DUST MONITORING, CHARACTERIZATION AND PREDICTION IN AN OPENCAST COAL MINING

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ABSTRACT: Dust pollution is the most important environmental issue associated with any opencast mining activity. Drilling, blasting, loading, transportation, crushing, conveying, haul road and the exposed overburden face generate large quantities of fugitive dust. Silica is a potential carcinogen and its exposure to the workers may be detrimental to their health which may result in progress of silicosis and lung cancer. Prediction of dust concentration in and around the mine is essential to have an impact assessment of the mining activity over the surrounding environment. In the view of this, current project work focuses on the real time monitoring of dust level at different sources of the mine using DustTrak II, personal exposure of dust to different workers using personal dust sampler, characterization of dust collected from different locations using FT-IR and finally prediction of dust concentration at different locations of the mine and nearby areas using AERMOD view software. Lakhanpur opencast project, the largest opencast mine of MCL in the Ib valley area producing more than 15MT of coal per annum, was chosen for study to have a better knowledge about the impact assessment due to dust from large opencast mines. The monitoring was conducted during December 2013 to assess scenario of dust pollution. The dust concentration was found to vary between 0.474mg/m3 to 150.0mg/m3 in PM10. Drilling and Surface Miner operations were found to be the major sources of dust generation. The dust exposure of worker was found to vary between 4.55mg/m3 to 29.41mg/m3 . Minimum quartz content was found at coal transport road at 0.23% and maximum quartz content was found at wet haul road of LOCP at 0.49%. The predicted value of dust concentration (PM10) at most of the places was found to be below NAAQS-2009 limit for annual average of 60µg/m3 .

Key Words: Fugitive Dust, DustTrak II, PDS, AERMOD, Quartz, FTIR

INTRODUCTION

Most mining operations produce dust when air-borne becomes serious hazard to miner's health and may cause respiratory diseases e.g. chronic bronchitis/pneumoconiosis. It can be collagenous/non-collagenous (non-fibrogenic). Based on size particulates can be divided into TSP, PM10 and PM2.5. Dust is generally measured in terms of weight of particles per cubic meter of air. Dust is a primary thing associated with all mining activity. In every step of operation there is generation of dust. Open cast mines produces more dust as compare to underground mines. The mining activities like drilling, blasting, loading, transportation, crushing, conveying, haul road and the exposed overburden face generate large quantities of fugitive dust. In view of this, identification dust emission sources and determination of emission rate of various activities of the mine site is pertinent to assess impact of mining activities on surrounding air quality. Silica is a potential carcinogen and its exposure to the workers may be detrimental to their health which may result in progress of silicosis and lung cancer. Hence determination of silica content in the respirable air is essential to assess its impact on miner's health.

Dust emission, dispersion patterns are difficult to predict through dispersion models due to the wide range of fugitive sources in mining activities that may give rise to dust, empirical emission factors for these activities, and the impact of local meteorology and topographic features. Dispersion modelling can provide simple predictions of probable isopleths, and ambient air quality monitoring can provide validation of possible levels of dust concentration in and around a site.

In order to accurately predict dust concentration levels around the mine, long-term and comprehensive dust monitoringz is essential. Dust dispersion patterns are often affected by wind speed, short lived dusting events, precipitation and the source of emission itself. Sometimes dust emission from the mining site itself may be low or immaterial, but the receptor may be subjected to background dust sources.

In this project, an attempt has been made to carry out dust monitoring and dust characterization at Lakhanpur opencast coal project using real time aerosol monitor DustTrak II and FTIR. Finally dust dispersion modelling was carried out using AERMOD to assess the magnitude of the dust concentration at the working and peripheral areas of the study area vis-à-vis NAAQS standards.

1.1 Objectives

- To monitor dust at different sources using DustTrak II
- Assessment of personal dust exposure using Personal Dust Sampler (APM-800)
- To determine quartz content of dust using FTIR and
- To carry out dust dispersion modeling using AERMOD

1.2 Plan of Work

The plan of work mainly focussed on a comprehensive assessment of the impact of dust due to mining activities. Previous work of the researchers in the field of dust monitoring, characterization and dispersion modelling were studied. The focus of the work is mainly to assess dust generation at different sources, to assess to effect of dust on the health of workers by going for characterization and to predict impact of dust generated by mining activities to the air quality of the surrounding area. A flow chart of the work plan is presented in Fig 1.1.

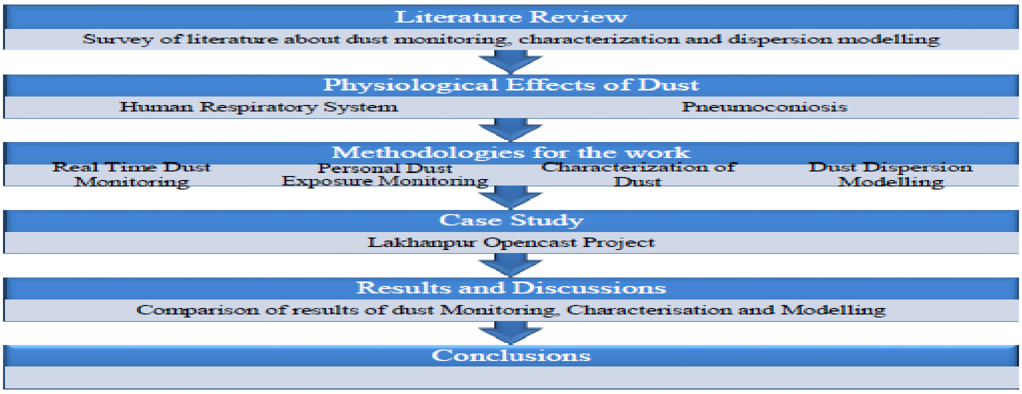

Figure 1.1 Plan of work

II.LITERATURE REVIEW

2.1 INTRODUCTION

Dust is used to describe fine particles suspended in the air. The size of dust particles vary from few nm to 100µm and the concentration of dust vary from few micrograms to hundreds of micrograms per cubic meter of air. Various factors such as dust lifted by weather, volcanic eruptions, pollutions, mining activity, construction activity etc. contribute to the formation of dust. The formation of dust can be attributed to the fine particles which become entrained in the atmosphere due to turbulent disturbances produced by wind; it is also formed from mechanical disturbances and through release of particulate rich gaseous emissions.

Dust includes wide range of particles varying from 1mm to less than 1µm. But the size range normally varies from 1-20µm. because particles above 20µm are usually quick to settle and particles below 1µm don't form in abundance. The size of particle considerably influences its characteristics. Depending upon the size dust can be classified as

1. Particles greater than 10µm:

These particles settle according to the law of gravity. In still air, they settle with increasing velocity.

2. Particles between 0.1µm to 10µm:

These particles settle with a constant velocity obeying Stoke's law. The velocity depends upon density and size of particles, acceleration due to gravity and viscosity of the medium.

3. Particles between 0.01µm to 0.1µm:

These particles don't settle in air rather remains in colloidal state.

2.1.1 Atmospheric Dust

Atmospheric dust is formed by saltation and sand blasting of sand seized grains from surfaces through the action of wind. Troposphere is the medium of transportation of atmospheric dust. Mostly atmospheric dust comes from the dry and arid regions which are more susceptible to weathering through high velocity wind.

2.1.2 Fugitive Dust

During dust generation particulate matter became airborne and flows in the downwind direction. When a dust is derived from a mixture of sources or when the source can't be easily determined, then it is termed as fugitive dust. In mining activities fugitive dust generates from the movement of HEMM over non paved haulage roads and from blasting and loading operation. Mine dusts are generally characterised as fugitive dusts since they are mostly generated from non-point sources.

2.1.3 Mine Dust

During mining and processing of ore body a number of stages of drilling, blasting, crushing, grinding are required. Abrasion and crushing of surface due to action of mechanical force produced fine particles which remain suspended in air due to small size. The movement of dumpers and other HEMM along the haul road also produces dust. In most of the cases the dust produced by the mine is of fugitive nature i.e. the sources can't be easily defined and mainly consists of disturbances of surface. Surface mining methods produces significant amount of dust as compared to underground dust due to use of HEMM, high mechanisation and large surface area which are vulnerable form dust production on action of air. In opencast mines, huge quantity of over burden has to be removed to facilitate accessing minerals. The removal of overburden requires dumpers, shovels, and draglines etc which discharge enormous quantity of fine particles into atmosphere. Blasting operations too generates huge quantity of dust. The closure of mine also involves loading and transportation of overburden and contributes to dust generation. Large surface area of overburden dump is also quite vulnerable to dust production if efficient measures are not taken to suppress it.

2.3 PHYSIOLOGICAL EFFECTS OF MINERAL DUST

2.3.1 Human Respiratory System

Through nose and mouth air is introduced into the respiratory system. With air other aerosols (dust, bacteria, and pollen) are also introduced into the body. When the aerosols pass through the nasal passages, larger particles are cleared by hair and mucus. After that air flows through the nasopharynyx region, where it is warmed. Then air passes through the trachea (windpipe), the bronchi (the two short branches off the trachea), and the bronchioles (branches off the bronchi) and into the alveoli (the terminal lung sacks where oxygen is transmitted into the blood stream). Along the trachea, bronchi and bronchioles, particles of medium size are impacted on the mucous layer lining the openings. Particles larger than 10μm are caught in ciliary escalator and brought back up through the bronchial tree to the throat. This material is then coughed or swallowed.

However, smaller particles are deposited on the lung surface through setting, impaction, Brownian motion. For these types of dusts, body's defence mechanism consists of phagocytes (wandering scavenger cells) called alveolar microphages. These microphages engulf the particles and isolate them to lymph nodes for disposal. These scavenger cells are called the garbage collector of respiratory system as they ingest invading particles. If the particles are common household dusts, then ingestion takes place and the particles are walled off by microphages. However, if the microphages ingest free silica particle, it explodes. The lung is left with destroyed microphages and free silica particle. The particle is then ingested by another microphage which in turn is destroyed by explosion and this process goes on.

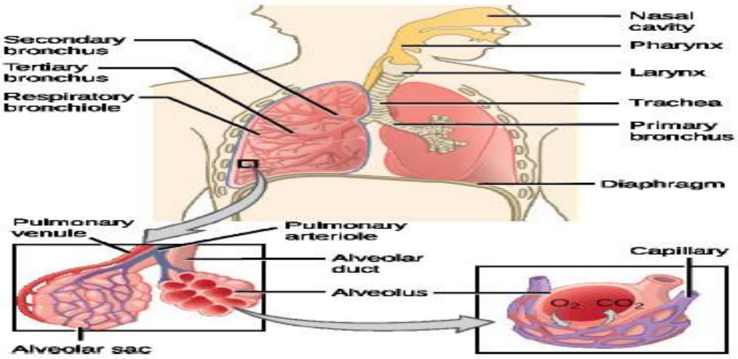

Figure 2.1 Human respiratory system

III.METHODOLOGIES FOR DUSTMONITORING, CHARACTERIZATION AND DISPERSION MODELLING

3.1 INTRODUCTION

The methodology followed for carrying out the research investigations have been presented in Fig.3.1.

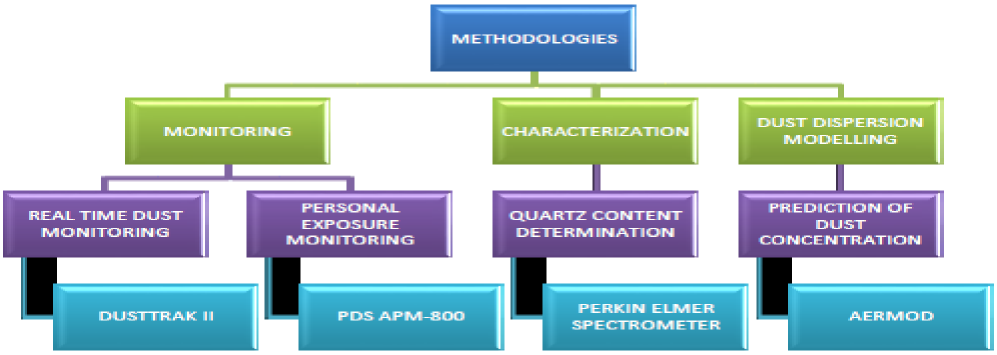

Figure 3.1 Methodology adopted for project work

3.2 Dust Monitoring

There are quite a number of ways in which monitoring airborne dust can be carried out. Based on principles of operation, they can be classified as

a. Filtration
b. Sedimentation
c. Inertial precipitation
d. Thermal precipitation
e. Electrical precipitation
f. Optical methods based on light scattering

However, for this study DustTrak II is used for real time dust monitoring at different sources of mine. It is based on the principle of scattering of light. Personal Dust Sampler is based on the principle of filtration.

3.2.1 DustTrak II Aerosol Monitor (Model No- 8532) [17]

DustTrak II aerosol monitor gives the real time aerosol mass readings. It is based upon the principle of light scattering through the laser photometer. It uses a sheath system which isolates the aerosol in the optic chamber to keep optic clean and to improve reliability. It can be used in harsh industrial workplaces and construction sites. It measures aerosols such as dusts, smokes, fumes and mists. Dust Track hand held model 8532 is light weight and portable. It can monitor indoor air quality, engineering control evaluations and for baseline trending and screening. It has single point data logging capability which can be used for walk through industrial sanitation survey and indoor air quality surveys. DustTrak II instrument is shown in Fig. 3.2

Figure 3.2 DustTrak II

3.2.2 Personal Dust Sampler

Generally workers keep on moving in the mine throughout the shift period for which it is difficult to monitor the exposure of workers to dust through any ordinary dust monitoring instruments. Hence personal dust sampler is used to determine occupation exposure of worker to dust. It is a portable instrument operated in battery power capable of measuring both total suspended particles and respirable particles for the total shift of 8 hour. It is a light weight instrument hence can be easily used by the workers. It can be mounted on the body of the workers through a belt and clip. The flow rate can be maintained as per the breathing rate of human being. For measuring the respirable fraction of dust, a separate cyclone can be attached to the sampler. The cyclone is designed for a cut off of particle size of 5μm as recommended by DGMS. Glass fibre filter of 37mm diameter is used for sampling. The air after passing through the cyclone gets deposited over the filter paper. The filter paper can be analysed further to determine the constituents of dust. A personal dust sampler is shown in Fig. 3.3.

Figure 3.3 Personal dust sampler PDS APM-800

3.3.1 Fourier Transform Infrared Spectroscopy

The aim of the absorption spectroscopy is to determine the amount of light absorbed or transmitted for each wavelength. The spectra of the sample contain emission, absorption and transmission corresponding to the frequency. Infrared spectrum is just like a finger print for a particular sample. The structure of the molecule can be determined with the characteristics absorption of infrared radiation for each wave number. The molecule absorbs radiation of particular wavelength and goes to the excited state. FT-IR shows peaks corresponding to the frequencies of vibration between the bonds of the atoms present in the sample. The constituent molecules of the sample can be identified by the characteristics peaks associated with each molecule. The height of the peak represents the quantity of a particular compound present in the sample. Hence infrared spectroscopy can be used for both qualitative and quantitative analysis of the material. Interferogram of the sample is obtained using an interferometer. Then the interferogram is analysed in computer using fourier transform to obtain spectra of the sample. For this study Perkin Elmer Spectrum Two Spectrometer is used. The spectra of the sample are obtained from wavenumber of 4000cm^{-1} to 400cm^{-1} with a resolution of 4cm^{-1} and 4 numbers of scans per sample. The spectrometer used for the experimental purpose is shown in Fig. 3.4.

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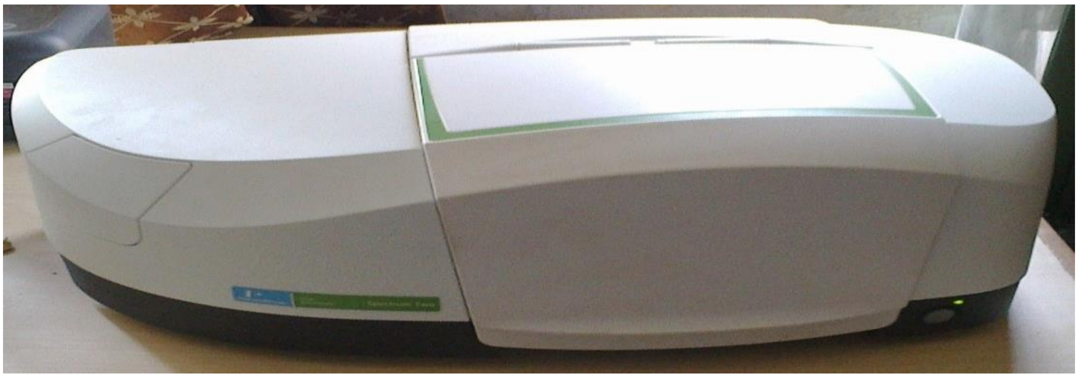

Figure 3.4 Perkin Elmer spectrum two spectrometer

3.4 Dust Dispersion Modelling

Dust dispersion modelling is generally carried out to predict the dust concentrations in the surrounding area so as to ensure dust levels don’t exceed the permissible limits. It takes into account various sources of emission from the mine and also the local meteorological conditions. Upper air data is also considered for predicting concentration levels. Topography of the area also plays an important role for the prediction of dust dispersion around the mine. The most important part is that the modelling method should accurately estimate the emission and dispersion of dust from a mining site.

IV.DUST MONITORING, CHARACTERIZATION AND DISPERSION MODELLING- A CASE STUDY

4.1 Study Area: Lakhanpur Opencast Project

Lakhanpur opencast project (LOCP) of Ib valley coalfield of Mahanadi Coalfields Limited (MCL) was selected for the study. The mine deploys state-of- the-art eco-friendly technology i.e. surface miner and is producing 15 Million Tons of coal per annum. Lakhanpur OCP is situated in Lakhanpur Tahsil of Jharsuguda district in Orissa. It lies between latitudes 21’43’30” to 21’46’44” and longitudes 83’49’11” to 83’52’38”. The mine was divided into 3 quarries, i.e. quarry1 to quarry 3. At present, quarry 1 is being worked by conventional shovel- dumper combination for overburden (OB) and by surface miner and tippers combination for coal.

Lakhanpur OCP envisages working of only one seam namely Lajkura seam. The upper two seams, namely Belpahar and Parkhani seams do not exist in the area very prominently and cannot be extracted. The two seams, namely Rampur and Ib, beneath Lajkura seam occur with large parting and can be worked by underground method, after exhausting the Lajkura seam. Lajkura seam is not exposed on the surface in the block. Width of in crop varies from 200 to 450m, occurring over 6 km along the strike. The minimum OB cover is 8m and maximum cover is about 116m. The dip of the formation is 1 in 16 and is generally towards west. The strike length of the mine is about 6 km. Along dip length of mine is about 2.5 km. Average thickness of workable Lajkura seam is 20-30m with an overall OB ratio of 2.34m3/ton coal. The available dirt bands, 1 to 5 in numbers, are generally carb shale and ranges in thickness from 1.47m to 6.91m (cumulative). Fig.4.1 shows the location of Lakhanpur mine in the map of India. Fig.4.2 shows the mining site of LOCP. Fig.4.3 shows the satellite view of LOCP.

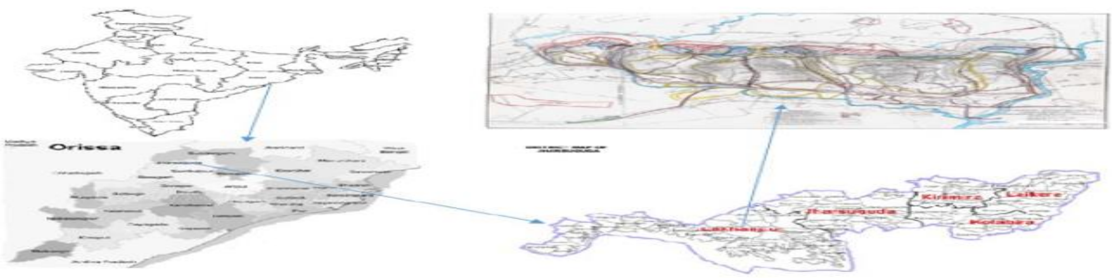

Figure 4.1 Location of Lakhanpur opencast project

Figure 4.2 Mining site of LOCP

Figure 4.3 Satellite view of LOCP

The study on the mine is broadly divided into four headings like

- Real Time Dust Monitoring at Sources Using DustTrak II
- Personal Exposure Monitoring of Different Workers Using PDS APM-800
- Characterization Using FTIR to Determine Silica Content
- Dispersion Modelling Using AERMOD

4.1.1 Real Time Dust Monitoring

Different sources of dust generation in the mine e.g. loading point, drilling, surface miner, blasting operation, haul road and transportation roads were chosen for monitoring. As per The Coal Mines Regulation, 1957 (CMR): 123, the instrument was kept within 1 meter of the dust source in the downwind direction. First zero calibration was done using a zero filter. Then different size selectors like PM10, PM4, PM2.5 and PM1 were used in a sequence for a period of 1hour to determine dust concentration at selected locations. The data generated were transferred to desktop and TrakPro software was used to analyse the data. TrakPro provides the statistical analysis of the data along with the generation of graph. The concentrations of dust at different locations for different size are as follows.

4.1.1.1 Dust monitoring at Loading point (Shovel-Dumper)

Loading point can be considered to be a major source of dust generation in any large opencast mine. Thousands of dumpers were loaded with coal each day to meet the annual target of 15Mt at LOCP. The loading point (shovel-dumper) of LOCP is shown in Fig.4.4. A comparative study for different size segregated dust fractions at loading point was carried out. Figs. 4.5, 4.6, 4.7, 4.8 show the variation of dust concentration with time for PM10, PM4, PM2.5 and PM1 respectively.

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Figure 4.4 Loading point at LOCP for shovel and dumper

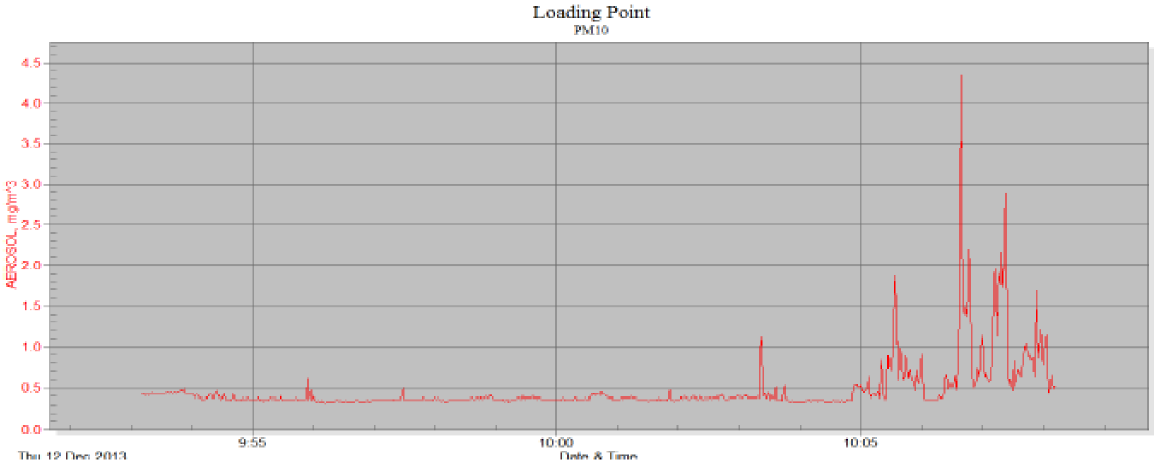

Figure 4.5 Concentration vs Time graph for dust at loading point in PM10

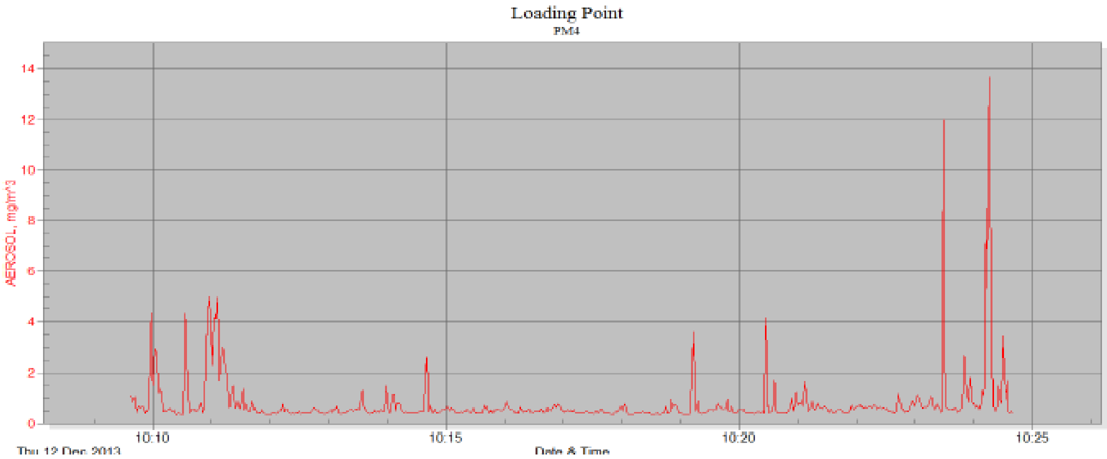

Figure 4.6 Concentration vs Time graph for dust at loading point in PM4

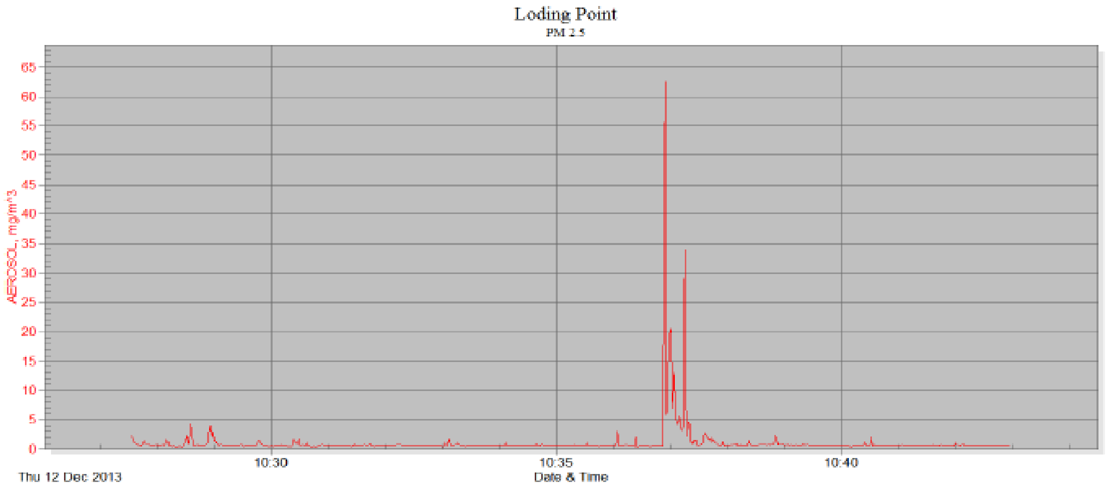

Figure 4.7 Concentration vs Time graph for dust at loading point in PM2.5

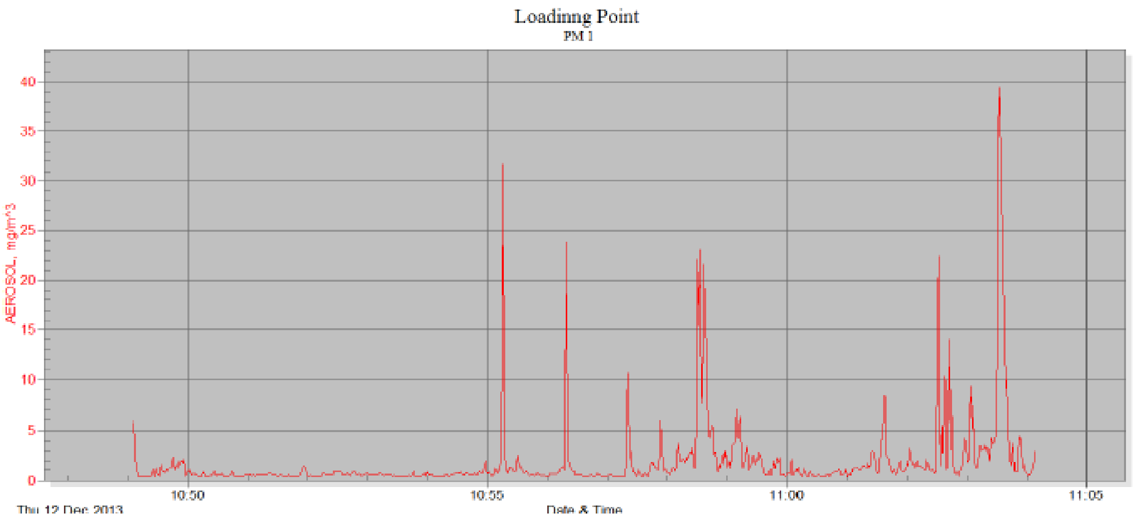

Figure 4.8 Concentration vs Time graph for dust at loading point in PM1

The peaks of the graph represents the time when loading action was taking place. Depending upon the wind direction and loading time, the peaks varied. The lower concentration part of the graph represents the time when the shovel was idle.

4.1.1.2 Dust Monitoring at Surface Miner

Surface miner is another area of concern for any large opencast mine. It is one of the eco-friendly mining methods adopted to reduce ground vibration due to blasting and to improve production. Mostly it is used in coal industry as the compressive strength of coal is within the cutting limit of surface miner and the gradient is usually flat which is also suitable for the operation of surface miner. But the surface miner produces large quantities of fine dust due to cutting of coal. Hence if proper quantity of water is not used to suppress dust then it can be hazardous to workers of the mine. At LOCP, Wirtgen surface miner was used for coal cutting purpose. The operation of surface miner at LOCP is shown in Fig.4.9. The graph of dust monitoring near surface miner at LOCP for the particle size of PM10, PM4, PM2.5 and PM1 were plotted in Figs. 4.10, 4.11, 4.12 and 4.13.

Figure 4.9 Surface miner in operation at LOCP

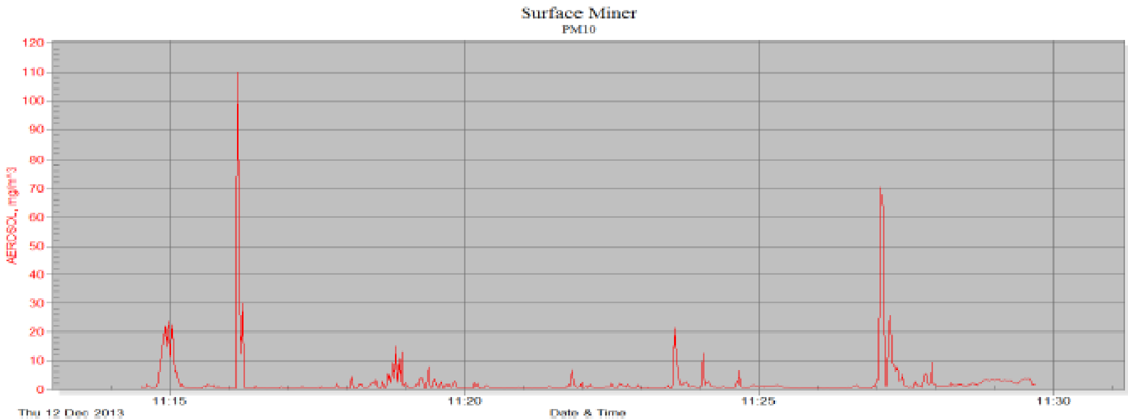

Figure 4.10 Concentration vs Time graph for dust at surface miner in PM10

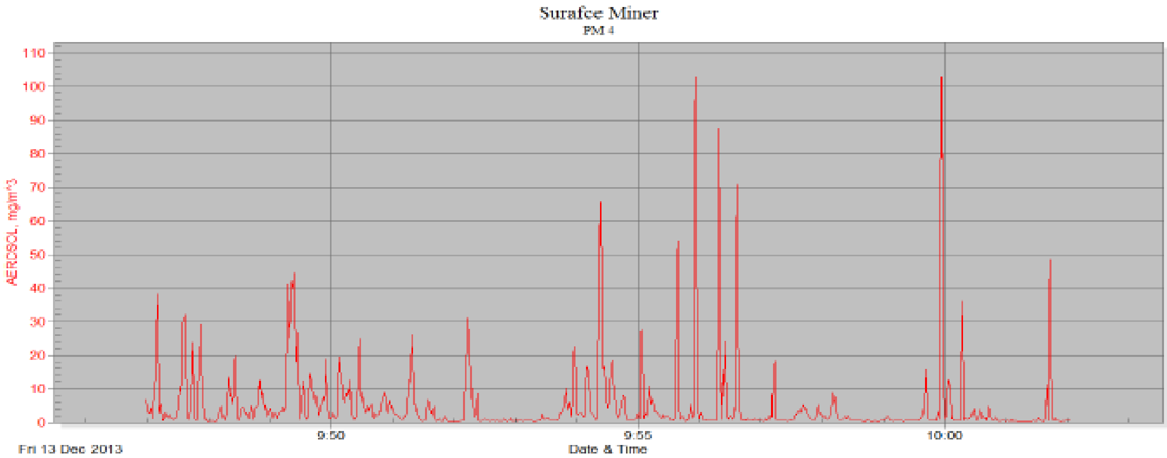

Figure 4.11 Concentration vs Time graph for dust at surface miner in PM4

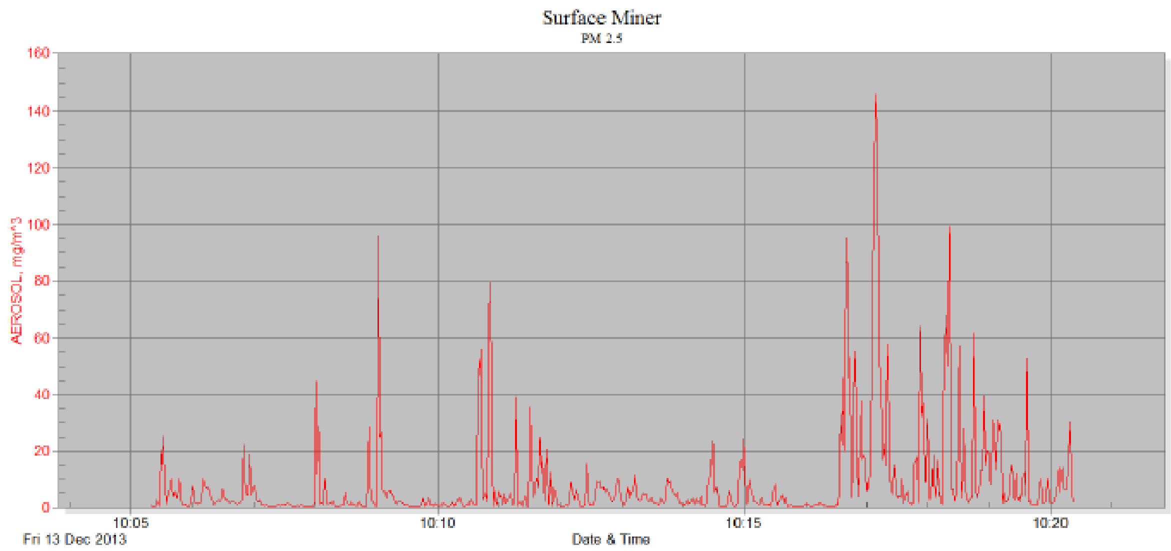

Figure 4.12 Concentration vs Time graph for dust at surface miner in PM2.5

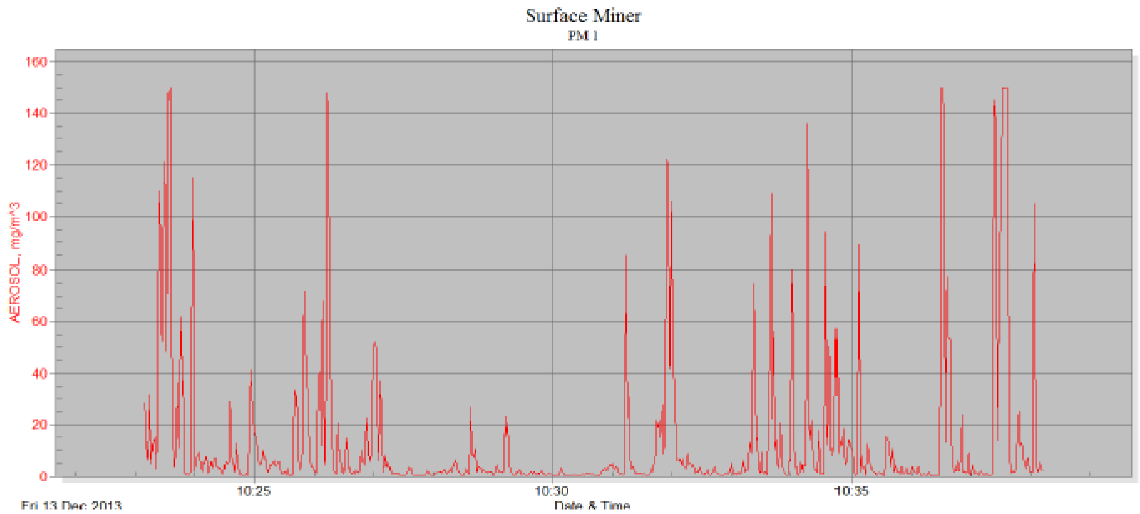

Figure 4.13 Concentration vs Time graph for dust at surface miner in PM1

The peaks in the graph depicted surface in operation whereas low concentration shows idle time of surface miner. Wind direction also played a major role in determining the dust concentration. Adequate water was not used for dust suppression, hence the graph shows higher concentration comparing to other locations.

V.RESULTS AND DISCUSSIONS

Lakhanpur Opencast Project

From the monitoring at various sources of LOCP, a comparison can be made for different dust generating sources. The comparison of average dust concentration in PM10, PM4, PM2.5 and PM1 at different locations was plotted in Fig.5.1. It can be concluded that drilling was the most polluting source in PM2.5, PM4 and PM10 whereas surface miner was the most polluting source in PM1.

Minimum concentration in PM10, PM4, PM2.5 and PM1 at different locations was plotted in Fig.5.2. It shows that least concentration was obtained at surface miner for PM1, PM2.5 and PM4. For PM10, least concentration was obtained at drilling point.

Maximum concentration in PM10, PM4, PM2.5 and PM1 at different locations was plotted in Fig.5.3. It can be concluded that at drilling point maximum concentration was obtained for PM1, PM2.5, PM4, & PM10 . Surface miner was the second most polluting source at all size range. Insufficient use of water for drilling and cutting purpose at these locations resulted in generation of high quantity of fine dusts.

Personal dust exposure to different workers was plotted in Fig.5.4. Exposure level of explosive carrier was highest whereas exposure level of dumper operator was lowest. However, for most of the workers the exposure was beyond statutory limit of 3mg/m3.

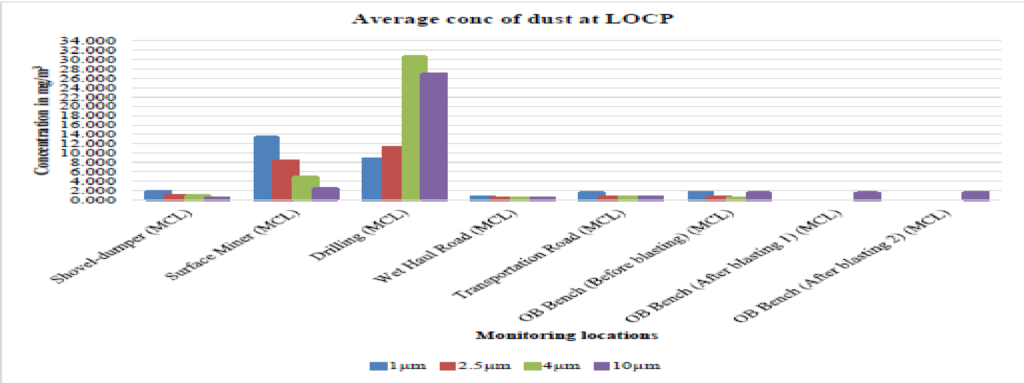

Figure 5.1 Comparison of average concentration of dust at different locations of LOCP

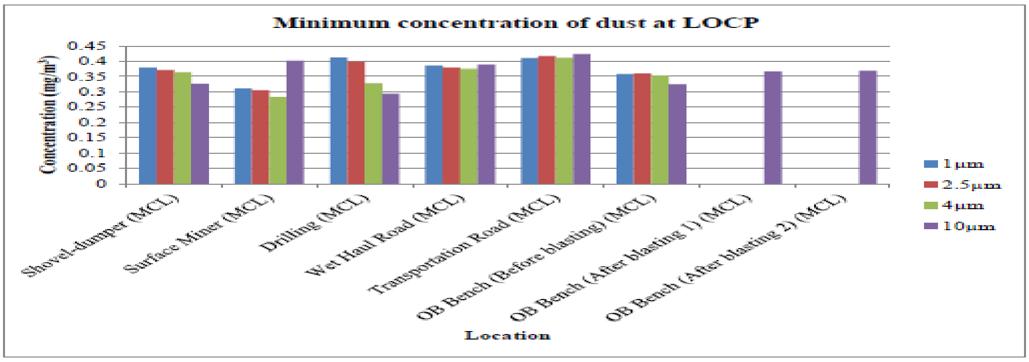

Figure 5.2 Comparison of minimum dust concentration at different locations of LOCP

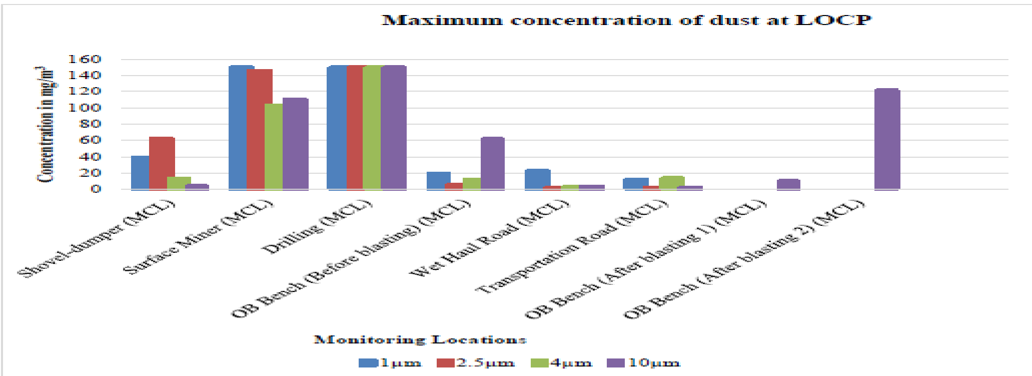

Figure 5.3 Comparison of maximum dust concentration at different locations of LOCP

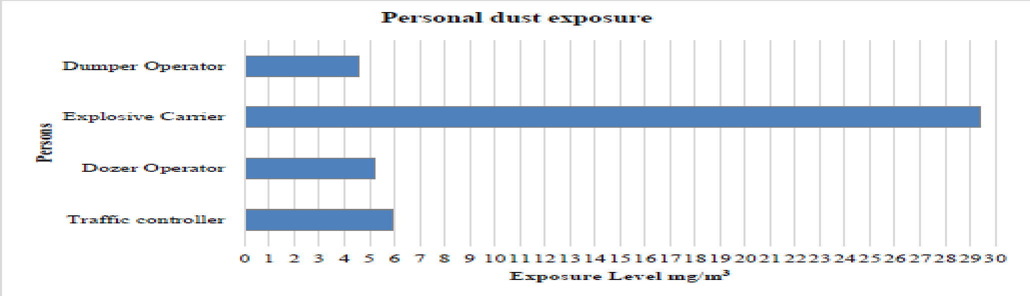

Figure 5.4 Personal dust exposure level of different workers at LOCP

A comparison of quartz content at different locations was plotted in Fig.5.5. Maximum quartz content was obtained at wet haul road-1 whereas minimum quartz content was found at coal transport road-3.

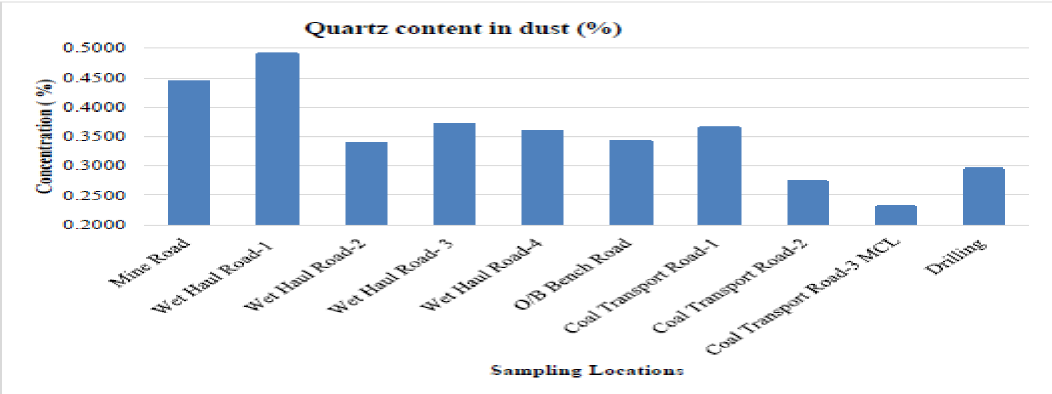

Figure 5.5 Quartz content of dust at different locations of LOCP

The predicted concentration at different locations in and around the mine was obtained from AERMOD. A comparison was made for the highest 24 hour predicted concentration in PM10 for the year at Fig.5.6. At most of the locations the predicted concentration level was higher than NAAQS limit of 100µg/m3. Similarly another comparison was made for the annual average predicted dust concentration in PM10 in Fig.5.7. It can be seen that debarring a few locations, dust concentration was below the NAAQS limit of 100µg/m3.

VI.CONCLUSION

- From the field monitoring of dust concentrations using DustTrak-II at LOCP, it can be concluded that: The maximum dust concentration was obtained at drilling point with average concentration of 26.8 mg/m3 and maximum concentration of 150.0mg/m3 in PM10 range. Minimum mean dust concentration was found at loading point at 0.474mg/m3 in the PM10 range. Drilling and Surface miner operations were found to be the major sources of dust generation.
- From personal dust exposure monitoring of workers using PDS APM-500, it can be concluded that: The dust exposure of worker was the maximum for explosive carrier at 29.41mg/m3 which is much above the regulatory limit of 3mg/m3. In general, for most of the employees under study, personal respirable dust exposure was found to be beyond the permissible limit.
- From Characterization of dust using FTIR, it can be concluded that minimum quartz content was found at coal transport road at 0.23% and maximum quartz content was found at wet haul road of LOCP at 0.49%.
- From the dust dispersion modelling, it could be observed that:
- For 24hr period for the year, the highest dust concentration for PM10 at all other places except at Lakhanpur, Mauliberena, Adhapara, Negipali, Kudopali and Baliput were found to be above NAAQS limit of 100µg/m3.
- For annual average, at most of the places at and around LOCP, the dust concentrations were found to be below NAAQS limit of 60µg/m3 except at Tingismal, Khuntmahul, Karlajori, Khairkuni, Khaliapali, Banjipali.

REFERENCES

1. Chakraborty, M.K., Ahmad, M., Singh, R.S., Pal, D., Bandopadhyay, C. & Chaulya, S.K., (2002), Determination of the emission rate from various opencast mining operations, Environmental Modelling & Software, 17, pp. 467–480.
2. Chaulya, S.K., Ahmad, M., Singh, R.S., Bandopadhyay, L.K., Bandopadhyay, C. & Mondal, G.C., (2002), Validation of two air models for Indian Mining conditions, Central Mining Research Institute, Dhanbad, India, Environmental Monitoring and Assessment 82. Pp. 23-43.
3. Chaulya, S.K., (2004), Assessment and management of air quality for an opencast coal mining area, Journal of Environmental Management, 70, pp. 1–14 .
4. Erol, I., Aydin, H., Didari, V. & Ural S., (2013), Pneumoconiosis and quartz content of respirable dust in the coal mines in Zonguldak, Turkey, International Journal of Coal Geology, 116-117, pp. 26-35.
5. Ghose, M.K. & Majee, S.R., (2007), Characteristics of hazardous airborne dust around an Indian surface coal mining area, Environ Monit. Assess. 130, pp. 17-25.
6. Hartman,H.L., Mutumansky, J.M., Ramani, R.V. & Wang, Y.J., Mine Ventilation and Air Conditioning, New York, 3rd ed, Willey-Interscience publication, 1993
7. Kumari, S., Kumar, R., Mishra, K.K., Pandey, J.K., Udaybandhu, G.N. & Bandopadhyay, A.K., (2011), Determination of quartz and its abundance in respirable airborne dust in both coal and metal mines in India, Procedia Engineering, Volume 26, pp. 1810-1819.
8. Mishra, G.B., Mine Environment and Ventilation, Oxford University Press, New Delhi, 2004.
9. Mishra, P.C. & Jha, S.K.,(2010), Dust dispersion modelling in opencast coal mines and control of dispersion in Mahanadi Coal Fields of Orissa, The Bioscan, Vol.2, pp.479-500.
10. Mukherjee, A.K., Bhattacharya, S.K. & Saiyed, H.M., (2005), Assessment of respirable dust and its free silica content in different Indian coal mines, International Health, vol-43, pp. 277-284.
11. Reed, W.R., (2005), Significant Dust Dispersion Models for Mining Operations, Information Circular 9478, DHHS (NIOSH) Publication,138.
12. Sengupta, M., Mine Environment and Ventilation, Vol-I. Alaska, CRC press, 1989.