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Study on Opencast Coal Mine Haul Road Dust Suppression using Guargum Grafted Polyacrylamide

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Abstract

Vehicle movement over haul road is the major source of fugitive dust emission from opencast coal mines which adversely affect the environment. Water spraying is the most common practice for controlling fugitive dust generationfrom haul road. In this work, an innovative polymer was synthesised to study its effectiveness as a dust suppressing agent. Guargum grafted polyacrylamide (GG-g-PAM) polymer was synthesised by free radical polymerisation technique using Ceric Ammonium Nitrate (CAN) initiator. Haul road dust sample was collected from a mine and characterised by sieve analysis and Energy Dispersive X-ray (EDX) analysis. An experiment was carried out at controlled environment in the oven to measure the moisture retention efficiency of the dust applying the synthesised polymerat different temperatures 25°C, 35°C and 45°C. For this purpose, 0.1 weight percentage of GG-g-PAM was mixed with water. The solution was sprayed over 20g dust sample (below 10 mesh size) in a petri dish. The same experiment was repeated with only water as the dust suppressant to compare with the effectiveness of GG-g-PAM. The experiments showed that application of GG-g-PAM polymer solution instead of only water helps to increasing moisture retention capacity of haul road dust by 12.9% after 8 h at 25°C, 14.7% after 8 h at 35 °C, and 25.4% after 2 h at 45°C. It is also observed that application of GG-g-PAM polymer solution helped in reducing the dust generation by 36% after 8 h at 25°C, 32% at 35°C after 6 h, and 65% after 2 h at 45 °C. This shows that during scorching summer when the temperature is, in general, above 40*°C*, GG-g-PAM solution has potential for suppression of haul road dust in opencast coal mines effectively.

Keywords: *Dust Suppression, Fugitive Dust, Haul Road, Guargum Grafted Polyacrylamide, Moisture Retention and dust emission*

1. Introduction

Excavation of minerals is broadly carried out either through underground mining method (UGM) or opencast mining method (OCM). The production of coal through opencast mining technology is very high as compared to underground mining technology. However, OCM has more of adverse effects on the environment causing air pollution in the mining area which is carried to the surrounding localities by the action of air currents (Chaulya *et al.*, 2011)water holding capacity, ash percentage, moisture content, volatile matter, bulk density, specific gravity and fixed carbon was found to be in the range of 5.1–7.7, 21.17–31.71%, 45–76%, 0.5–3.0%, 12.6–20.0%, 1.15–1.70 g cm −3 , 1.73–2.30, and 10.2–45.3%, respectively. The study revealed that the coal dust

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abundantly available on road surface of opencast coal mines may be used as domestic fuel. Hence, collection and utilization of coal dust accumulated on mine road would not only reduce air pollution in mining regions but also help in enhancing economic benefit of coal mining industry by selling waste coal dust as domestic fuel. Keywords Opencast mine, haul and transport roads; , coal dust; physico-chemical properties; domestic fue I. INTRODUCTION Coal is the most abundant fossil fuel resource present in India. Indeed there has been historical link between economical progress of India and use of coal for numerous basic requirements of the country, ranging from energy for domestic purpose to industrial application, like steel (8%. Several activities like overburden removal, coal extraction, drilling, blasting, crushing, screening, soil erosion from overburden dumps, haul road, loading and unloading, coal washery etc. go on simultaneously which produce huge amount of fugitive dust in mining area (Ghose, 2002). Out of all the operations, tremendous amount of dust has been emitted due to hauling of trucks on unpaved haul roads (Kashi *et al.*, 2020). Haul roads contribute approximately 78% to 97% of total dust emission of a mine (Reed and Organiscak, 2007)using the United States Environmental Protection Agency's (EPA. Fugitive dust has adverse effect on human health causing diseases like lung cancer, abnormal kidney function, black lung, asthma, cardiovascular diseases, rheumatoid arthritis and other pneumoconiosis. Crops, trees and animals are also affected by fine airborne particulate matters (Hendryx, 2015).

Emission of particulate matter as dust from unpaved haul roads results in loss of fines which gradually decreases cohesive force between fines and gravel material. Loss of fines causes soil erosion exposing gravel material (Gillies *et al.*, 2005). This causes the deterioration of unpaved haul roads and affects the vehicle as well as road maintenance, inducing vibrations in operator, increasing travel time, and a decline in production rate.

Water spraying has been used for many years as a primitive method to control this type of dust emission. It has the limitations like it works for very short time, requires large water quantity and is not effective in severe conditions such as in the summer season (Foley *et al.*, 1996). Though many preventive measures have been taken to control the dust emission from haul roads but no systematic approach could yet be evolved. Chemical suppressants like- spray-on type or mix in type that have been tried include petroleum resins, hygroscopic salts, lingo-sulphonate, tar and bitumen and polymers (USEPA, 1987; Dixon-Hardy *et al.*, 2008; Cecala *et al.*, 2012). Research shows that polymers give better performance and greater longevity for dust control from haul road of mines (Omane *et al.*, 2018). Water soluble polymers are hydrophilic and have the properties to easily dissolve, disperse or swell in water (Oodrow *et al.*, 2008). The concept of dust suppression by polymers is that they bind the surface particles with the help of moisture content or adhesive properties forming a thin layer on haul road surface. Guargum and polyacrylamide are environment-friendly, biodegradable, and also easy to apply (Wen *et al.*, 2010; Zou *et al.*, 2013; Zhang *et al.*, 2018). Moreover, they do not suffer embrittlement, leaching or UV degradation, and have good adhesive properties. This makes them potentially successful as dust suppressants.

In this study, an attempt is made for developing a novel water-soluble guargum grafted polyacrylamide (GG-g-PAM) for effective dust suppression in haul roads. The synthesised polymer has been examined for its moisture retention capacity as a chemical dust suppressant at different atmospheric temperatures — namely 25**°C**, 35**°C** and 45**°C**. This research gives an idea regarding the preventive techniques of haul road dust emission by improving its moisture holding capacity for longer duration.

2. Experimental Details

2.1 Details of Mine Area

Haul road dust sample was collected from one of the Opencast Coal Mine, under the Bharat Coking Coal Limited (BCCL) in Dhanbad district of Jharkhand state in India.

2.2 Characterisation of Haul Road Dust

The size distribution of dust sample was carried out by sieve analysis. Elemental compositions of dust were identified by EDX spectroscopy.

2.2.1 Size Distribution

Cross-section of haul road can be divided into four parts from the top layer to bottom layer, namely surface course, base course, sub-base and sub-grade (Thompson and Visser, 2000). Dust emission highly depends on the size of the road surface course materials (Patra *et al.*, 2016) According to ASTM-D6913, (2017) standard, weight of the soil sample should be 20 g and particle size below 10 mess to get 99.99% accuracy in the measurement of moisture content. The collected dust sample was screen-edusing sieves of mess size 10, 12, 20, 50, 100 and 200 of ASTM standard to get the particle size distribution.

2.2.2 EDX Spectroscopy

High resolution EDX (51N100-CARL Oxford Nanoanalysis) was used for elemental analysis of the dust sample.

2.3 Chemical Materials Details

The chemical used for the synthesis of the polymer GG-g-PAM, namely guargum (GG), acrylamide (AM), ceric ammonium nitrate (CAN), hydroquinone and acetone were procured from S.D. Fine Chemicals, Mumbai, India. All the chemicals were used without any further purification.

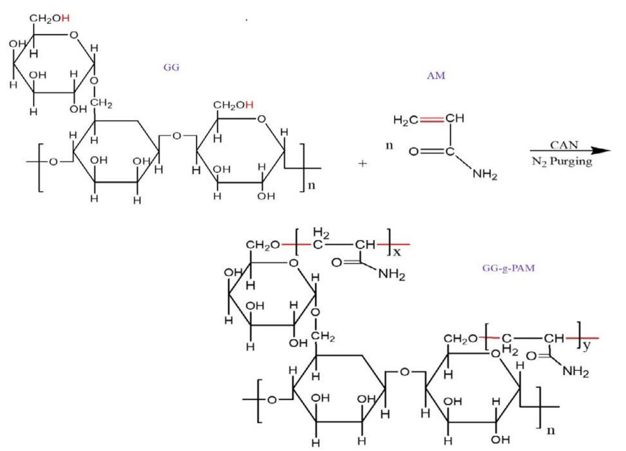

Figure 1. Chemical reaction for synthesis of GG-g-PAM.

2.4 Synthesis of Guargum Grafted Polyacrylamide (GG-g-PAM)

Guargum graft polyacrylamide was synthesised by free radical polymerisation technique using CAN initiator (Adhikary *et al.*, 2011) (Figure 1). 2 g of acrylamide was dissolved in 10 ml distilled water in a conical flask. Then 1 g of GG was dissolved in 200 ml distilled water and mixed with acrylamide solution. The conical flask was placed in a water bath at 60**°C** and nitrogen gas (N_2) was purged for 20 min. Thereafter, 15 mg of CAN was added to the reactants. N_2 gas was purged yet again for 20 min. Then the supply of N_2 gas was stopped, and the reaction was allowed to go up to 24 h. Thereafter reaction was terminated by adding 2 ml of saturated solution of hydroquinone. The final product was precipitated by acetone and then dried in a vacuum oven. The product was broken into small pieces. It was pulverised and stored in a desiccator.

2.5 Experimentation on Moisture Holding Capacity of Dust

Experiments were carried out in the oven (ISO 9001-2000, Associated Scientific Technologies, Delhi, India) at three different atmospheric temperatures 25°C, 35°C and 45°C. Initially, the dust sample was fully dried in the oven at 110 ± 5 °C for 72 h. The moisture content of the dust sample was calculated through well known standard procedure given by ASTM D2216-10, (2010). Dust sample of 20 g was placed on a petri dish (9 cm diameter) and made a uniform thin layer so that the added solution uniformily spreads throguhout the dust layer. so that the solution reaches up to the surface of the dish and spread uniformly over it. 10 ml of 0.1% by weight of optimum concentration solution was sprayed. The sample was weighed before spraying and after spraying of the polymer solution. Then the treated sample was placed in the oven. The sample was weighed at an interval of 1 h each. Moisture retention capacity of GG-g-PAM treated solution was studied for 8 h duration. Similarly, the experiment was carried out using only distilled water, in place of the polymer solution.

2.6 Prediction of Haul Road Dust Emission Rate

There are several mathematical equations available for prediction of dust emission rate from haul road of coal mines (Patra *et al.*, 2016) Out ofthe predicated formulae, the empirical equation (1) given by Chakraborty *et al.* (2002) is claimed to be more suitable under Indian mining conditions. As per this, dust emission rate depends on six variables namely moisture, silt, wind speed, average vehicle speed, frequency of vehicle movement, and capacity of the dumper.

$$E= [\{(100-m)/m\}^{0.8} \{s/(100-s)\}^{0.1} \times u^{0.3}\{2663 + 0.1(v+fc)\} 10^{-6}] \quad \ldots\ldots\ldots(1)$$

where,

m= Moisture content (%)

s= Silt content (%)

u= Wind speed (ms^{-1})

v= Average vehicle speed (ms^{-1})

Table 1. Collected data for emission parameters of the case study mine

Silt content (s)	Wind speed (u)	Avg. vehicle speed (v)	Vehicle movement frequency (f)	Vehicle capacity (c)
16%	2.22 m/s	5.56 m/s	50 per h	100 T

Table 2. Particle size distribution of the haul road dust

Sieve size (mess)	Sieve size (mm)	Wt. of Particles (g)	% Wt. of particle	Cumulative wt. (%)	% Finer by mass
10	2.0	0	0	0	100
12	1.68	250	25	25	75
20	0.84	96	9.6	34.6	65.4
50	0.3	246	24.6	59.2	41.8
100	0.14	146	14.6	73.8	26.2
200	0.074	62	6.2	80	20

f= Frequency of vehicle movement (h^{-1})
c= Capacity of dumper (T)
E= Emission rate (g m^{-1} s^{-1})

All the data except moisture and silt contents were collected from the case study mine as given in Table 1. The value of silt content was found to be 16% through sieve analysis of the dust sample. The value of moisture content of dust was calculated from the experiment using GG-g-PAM treated solution and only water separately. When the moisture content is below 1%, the emission rate is unusually high and thus other parameters are more dominant for dust emission.

3. Results and Discussion

3.1 Haul Road Dust Characterisation

3.1.1 Size Distribution

In this study, a haul road dust sample was screened by sieves size ranging from 10 mesh to 200 mesh (2.04 mm to 74 µm) size (Table 2). Silt is the fraction of soil having particle size below 75 µm. Silt content was found to be 20% of the total weight percentage. The dust emission from haul road increases as the percentage of silt increases (Kavouras *et al.*, 2009).

3.1.2 EDX Analysis

The high resolution EDX image and elemental spectrum of haul road dust are shown in Figures 2 and 3 respectively. In Figure 3, Y-axis represents the concentration of each element in the haul road dust, whereas the X-axis of EDX spectrum indicates the energy's intensity of the X-rays. Weight percentage of major concentrated elements like carbon, aluminium, silica, oxygen and potassium are given in Figure 4. The weight percentage of oxygen is high which indicates that oxides of silica, carbon, aluminium etc. exist in high proportion in the haul road dust.

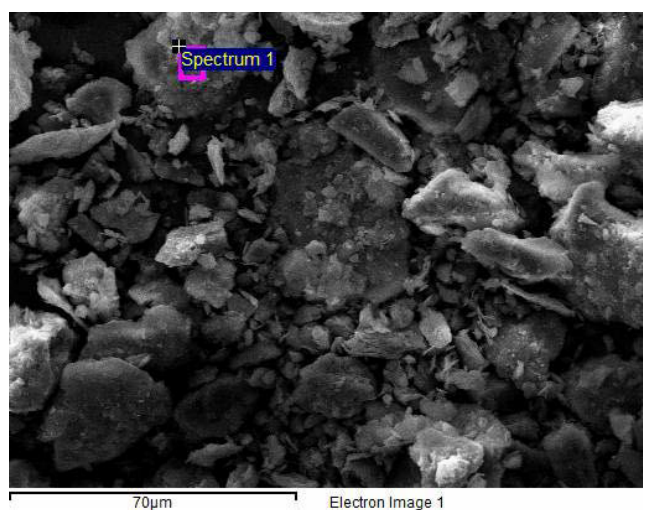

Figure 2. EDX Image of dust particles

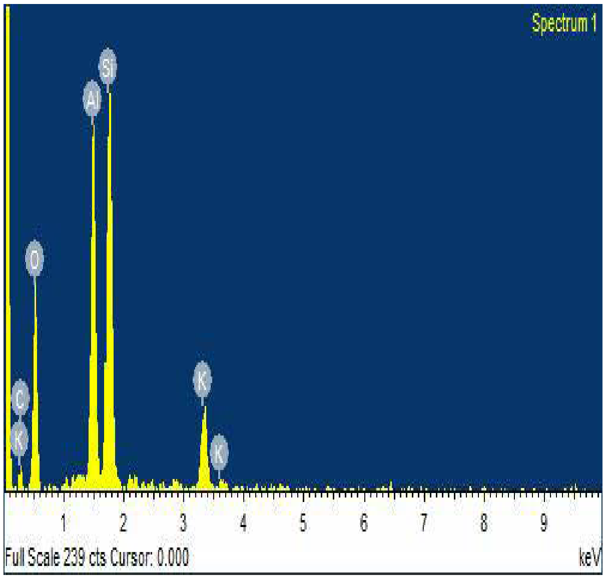

Figure 3. Elemental spectrum of dust particles by EDX.

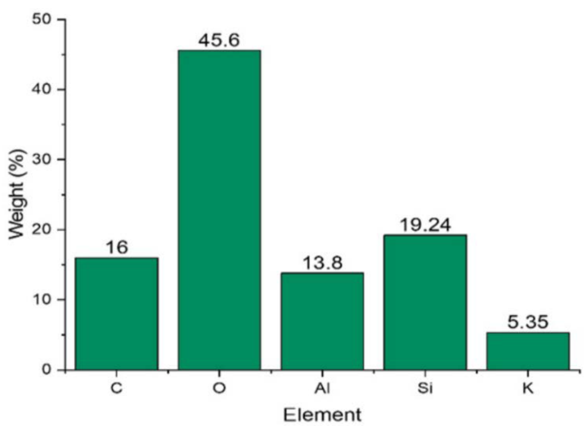

Figure 4. Weight % of elements present in haul road dust.

3.3 Effectiveness of Water as Dust Suppressant

Haul road dust sample was tested under the application of water and analysed its moisture retention efficiency over the period of 8 h at the temperature of 25°C, 35°C and 45°C (Figure 5). At 25°C and 35°C, water treated dust sample shows more or less uniform loss of moisture in each 1 h of intervals and retains 29.8% and 0.9% moisture after 8 h of heating respectively. At 45°C, moisture retention is 15.8% after 2 h. Negligible amount of moisture is left after 3 h of heating, and there after no moisture is present in the dust sample. Expected emission rate of haul road dust has been calculated taking into consideration of moisture retention at different temperature and different time as shown in Figure 6. After the first hour of heating, dust emission rate is 0.50 mg m^{-1} s^{-1}, 0.66 mg m^{-1} s^{-1} and 2.6 mg m^{-1} s^{-1} at 25°C, 35°C and 45°C respectively. Emission rate starts to increase because of moisture loss after elapsing of time in the oven. At 25°C, emission rate reaches to 6.75 mg m^{-1} s^{-1} after 8 h. In case of 35°C, the emission rate reaches to 7.8 mg m^{-1} s^{-1} in only 6 h. But in case of 45°C, emission rate reaches 12.97 mg m^{-1} s^{-1} within 2 h due to extreme loss of moisture from the dust sample.

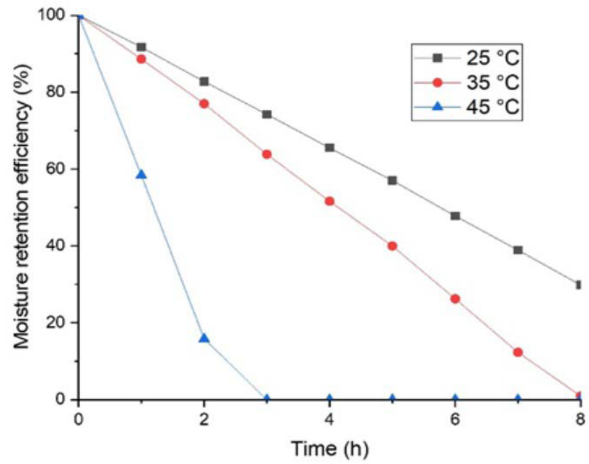

Figure 5. Moisture retention efficiency of dust when water applied as a dust suppressant.

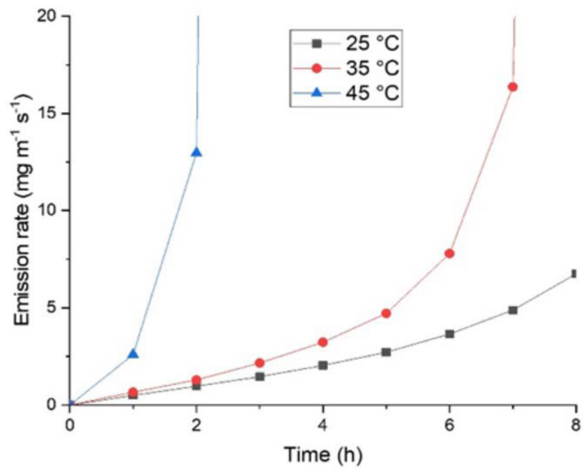

Figure 6. Emission rate of dust when water applied as a dust suppressant.

3.4 Effectiveness of GG-g-PAM as Dust Suppressant

The effectiveness of GG-g-PAM as a dust suppressant has been studied at the same three different atmospheric temperatures 25 °C, 35 °C and 45 °C at 1 h intervals up to 8 h duration (Figure 7). GG-g-PAM shows uniform loss of moisture in each 1 h of interval. 42.7% and 15.6% moisture is retained after 8 h of the experiment at 25°C and 35°C respectively. At 45°C, 41.2% and 9.6% moisture is retained after 2 h and 3 h of the experiment, after which negligible amount of moisture is present in the sample.

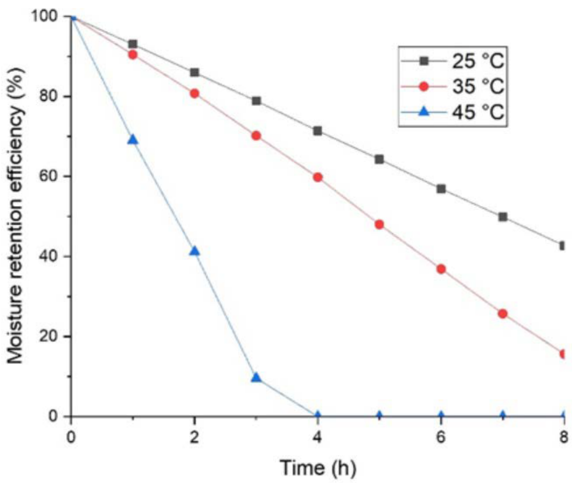

Figure 7. Moisture retention efficiency of dust when GG-g-PAM applied as a dust suppressant.

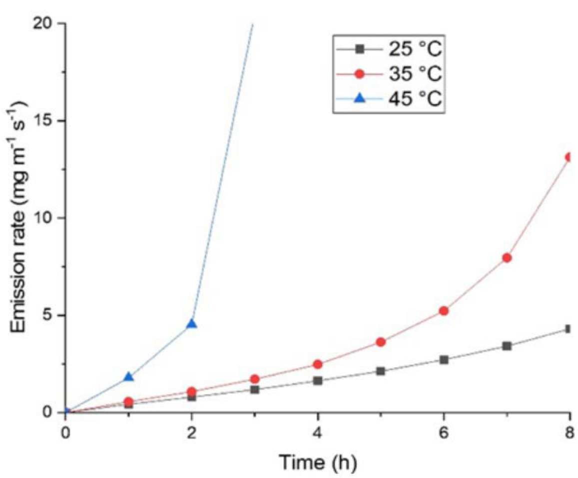

Figure 8. Emission rate of dust when GG-g-PAM applied as a dust suppressant.

The predicted emission rate of haul road dust under these conditions is shown in Figure 8. After the first hour, estimated dust emission rate is 0.43 mg m^{-1} s^{-1}, 0.56 mg m^{-1} s^{-1} and 1.79 mg m^{-1} s^{-1} at 25°C, 35°C and 45°C respectively. At 25°C, the emission rate increases after each hour of heating and reaches to 4.3 mg m^{-1} s^{-1} after 8 h. In case of 35°C, the emission rate reaches to 5.2 mg m^{-1} s^{-1} in only 6 h. But in case of 45°C, emission rate reaches to 4.5 mg m^{-1} s^{-1} within 2 h. Beyond 2 h, emission rate rises steeply due to very fast evaporation of moisture from the dust sample.

PAM has been grafted over the guar-gum polymer. A schematic presentation of GG-g-PAM has been shown in Figure 9. PAM has amide function group, which has capability to form hydrogen bond with water molecules (Figure 10). Each amide group of PAM chain has tendency to make hydrogen bond with four water molecules. Solubilization process of PAM in water is due to the insertion of water molecules in interstitial space of PAM chain (Patyukova *et al.*, 2018). Sonker *et al.*, (2019) have found that water uptake capacity of PAM is very high and go up to 4520%. On the other hand gaurgum has alcoholic group that also is capable of making H-bond with water molecules. When water molecules come in contact with PAM molecules, initially swelling process of PAM starts. Thereafter unfolding of PAM chain and GG chain occurs inside the grafted polymer. During unfolding, more water molecules intact with the polymer matrix. Guargum has viscous properties which also has capability to hold the molecules in its matrix. This combinedly increases water holding capacity of GG-g-PAM polymer.

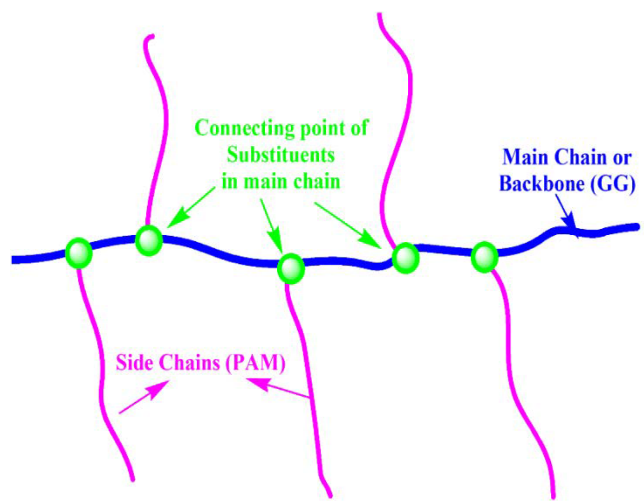

Figure 9. Schematic presentation of GG-co-PAM.

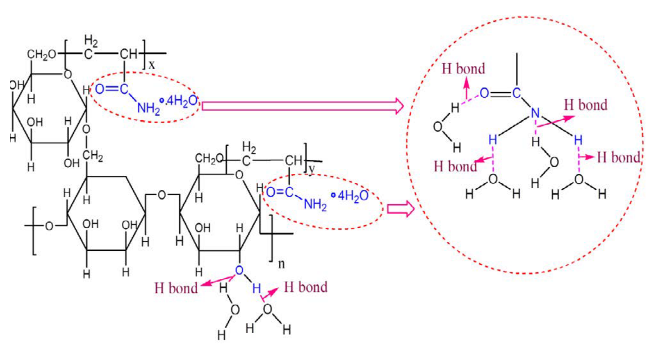

Figure 10. Formation of hydrogen bond between amide group and water molecules in GG-g-PAM polymer.

3.5 Comparison Between the Effectiveness of Water and GG-g-PAM

Dust samples are separately treated by water and GG-g-PAM solution at three different atmospheric temperatures 25°C, 35°C and 45°C for 8 h duration. The capacity of moisture retention and emission rate for these dust suppressants have been studied and compared in Figures 11 and 12 respectively. At 25°C, moisture retention capacity of GG-g-PAM treated solution is 12.9% higher than the water after 8 h. Initially after first hour, dust emission rate is 0.50 mg m^{-1} s^{-1} for water application and 0.43 mg m^{-1} s^{-1} for GG-g-PAM application. So dust generation reduces by 14% using GG-g-PAM solution in place of water as a dust suppressant in 1 h of application. After 8 h of polymer application, dust production from haul road will be lowered down by 36%.

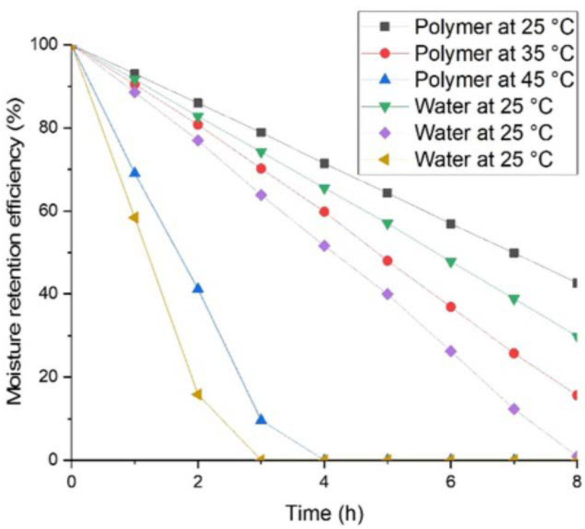

Figure 11. Comparison of moisture retention efficiency of dust with water and GG-g-PAM.

Similarly at 35°C, moisture retention capacity of GG-g-PAM treated solution is 14.7% higher than the water after 8 h. In first hour, dust emission rate is 0.66 mg m^{-1} s^{-1} and 0.56 mg m^{-1} s^{-1} with respect to application of water and GG-g-PAM. It means dust emission reduces by 15.2%. After 6 h of polymer application, dust generation reduces by 32% from haul road. After 8 h also the polymer solution provides a better result than water.

At 45°C, after 2 h, moisture retention capacity of GG-g-PAM treated solution is 25.4% higher than the water. Therefore, dust emission will reduce by 65% after 2 h when polymer solution is used instead of only water.It is because at high temperature, rate of release of water molecules from grafting matrix is retarded as water molecules are strongly binding through hydrogen bonding.

This shows that use of GG-g-PAM treated solution, instead of water alone, would be more beneficial during peak summer period when ambient temperature is, in general, above 40°C.

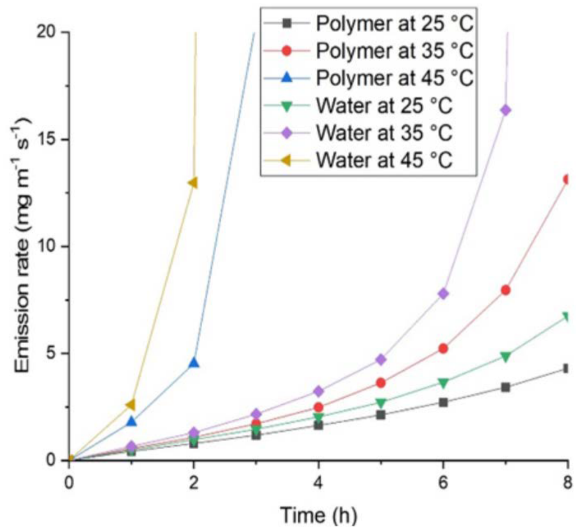

Figure 12. Comparison of emission rate of dust with water and GG-g-PAM.

4. Conclusions

The size distribution and compositional analysis of haul road dust have been determined by sieve analysis and EDX analysis respectively. Silt present in the haul road is 20%. The weight percentage of oxygen is high which indicates that the haul road dust consists mainly of oxides of silica, carbon and aluminium. GG-g-PAM has been synthesised by free radical polymerization method using CAN initiator. From the experiment, it can be concluded that application of GG-g-PAM polymer solution instead of only water helps in increasing moisture retention efficiency of haul road dust by 12.9% after 8 h, 14.7% after 8 h, and 25.4% after 2 h at 25°C, 35°C and 45°C respectively. These moisture retention capacities of haul road dust has the potential to reduce the dust emission by 36% after 8 h, 32% after 6 h, and 65% after 2 h at 25°C, 35°C and 45°C respectively. Maximum benefit of application of the grafted polymer solution would be accrued during peak summer having ambient temperature over 40°C, in general.

The value of emission rate is related to the concentration level of fugitive dust and thereby gives a simple measure in the monitoring of air quality in the vicinity of a mine. The visibility of vehicle drivers also improves if less amount of dust is generated. This leads to the enhanced mine's productivity and safety of the miners. The application of biodegradable guargum grafted polyacrylamide solution in place of only water as a dust suppressant is expected to provide provides a novel approach for the development of effective dust control management system in haul roads of mine.

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