987 ft, chamber # 36 R.L 956 ft which are 1459 m, 1220 m and 853 m away from the LLT respectively. Chamber # 46 and chamber

37 are in the 'Tunnel BB' and chamber # 36 is in the 'Pharwala Development Tunnel'. The surface data for temperature and humidity was recorded at PMDC Khewra for the months of August, 09 through December, 09 which is about 500 m away from the entry of the salt mines. The temperature and humidity data of Jhelum district was collected to see the general trend of the climate in the study area.

Methodology

Topographic map of Survey of Pakistan Sheet No: 43 H/2 on scale of 1000 meters was used as a base on which the topographic information was obtained. The Geological map of Geological Survey of Pakistan Advanced Geosciences Laboratory sheet No: 5 on the scale of 1500 meters was used to obtain the geological information of the area. Field equipments used were dry and wet bulb thermometers, hygrometer, compass, measuring tape, and torch. Important features of the rock units were noted and photographs were taken, especially which are affected by the humidity.

Means of temperature and humidity of the chambers were then mutually compared and represented by means of statistical method i.e., graphical representation of the data to see the differences in the meteorological parameters and their effects at those places on the salt layers.

The mean value of temperature and humidity data of surface (Khewra) was calculated. The climatic data of Jhelum district was represented for normal of 1971 to 2000.

The hygrothermal threshold for salt mines was calculated after the comparison and analysis of the meteorological data and observations of the disturbed salt layers at those places which were sampled for the collection of meteorological data.

Differential thermal analysis (or DTA)/ Thermogravemetric analysis TGA-DTA/DSC was done using the model T.A.S.C 414/3 STA 409 to determine the temperature at which thermal reaching occur in salt undergoing continuous heating to high temperatures. It also involves the determination of the intensity of reactions through thermo gram. Two samples S-2 from chamber 36 and S-6 from chamber 46 of 29 mg each were taken and tested up to the temperatures 200°C and 250°C for the change in structure like contraction or expansion.

Discussion and Results

Humidity in Khewra Salt Mines

In Khewra Salt Mines the mean relative humidity in the months under study is 65.26% which is lower than 75%. In a salt deposit, the lengths of airways through excavations affect the processes of exchange of heat and moisture is shown in the figures:

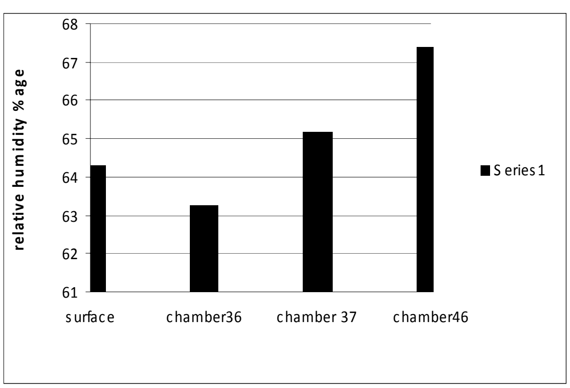

Figure 1: Comparison of mean monthly relative humidity inside and outside mines

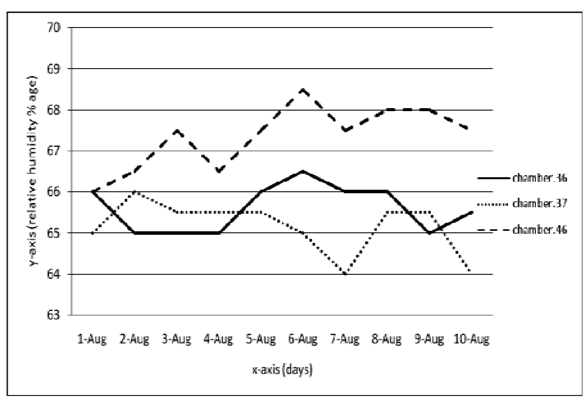

Figure 2: Relative Humidity inside mines for August

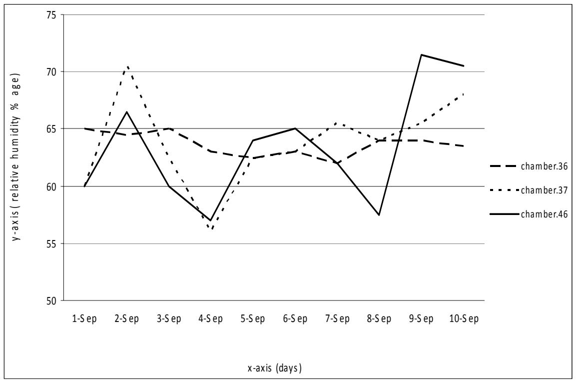

Figure 3: Relative Humidity inside mines for September

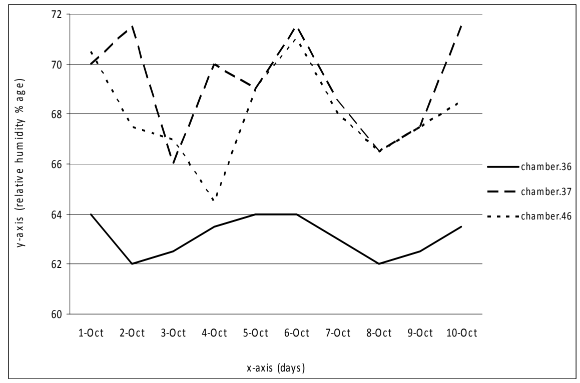

Figure 4: Relative Humidity inside mines for October

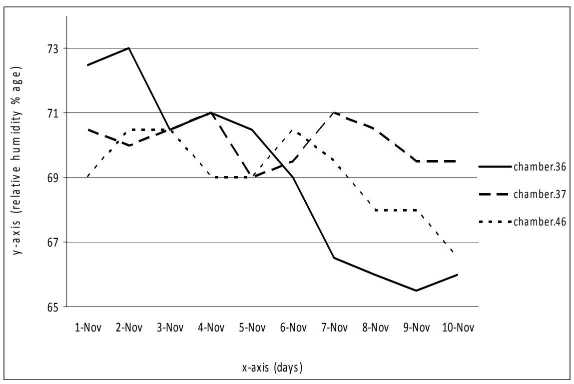

Figure 5: Relative Humidity inside mines for November

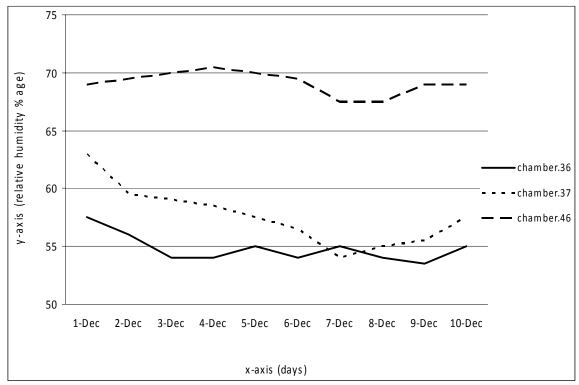

Figure 6: Relative Humidity inside mines for December

The intensity of the dehumidification process inside mines depends upon three things.

a) Temperature and humidity of atmospheric air.

b) Chemical constituents of salt deposit like SiO2, Al2O3, Fe2O3, MnO, MgO, CaO, Na2O, K2O, SO3, CI and

c) The presence of impurities in the deposit like magnesite, gypsum, anhydrite, sylvite and carnallite.

Inside the mines, the mean relative humidity in August decreases by the value of 3.86, in September it decreases by 6.9, in October it increases by 8.13, in November it increases by 4.45 and in December it increases by 0.3 of the mean relative humidity of the influx air from the surface in respective months due to the processes of exchange of heat and moisture inside mines. The relative humidity fluctuates up to 30 ft by the value of 0.14 per ft vertically and 0.007 per meter horizontally inside the mines. In this study, the difference of mean relative humidity among different chambers with respect to the distance from entry of the mines is up to 4.2. The given observations show that the relative humidity is less than 75% so the salt walls are producing brine water through the process of dehumidification. Due to this, the pathways, side walls and floors inside the mines are found slippery. Here the greater air ways from the surface are showing weaker effects of exchange of moisture. When the influx of atmospheric air contains more heat, then heat flows from the air inside the mines towards rock mass, it causes the cooling of air and increases its humidity. Brine absorbs the moisture from the air. When the influx of atmospheric air has less temperature than the temperature inside the mines, then heat is released from the rock mass into the air and condensed moisture can evaporate. It is favorable to the re-crystallization of salt i.e., Stalagmites and stalactites. The production of brine water ponds, salt pans and change in appearance of salt also indicates the high humidity levels.

There is no to very less brine generation and other effects of humidity in chamber 36 due to frequent exchange of heat and moisture with the intake air because it is nearer to the ventilator as compared to the other sampled chambers.

Stalactites and re-crystallization of salt, brine solution on the floor and hole in the roof of chamber 37 is observed due to less exchange of heat and moisture with the intake air and high relative humidity as compared to chamber 36 because it is at large distance from the ventilator. The effects of humidity in different chambers are shown in figures below.

Figure 7: No effects of humidity in chamber 36

Figure 8: Stalactites and re-crystallization of salt

Figure 9: Brine solution on the floor of chamber 37

Figure 10: Hole in roof of chamber 37 and stalactites

Figure 11: Brine solution on the floor of chamber 46

Figure 12: Effects of humidity on the roof of chamber 46 disturbing the salt layers

Temperature in Khewra Salt Mines

The temperature and humidity levels of the influx air affect the temperature and humidity levels of the air inside the mines according to the distance from the entry of the mines. In Khewra Salt Mines, the mean for recorded temperature of five months at different distances (chamber # 46 R.L 987 ft, chamber # 37 R.L 987 ft, chamber # 36 R.L 956 ft which are 1459 m, 1220 m and 853 m respectively) from the entry of the mines at 8:00 am and that of the surface is shown in the figures:

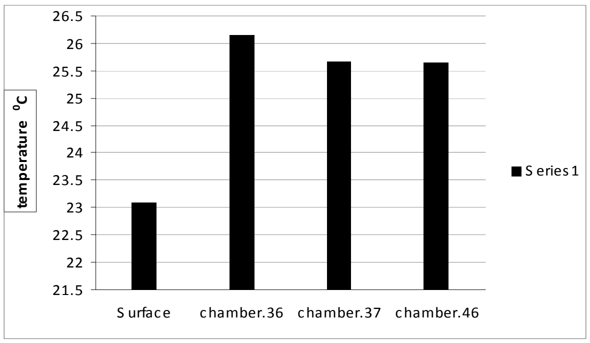

Figure 13: Mean monthly temperature inside and outside mines at 8:00 am

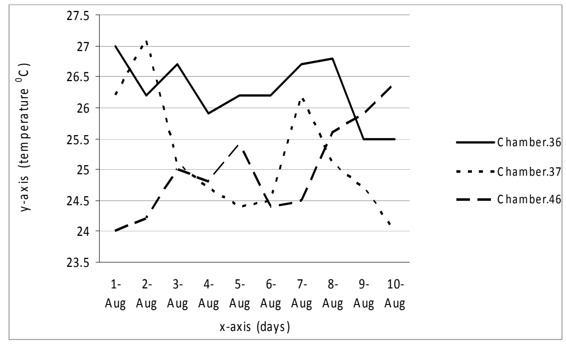

Figure 14: Temperature inside mines at 8:00 am for August

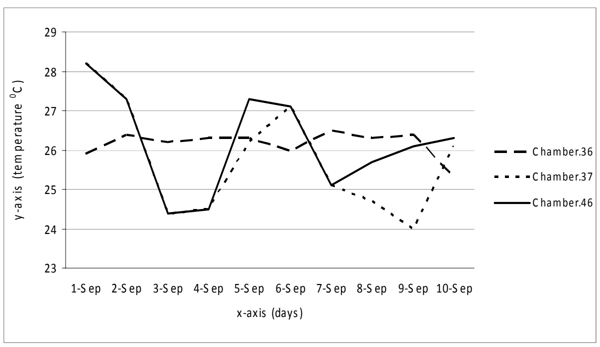

Figure 15: Temperature inside mines at 8:00 am for September

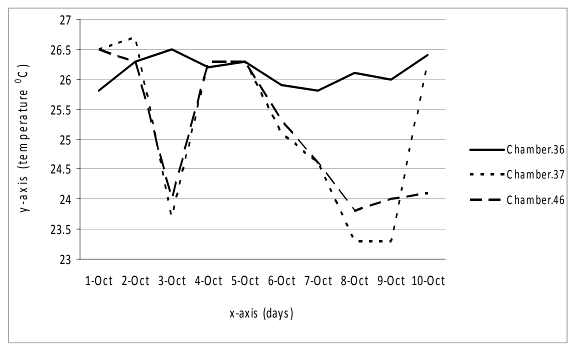

Figure 16: Temperature inside mines at 8:00 am for October

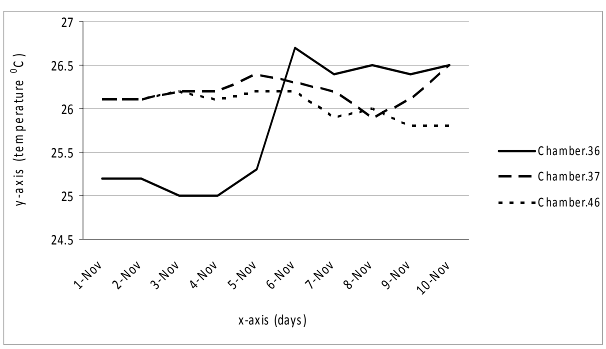

Figure 17: Temperature inside mines at 8:00 am for November

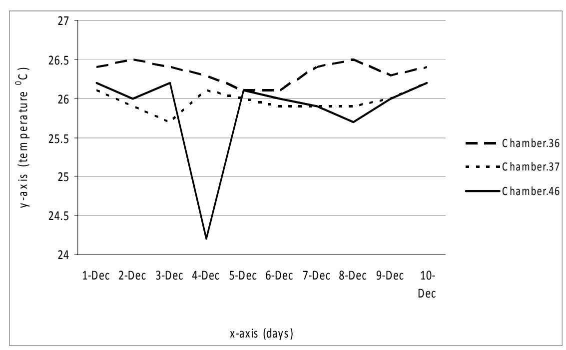

Figure 18: Temperature inside mines at 8:00 am for December

In Khewra Salt Mines, the mean for recorded temperature at different distances (chamber # 46 R.L 987 ft, chamber # 37 R.L 987 ft, chamber # 36 R.L 956 ft which are 1459 m, 1220 m and 853 m respectively) from the entry of the mines and that of the surface at 2:00 pm is shown in the figures:

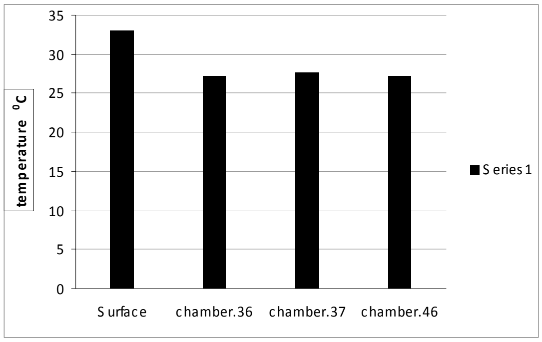

Figure 19: Mean monthly temperature inside and outside mines at 2:00 pm

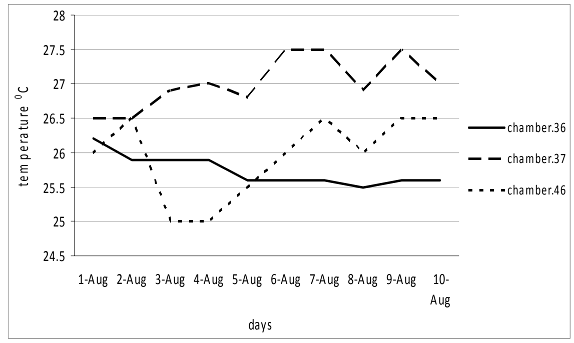

Figure 20: Temperature inside mines at 2:00 pm for August

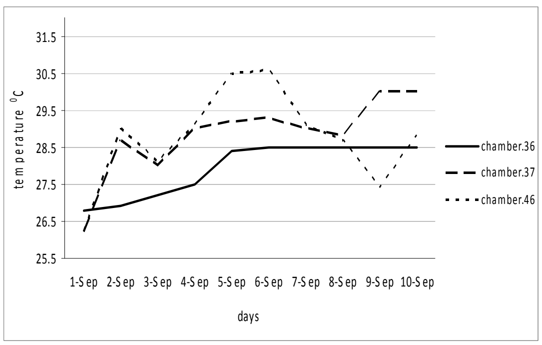

Figure 21: Temperature inside mines at 2:00 pm for September

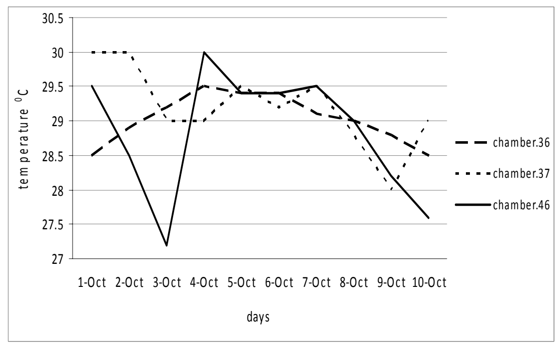

Figure 22: Temperature inside mines at 2:00 pm for October

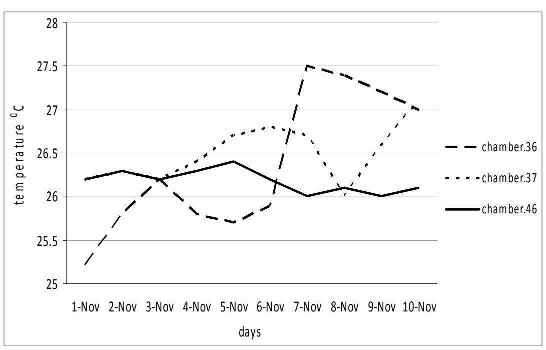

Figure 23: Temperature inside mines at 2:00 pm for November

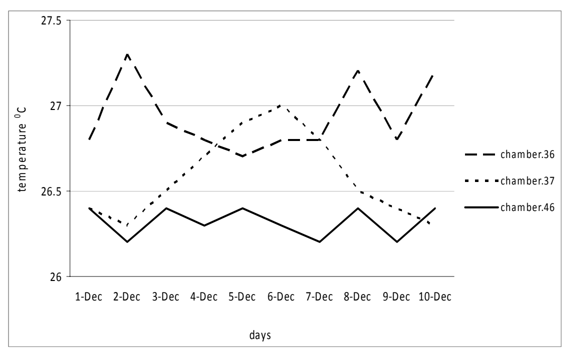

Figure 24: Temperature inside mines at 2:00 pm for December

These figures present the results of measurement of temperature of air on the surface and in different distances from entry of the mines.

Inside the mines, the mean temperature at 8:00 am inside the mines in August decreases by 7.8°C, in September it decreases by 1.2°C, in October it rises by 0.6°C, in November it rises by 10.2°C and in December it rises by 11.5°C of mean temperature of the influx air from the surface in respective months.

Similarly, the mean temperature at 2:00 pm in August decreases by 14.5°C, in September the temperature decreases by 6.8°C, in October the temperature decreases by 6.1°C, in November the temperature decreases by 6.8°C and in December the temperature rises by 5.7°C of mean temperature of the influx air from the surface in respective months. The temperature fluctuate between 853m-1459m (2798.52ft-4786.68ft) by the rate of (0.001) °C per meter horizontally and between 956ft-987ft by the rate of 0.02 °C per ft vertically. In this study, the average difference of mean temperature among different chambers with respect to the distance form entry of the mines at 8:00 am is approximately 0.5 °C and the average difference of mean temperature among different chambers with respect to the distance form entry of the mines at 2:00 pm is approximately 0.4 °C.

Results of DTA

By Differential Thermal Analysis it is observed that there is no change in structure of salt up to the 200°C or up to 250°C. There was no change occurred, neither contraction nor expansion or degradation in the structure of salt due to increasing cycles of temperature by 20°C or 50°C.

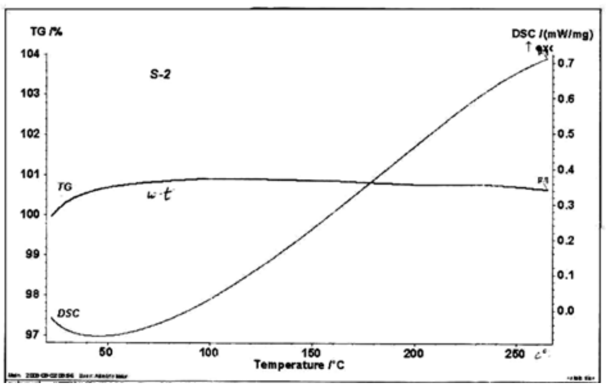

Figure 25: DTA curve for salt sample showing no change in structure up to 250°C

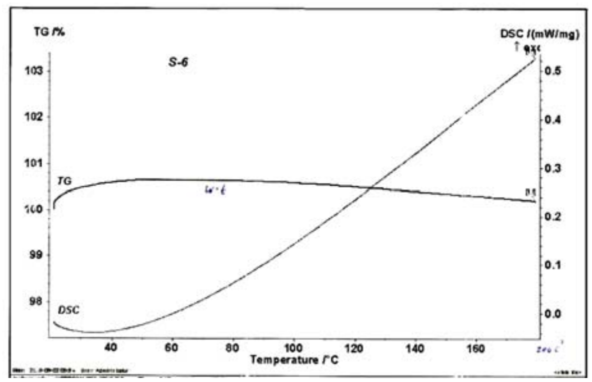

Figure 26: DTA curve for salt sample showing no change in structure up to 200°C

Results of XRF

XRF analysis for salt samples carried out. The results of XRF for the samples taken from two different points inside the salt mines are given below:

Table 2: Results of X-ray fluorescence (XRF) test for determining the elements and their quantity present in salt samples taken from salt mines

	Chemical Compound	Chemical Formula	S-2	S-6
1	Silicon Dioxide	SiO2	0.193	0.076
2	Aluminum Oxide	Al2O3	0.077	0.035
3	Iron Oxide	Fe2O3	0.028	0.014
4	Manganese Oxide	MnO	0.375	-
5	Magnesium Oxide	MgO	-	0.603
6	Calcium Oxide	CaO	0.052	0.020
7	Sodium Oxide	Na2O	49.305	48.798
8	Potassium Oxide	K2O	0.093	0.103
9	Sulfur Trioxide	SO3	0.700	1.768
10	Chlorine	Cl	49.176	48.494

Results of XRD

The results for XRD showed no difference in the characteristics of both salt samples. Both samples are containing very less amount of other minerals which can not be detected by XRD analysis. Both salt samples are detected as halite.

The change inside the mines due to the parameters of influx atmospheric air is recorded more in humidity levels rather than the temperature levels. The humidity inside mines affected the salt strata more than the temperature.

Conclusion and Recommendations

Conclusion

On the basis of analysis for the meteorological parameters of temperature and humidity inside and outside the salt mines during five months from August 2009 to December 2009, these facts are found that

1. Climate of Jhelum is associated with hot and humid summers, dry and mild winters. In summer; influx of hot and humid air brings a lot of moisture and heat inside the mines with it, and in winter; the dry and mild air brings less moisture and heat inside the mines with it. The process of heat and moisture exchange occur inside the mines between salt walls and the influx air which regulates the relative humidity and temperature and keep it less fluctuating in any season depending on the distance from entry of the mines.
2. Two factors are affecting the salt mines these are temperature and humidity levels which are interdependent.
3. Temperature is fluctuating inside the mines which are affected by outer environment. It is fluctuating by 1.9 °C in chamber 36, 1.8 °C in chamber 37 and approximately 2°C in chamber 46 inside the mines and 10 °C at surface in five months.
4. Humidity is fluctuating inside the mines which are affected by outer environment. It is fluctuating by the value of approximately 14.2 in chamber 36, 12.5 % in chamber 37 and 5.7 % in chamber 46 inside the mines and 14.6% at surface in five months.
5. In a confined chamber of hygroscopic salt, as the temperature fluctuates relative humidity fluctuate in low percentage than the absolute humidity.
6. There is infrequent exchange of moisture from surroundings with the air at greater distances from the entry of the mines. It means that there is less fluctuation in relative humidity at points which are at greater distances from ventilation. So stalagmites, stalactites, brine solution, salt pans and holes in salt walls are observed at these places. On the other hand, in those areas of mines which are closer to the ventilator, it is observed that there is no or very less brine generation, less formations of stalagmites and stalactites and less or no signs of salt strata disturbances.

Recommendations

To preserve the inner environment of salt mines the calamitous effect of changes in parameters of air on salt chambers and manifestation in different parts of salt mines should be limited. The identification of the range of changes in temperature and humidity of air during a particular season inside mines is required. The aggregate of heat and moisture exchanged in a particular season is necessary to determine. It is possible by monitoring the parameters of air along the airways.

- By means of air conditioning equipment, the same parameters of influx air into mines during a particular season can be maintained, which can preclude salt mines from moisture hazard. The relative humidity of air should be kept down to below 75%.

- The whole air flow can be air conditioned by installing the equipment at the entry to the mines. The air would be cooled and dehumidified or heated to ensure the proper parameters of intake air.
- The parameters of conditioned air should be stabilized to modify the temperature of intake air from August to December by 6°C (decrease in summer and increase in winter) and 5% (decrease in summer and increase in winter) relative humidity. The system should be fully automated and it should switch off as the desired value of the parameters to be obtained.
- It is observed that in chamber no 36 the temperature (mean minimum 26.1°C and mean maximum 26.3°C) and humidity (63.2 %) level is causing very less brine generation, less formations of stalagmites and stalactites and less or no signs of salt strata disturbances because the ventilator is situated nearby while in other chambers the destruction is high as there the ventilators are located quite away from them. Therefore, it is proposed that
- To protect the geological layers of the salt inside the salt mines where the destruction is high; ventilators should be erected and regulated in a way that the above mentioned levels of temperature and humidity might be maintained for frequent exchange of the parameters of air with the influx air.

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