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Analysis of Wind Characteristics in And Around Open Cast Uranium Mine

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Abstract: Flow of wind direction and type of soil like silt content, moisture content are the factors that mainly affects the emission rates of the dust due to various mining activities. Opencast mining activities like drilling, blasting etc. result in emission of dust which eventually dispersed and migrated to the surrounding environment. Additionally other parameters like wind speed, wind rose and frequency distribution etc also influence emission rates. The wind characteristics thus developed will be very useful for estimation and prediction of likely impact in the surrounding environment using dispersion models.
Keywords: Emission rate; Opencast mine; Wind speed.

1.0 Introduction

Historically and into the present day, mining operations have generated substantial quantities of airborne respirable dust, which has led to the development of lung disease in mine workers. Pneumoconiosis and silicosis are lung diseases that have adversely impacted the health of thousands of mine workers. Depending on the severity of the lung disease, symptoms range from reduced breathing capacity to death. Although significant advances in dust control technology have been realized, improved mining practices and equipment have meanwhile led to record production levels which have in turn resulted in the generation of additional dust. One tool that can be used to investigate dust generation and dispersion is computer modeling.

Dust of any kind when inhaled in large quantities lead to the development of respiratory diseases such as pneumoconiosis, silicosis etc. If silica is a component of respirable dust, then the effects of exposure pose a very serious health concern. Silicosis has no cure and is fatal. There are other adverse impacts from dust exposure in addition to health effects[1]. It is known that even small particle in air hinders visibility. Climate change may occur from PM_{10} exposure because the small particles in the atmosphere absorb and reflect the radiation from the sun, thus, affecting the cloud physics in atmosphere.

2.0 Modeling

Modeling or simulation is a process whereby a system is created to simulate a real-life situation. Computer modeling is generally the most inexpensive and versatile method for analyzing a real-life situation and has become prevalent for solving problems related to physical processes, especially in research and development. Simulation generally involves modeling a physical process and analyzing it through the use of a personal computer. This analysis involves trial-and error methods applied to the model and tested with the actual physical process to perfect the model[21]. Once this process is completed, the computer model can be used to identify problematic areas, and efforts can focus on finding solutions to address these particular concerns. Computer modeling of dust dispersion from mine sources can allow for the identification of potential hazard areas surrounding the source from a health and safety standpoint. It can also allow for the evaluation of dust control techniques to determine modifications necessary to improve dust control. The results from modeling the emissions of a facility are used to ensure that the regional air quality does not exceed the NAAQS[3] or deteriorate the air quality further. If the modeling results show the facility will not cause the regional air quality to exceed the NAAQS or deteriorate the air quality then the air quality permit will be granted, otherwise the quality permit application will be denied.

3.0 Literature Review

The dust dispersion models used in surface mining have been adopted from existing industrial air pollution models. The surface models do not focus on particular size fraction and are applicable to all size. Following is the summary of studies carried out by different researchers.

Dust Dispersion Models Used In Surface Mining

Cole and Fabrick (1984) have discussed pit retention of dust from surface mining operations. They have suggested a very simplistic model[8] that is representative of box – model algorithm and is given as:

$$\varepsilon = 1/[1+(V_d/ K_z)H]$$

Where,
ε = mass fraction of dust that escapes an open pit
V_d= Particle deposition velocity(m/sec).
K_z= Vertical diffusivity (m^2/sec),
H= Pit depth (m)

EPA(1995) Dust dispersion modeling for surface mining operations, as required for air quality protection, was completed using an established model—the Industrial Source Complex model (ISC3) created by EPA[9-10]. This model also includes a subroutine for modeling flat/ complex terrain and has the ability to model dispersion from four types of emissions sources: point, which are typically stacks; volume, which are typically buildings; area, which are typically haul roads or storage piles; and open pit. The ISC3 model[11] is based on the Gaussian equation for point source emissions which is given as:

$$\chi = (QKVD/2\mu u_s \sigma_y \sigma_z \exp[-0.5(y/\sigma_y)^2$$

Where,
Q = pollutant emission rate (gm/sec)
K=scaling coefficient to convert calculated concentrations to desired units
V = vertical term, D = decay term
u_s= mean wind speed at release height(m/sec)
$\sigma_y \sigma_z$= standard deviation of lateral and vertical concentration distribution(m),
χ = hourly concentration at downwind distance x ($\mu g/m^3$)
y = crosswind distance from source to receptor.

Pereira et al. (1997) used a Gaussian dispersion equation to predict dust concentrations from the stockpiles of an operating surface mine in Portugal[13]. The equation is as follows:

$$c = Q /(2\Pi \sigma_y \sigma_z \bar{u})\exp[-0.5(y_r/\sigma_y)^2]\exp[-0.5(h_e - z_r)/ \sigma_y)^2]$$

Where,
c = pollutant concentration at location receptor (μg/sec)
Q = emission rate (gm/sec)
$\sigma_y \sigma_z$ = horizontal and vertical standard deviation respectively (m).
$\bar{u}$ = average wind speed (m/sec)
h_e = effective emission height (m)

This equation was used to create risk maps of air quality for locations surrounding the mine site.

Ghose and Majee (2000) carried out assessment of dust generated due to opencast coal mines. Emission factor data was used to quantify the generation of dust. The main sources of air pollution were identified. It was estimated that due to topsoil removal, overburden (O/B) removal, extraction of coal, size reduction generated 7.8 t of dust per day[26]. Wind erosion generated 1.6 t of dust per day and the whole operation produced dust which accounted for 9.4 t/day. This caused air pollution in the work zone and surrounding locations. This methodology may be used to quantify generation for other projects also[12].

Reed et al. (2001) completed a study on the ISC-3 model using a theoretical rock quarry. The study also concluded that hauling operations contributed the majority of PM_{10} concentrations an that the haul truck emissions factors may be part of the cause of the over production of PM_{10} concentrations aby the ISC-3 model. Reed described a model called the Dynamic Component Program that can be used for predicting dust dispersion from haul trucks[14]. The model is based on a Gaussian equation similar to that used by the ISC3 model[16]:

$$\chi = (QKVD/2\mu w_s \sigma_y \sigma_z \exp[-0.5(y/\sigma_y)^2$$

Where,
Q = pollutant emission rate (g/sec)
K = scaling coefficient to convert calculated concentrations
to desired units
$w_{s=}$ mean wind speed at release height (m/sec)
$\sigma_y \sigma_{z=}$ standard deviation of lateral and vertical concentration distribution(m),
χ = hourly concentration at downwind distance x ($\mu g/m^3$)
y = crosswind distance from source to receptor (m)

The major difference between the Dynamic Component Program and the ISC3 model is the methodology of applying the source emissions when predicting dust dispersion from that source.

Reed (2001) designed a computer model named the dynamic component program (DCP) for predicting the dispersion of dust from haul trucks[27]. Validation of DCP was completed by comparing its results with the results of the ISC3 model and with actual dust measurements taken from two operating mine sites. Comparisons of the field measurements, predictions of the ISC3 model and the prediction of DCP demonstrated that the results from the DCP represent, on average an 85% improvement over the ISC3 dust dispersion model results[14-15].
The DCP model generally better predicts PM_{10} dispersion from haul by a factor of two to three. If the frequency of haul trucks is high (over 200 trucks per day), then the DCP's performance becomes significantly better. By comparing the modeling and field study results, it was concluded that the following causes contributed to the over prediction of dust dispersion of the ISC3 model over the actual results. The main reason was due to the inability of the ISC3 model to handle mobile emissions sources.

Chaulya et al. (2003) carried out study for the determination of emission rate for SPM to calculate emission rate of various opencast mining activities and validation of commonly used two air quality models for Indian mining conditions[23]. To achieve the objectives, eight coal and three iron ore mining sites were selected to generate site specific emission data by considering type of mining, method of working, geographical location, accessibility and above all resource availability[6]. The study covered various mining activities and locations including drilling, overburden loading and unloading, coal/mineral loading and unloading, coal handling or screening plant, exposed overburden dump, stock yard, workshop, exposed pit surface, transport road and haul road[25]. Validation of the study was carried out through Fugitive Dust Model (FDM) and Point, Area and Line sources model (PAL2) by assigning the measured emission rate for each mining activity, meteorological data and other details of the respective mine as an input to the models[4]. Both the models were run separately for the same set of input data for each mine to get the predicted SPM concentration at three receptor locations for each mine. The receptor locations were selected such a way that at the same places the actual filed measurement was carried out for SPM concentration[18]. Statistical analysis was carried out to assess the performance of the models based on a set of measured and predicted SPM concentration data. The value of coefficient of correlation for PAL2 and FDM was calculated to be 0.990–0.994 and 0.966–0.997, respectively, which showed a fairly good agreement between measured and predicted values of SPM concentration[33-34]. The average index of agreement values for PAL2 and FDM was found to be 0.665 and 0.752, respectively, which showed that the prediction by PAL2 and FDM models are accurate by 66.5 and 75.2%, respectively. These indicate that FDM model was more suited for Indian mining conditions[7].

Singh et al (2006) carried out comparison and performance evaluation of dispersion models FDM and ISCST3 for a gold mine at Goa. The emphasis of large-scale opencast mining had resulted in widespread concern about the deterioration in environmental quality, specially the increase in concentration of Suspended Particulate Matter (SPM) within and around the mining site. Thus, to gain better understanding of the fate and transport of the pollutants and to predict future conditions under various inputs and management action alternatives, the mathematical simulation of the dispersion process was done[29]. For this, application of the EPA models for the short-term prediction of the pollution level due to mining activities was explored. The two models considered in the study were Industrial Source Complex Short-Term (ISCST3) and Fugitive Dust Model. The emission inventory and meteorological data were primary inputs for air quality model. Various statistical approaches were used to compare and evaluate the models under study and it was found that FDM is more accurate then ISCST3 and thus is more useful as a screening tool for regulatory purposes[30].

Chakraborty et al. (2008) studied the dispersion of air borne dust generated due to mining activities in Gughus opencast coal project[19], W.C.L. The concentration of gaseous pollutants such as CO, NO_X etc. was much lower than threshold limit values. Therefore the air quality modeling was restricted to the determination of particulate matter i.e. SPM and RPM. Primary data for analysis of air-borne dust dispersion included the activity wise generation of particulate matters as well as micro-meteorological data. They used modified Pasquill and Gifford formula for calculation of emission rate. Stability classes were found to be B, C & D. With the help of mine plan, for locating different activities, activity wise emission rates and meteorological data, Fugitive Dust Model was run and it was found that the ambient air quality at three sites of Gughus OCP was well within the limits[20].

Trivedi et al. (2008) studied the different sources of dust generation due to coal mining activities and quantification of dust emission and it's dispersion for the Durgapur Opencast Coal Project of Western Coalfields Limited[3]. The dust dispersion in horizontal as well as vertical direction was estimated by the procedure suggested by Pasquill and Gifford keeping in view the Pasquill stability class of prevalent meteorological conditions[31]. Dust emission rates for different point, area and line sources were estimated considering the background dust concentration. Ambient air quality data was generated for selected stations. And air quality modeling was attempted using Fugitive Dust Model (FDM)[24]. With the help of FDM, dust concentration was predicted at the source as well as at the selected receptors at different distances along downwind direction[7-8]. The [air] quality modeling using FDM revealed that the dust generated due to mining activities does not contribute to ambient air quality significantly in surrounding areas beyond 500m in normal meteorological conditions[19].

Trivedi et al. (2009) examined different sources of dust generation and quantified dust emission rates from different point, area and line sources considering background dust concentration at one of the opencast coal project of Western Coalfields limited[2]. Air quality modeling using Fugitive Dust Model[34] revealed that dust generated due to mining activities did not contribute to ambient air quality significantly in surrounding areas beyond 500 m in normal meteorological conditions[17]. Predicted values of total suspended particulate matter were 68 – 92 % of observed values. They formulated a management strategy for effective control of air pollution at source and other mitigative measures including green belt design were also recommended[20].

4.0 Theory

In the present study an uranium ore mine in East Singhbhum district of Jharkhand was selected. Air quality modeling software named Industrial Source Complex model (ISC-3) is going to be used here. ISC-3 has been designed to handle the computation of pollutant impacts in both flat and complex terrain within the same modeling framework[4-5]. ISC-3 is a steady-state plume model that assumes that concentrations at all distances during a modeled hour are governed by the temporally averaged meteorology of the hour. The steady state assumption yields useful results since the statistics of the concentration distribution are of primary concern rather than specific concentrations at particular times and locations.

5.0 Instrumentation

a. Mini Digital Vane Anemometer

Digital Vane anemometer is used in order to get hourly wind data and other atmospheric parameters as shown in Figure 4.1. It has sensor used for following measurement like Wind Speed, Temperature, Pressure, and Humidity**.**

b. Global Positioning System

Global Positioning System (GPS) is used for finding the latitude, longitudes and mean sea level of the receptor locations. Model is GARMIN e-trex HCx as shown in Figure 4.2.

Figure5.1Anemometer

Figure 5.2 Global Positioning System

Table 5.1 Instrument Specifications

Specifications	**Global Positioning System**
Size	106.68 mm H X 55.88 mm W X 30.47mm D
Weight	159 gm with battery installed
Display	33.01 mm W X 43.18 mm H, 256 colours
Source	Two 1.5V AA batteries, 12V DC Adapter
Specifications	**Mini Digital Vane Anemometer**
Display LCD size	28 mm x 19mm.
Anemometer Unit	m/s
Temp. Unit	°C
Barometer unit	hPa, mm Hg

6.0 Analysis

Wind analysis has been done in order to identify the major flow direction of the dust that has been emitted from the mines. According to the wind data collected during 4th March to 15th May 2011 prominent wind direction was in the NEE (North East East) region, which determines the dust flow is towards the eastern boundaries of the Jamshedpur city. On March 29th, the wind direction was prominent towards the west from the data collected which determines that the dust is being carried further away from the city. This show that the dust is being carried away from the highly populated areas of the Jamshedpur city and the mining doesn't cause many problems. Even when the wind is carrying the dust towards the city the dust concentration is very less in order to cause any sort of problems for life. Wind speed is never constant during a day. Due to continuous fluctuation of wind velocity, power generated also continuously fluctuates. Under such conditions, in order to derive maximum benefit i.e. optimal efficiency of the generator some WTG manufacturers opt for dual speed generators wherein higher power winding gets connected during maximum wind velocity and lower speed winding during lean velocity period. However some OEMs use single speed generators[21-28].

The Figures 1 and 2 shows the wind-rose diagrams of the wind patterns with respect to the AMD Complex. This depicts the direction of wind and the speed with which they move. Just as in these diagrams 360 degrees of a circle is divided into different zones and each zone was categorised as direction zones such as N, NNW, NWW, W etc. The prominent wind direction zone is selected and used for further calculations[2].

Analysis of the PM_{10} concentration has been done. The ISC-3 model is used and the PM_{10} concentration is predicted from the data that has been observed using the vane anemometer and the GPS. The actual PM_{10} concentration is measured from the Respirable Dust Sampler. The measured value and the predicted value are compared with each other and the accuracy of the predicted PM_{10} concentration is evaluated[32].

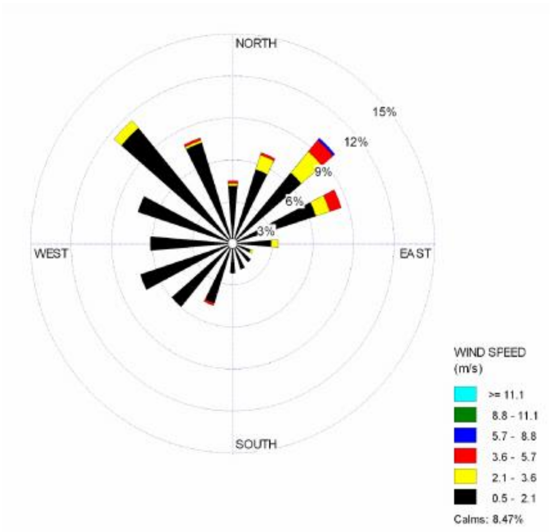

Figure 6.1 Wind-Rose diagram at EEL, Dec-2009

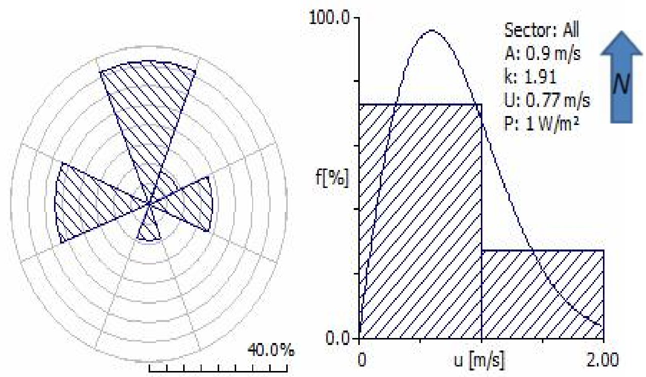

Figure 6.3 Wind Char. at Environmental Lab. (Mine Site)
Observed Wind Climate 4/3/2011 to 10/5/2011

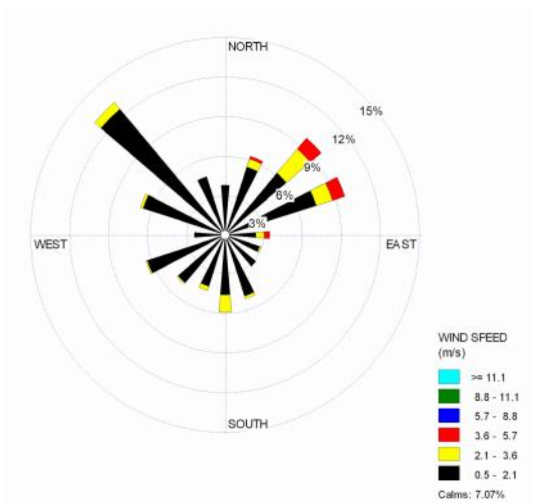

Figure 6.2 Wind-Rose diagram at EEL, Jan 2010

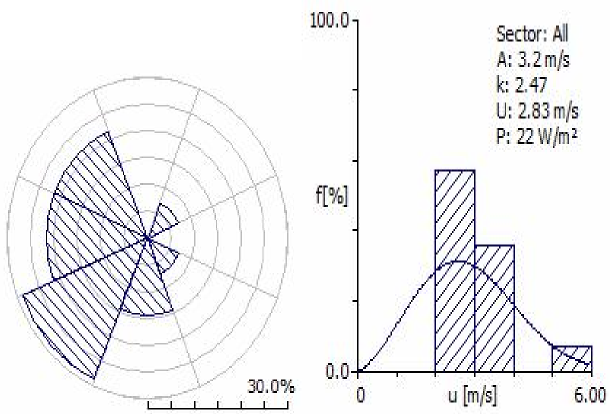

Figure 6.4 Wind Char. at AMD Complex Observed Wind Climate from 4/3/2011 to 10/5/2011

The Figures 6.1 and Figures 6.2 show the wind-rose diagrams of the wind patterns at EEL Turamdih. The prominent wind direction is noted and used for analytical prediction of dust concentration. The PM_{10} concentration is measured from the Respirable Dust Sampler.

Figure 4.4 shows the wind-rose diagrams and wind speed frequency plot of the wind patterns at AMD Complex, Jamshedpur. The prevailing wind direction at the AMD Complex from South-West direction with mean wind speed as 2.83 m/s.

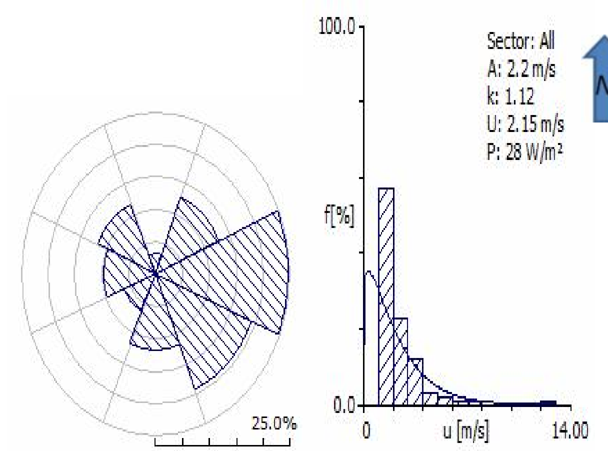

Figure 6.5 Wind Char. at NIT Jamshedpur Observed Wind Climate 4/3/2011 to 10/5/2011

Figure 6.5 shows the wind-rose diagrams and wind speed frequency plot of the wind patterns at NIT, Jamshedpur. The prevailing wind direction at the NIT Jamshedpur from South-West direction with mean wind speed as 2.15 m/s.

A and U are given in m/s, E in W/m²; and the frequencies of occurrence in per mille and percent (f).

7.0 Conclusion

As we can infer from the literature review and study of the site, the major source of emission can be considered as surface sources. Preliminary work is started for computational modeling of dust dispersion from mine sources can allow for the identification of potential hazard areas surrounding the source from a health and safety standpoint. In order to identify the major flow direction of the dust that has been emitted from the mines. According to the wind data collected during the period prominent wind direction was in the NEE (North East East) region, which determines the dust flow is towards the eastern boundaries of the Jamshedpur city. During the period the wind direction was prominent towards the west from the data collected which determines that the dust is being carried further away from the city. This show that the dust is being carried away from the highly populated areas of the Jamshedpur city and the mining doesn't cause many problems.

The monitoring of the vital parameters of source, dispersion, wind, temperature, humidity etc. can be applied to the future research and development. Emission rate would be useful to predict the maximum concentration of pollutants by modeling and the data may be used for green belt design and air pollution management.

Scope of Future Work:

- Collection of dust data at further more locations at Jamshedpur .
- Chemical Characterization (BARC, Mumbai).
- Collection of Meteorological Data during 2010-12 from Meteorology Department, Kolkata.

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