Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

p-ISSN: 0972-6268
e-ISSN: 2395-3454

Vol. 19 | No. 1 | pp. 413-419 | 2020

Original Research Paper | Open Access

Reducing the Dust Generation of Haul Road by Improving Water Holding Capacity with the Application of Synthesised Polyacrylamide at Laboratory Condition

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Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 14-06-2019
Accepted: 23-07-2019

Key Words:
Fugitive dust
Haul road
Polyacrylamide
Dust emission
Moisture holding capacity

ABSTRACT

Surface mining method enormously affects the environment in terms of fugitive dust emission than underground mining method. All the several sources of dust emission from opencast mining, haul road transportation system are the main source of fugitive dust. In this research article, a biodegradable polyacrylamide (PAM) was used to suppress dust generation from haul road of mine. It improves the moisture carrying capacity of haul road than the water. PAM has been synthesized by free radical polymerization process using ceric ammonium nitrate initiator. It was characterized by 1H NMR, IR & intrinsic viscosity measurements, whereas size distribution of haul road dust was measured by sieve analysis. Laboratory work has been carried out to investigate the water holding capacity of haul road dust particles using PAM solution and compared with only water for 8 hours duration. The temperature of the chamber was kept constant at 35°C while relative humidities (RH) varied from 40% to 70%. It was observed that moisture retention of dust with the application of PAM solution and only water were 25.65% and 20.4% at 70% RH and 7.14% and 1.65% at 40% RH, respectively after 8 hours.

INTRODUCTION

In India, coal production from opencast mining (OCM) has risen to 250 million tons (MT), which represented about 70 percent of total coal production in 2000 (Ghose 2007). After 17 years, 618.445 MT (93.31%) coal production was through OCM in 2016-17, whereas only 44.347 MT was through underground mining (UGM) (Coal India Report 2017). Excavation of minerals, done both through UGM or OCM, is extremely risky and affects the environment adversely. OCM has a high rate of production and is less risky than UGM, but at the same time, it affects the atmosphere more than UGM due to more exposure to the outside environment. Dust emission of opencast mine is high due to multiple operations take place simultaneously like drilling, blasting, coal extraction, coal handling and stockpile, screening plant, topsoil handling, overburden removal, haul road transportation system and other miscellaneous activities (Shao & Lu 2000).

Out of these, haul road transportation system produces a huge amount of dust which polluted the environment as shown in Fig. 1 (Chaulya et al., 2011). Transportation of overburden, reaching to ore and then carrying of useful material i.e. ore to mineral processing plants is done over the road with a specific direction that is known as the haul road. Movement of haul trucks and other heavy machines over the haul road system has been identified as the immense source of fugitive dust generation. It contributes approximately 78% to 97% of total dust emission (Addo et al. 2004, Reed & Organiscak 2007).

Dust generation from haul road shows that if the dust emissions are uncontrolled, there is a high risk of the safety hazard by weakening the operator's visibility and damaging his efficiency. The SIMRAC report (Simpson et al. 1996) found that 74% of the accidents were associated with ore or overburden transfer by haul tracks and service vehicle operation on haul road surface mines in South Africa (Thompson & Visser 2001). Therefore, the probability of haul road accidents will increase, and that makes a high fatality rate. Various other adverse effects can also occur by emission of dust including human health, annoyance, biological and ecological impacts. (McHattie 2015).

Spraying of water is the most common mode for handling the dust generation in the different types of mining activities (Reed & Organiscak 2008). Earlier, either due to abundance of water source or easy availability or lack of proper innovative techniques, dust suppression on haul roads mostly depended on water. But in the present scenario, water is scarce around the mining area as well as the need of people

Fig. 1: Emission of dust from haul road.

around the mining site is also increasing especially during the summer season. Several published research reports have shown that different dust suppressants, when applied after mixing with water or without water, provide more effective dust control results (Cecala et al. 2012). Recently many chemical dust suppressants are applied for controlling the haul road dust generation like calcium chloride, magnesium chloride, petroleum emulsions, lignosulphonates and polymers (Bolander 1999, Zhang et al. 2018). These may be hazardous to the environment and damaging to haul tracks to varying degree (Foley et al. 1996, Cecala et al. 2012). This has led the mining industry to look forward to reducing the application of water as well as such hazardous chemicals and introducing a suitable alternative which has the capability to reduce dust emission and is also eco-friendly in its nature.

The objective of this study is to examine the effects of PAM as a chemical dust suppressant on fugitive dust emission from haul roads at the most viable temperature of 35°C under Indian context and low as well as high relative humidity (RH) condition of 40% & 70% respectively. These experiments show the role of temperature and humidity on the performance of PAM. This paper gives a behavioural idea of controlling the dust generated by the haul road system and assist in minimising the threat of fugitive dust to workers' health and safety.

MATERIALS AND METHODS

Description of the Case Study Mine Area

Dust sample was collected from haul road of a mine which comes under Block-II of Bharat Coking Coal Limited in Dhanbad district of Jharkhand state.

Block-II area is situated about 40 km west of Dhanbad town with Latitude-23º 47'30' to 23º 46'30' and Longitude-86º 13'30' to 86º 10'30'.

Materials

Acrylamide, ceric ammonium nitrate, hydroquinone and acetone were supplied by S.D. Fine Chemicals, Mumbai, India. All the chemicals were used as they were procured without further purification.

Size Distribution

In the design of a haul road, a mining company takes into consideration the wheel load of the haul truck and the particle size distribution of the soil before deciding what type of soil will be added to the wearing course materials (Thompson & Visser 2007, Mandal et al. 2012). According to the typical design standard for the mine haul road, the particle size distribution of the used soil sample, as shown in Table 1, falls within the design limit.

The sample was screened by sieve analysis of the size of 10, 12, 20, 35, 50, 100 and 200 mesh size of ASTM standard. Screening opening size was 10 mess, particles above this size have not played any crucial role in the dust generation due to high weight.

Polyacrylamide (PAM) as a Dust Suppressant

PAM is a water soluble polymeric organic substance formed from acrylamide units ($CH_2CHCONH_2$) that dissolve, disperse or swell in water. The polymer is hydrophilic (displays an affinity for water) and can form aqueous solutions of very high concentration (Abdollahi & Gomes 2006). Usually, it has repeating units containing hydrophilic groups of the amide as in Fig. 2. PAM is most often used as a viscosifying agent (creating a thicker solution) (Woodrow et al. 2008). The main advantage of the application of PAM as a dust suppressant is because of its non-toxic nature as well as its biodegradability. Therefore, they find an extensive usage in industrial applications such as in drinking and industrial wastewater treatment, oil sand tailings treatment, improvements of soil stability, and enhanced oil recovery.

Table 1: Illustration of the particle size distribution of the dust sample used for the experiment.

Sieve size (mess)	Sieve size (mm)	Weight (g)	Weight (%)
b/t 10 to 12	2.04 to 1.68	125	25%
20	0.84	47	9.4%
35	0.5	22	4.4%
50	0.297	100	20%
100	0.14	73	14.6%
200	0.074	31	6.2%
Below 200	0.074	102	20.4%

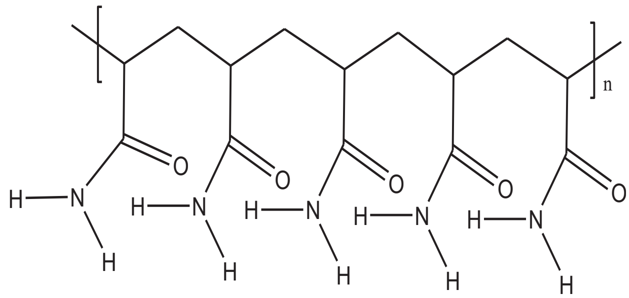

Fig. 2: **Chemical structure of polyacrylamide.**

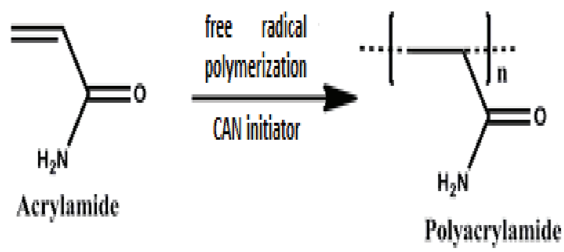

Fig. 3: Polymerization process of polyacrylamide.

Synthesis of PAM

PAM was synthesized by a free radical polymerization reaction mechanism in the laboratory. Free radical polymerization is a type of chain growth polymerization. It is a process of polymer synthesis in which polymer grows by sequential addition of the monomer units. Free radical propagates at double bond of monomer units by successive braking of monomer double bond (Fig. 3). Five g of the monomer was dissolved in 20 mL of distilled water in a conical flask. This solution was stirred for 20 min in the nitrogen atmosphere. 20 mg of ceric ammonium nitrate (CAN) was mixed with a solution as initiator and N_2 purging was done for the next 30 min at 50°C. It got viscous and left for cooling at room temperature. The reaction was terminated by adding 2 mL of a saturated solution of hydroquinone. The product was precipitated by using acetone as a non-solvent. The resultant polymer was broken into small pieces and then pulverized. It was dried into oven for 24 h at 70°C and preserved in a desiccator.

Characterization

Polyacrylamide was characterized by ^{1}H NMR spectroscopy, IR Spectroscopy and intrinsic viscosity measurements.

^{1}H NMR spectroscopy: ^{1}H NMR spectra of the polymers were recorded by FT-NMR spectrometer (Model JEOL AL 500) with sample solution in D_2O. Tetramethylsilane (TMS) was used as an internal reference.

IR Spectroscopy: Thermo Nicolet FT-IR spectrophotometer (Model JASCO FT-IR-5300) was used to record the IR spectra within the range of 4000-400 cm^{-1} by using solid state KBr pellet method.

Intrinsic viscosity measurements: Viscosity measurements of the aqueous solutions of polyacrylamide were carried out with the help of Ubbelohde viscometer (P/2741) at 25 ± 0.1°C. Intrinsic viscosity was determined from the point of intersection of two extrapolated (to zero concentration) plots i.e., inherent viscosity (η_{inh}) versus concentration (C) and reduced viscosity (η_{red}) versus concentration (C).

Methodology of the Experiment

A general experimental procedure was followed for testing the tested chemical dust suppressant at each considered dosages under fixed temperature and humidity. 20 g dried dust sample of below 2.04 mm (sieve mess size 10, ASTM standard) was taken for an experiment (ASTM-D6913/D6913M, 2017). The dust sample was weighed on the Petri dish before the dosage of a chemical suppressant was applied. After several trials, a depth of one cm was selected as the thickness of the dust sample on the Petri dish so that solution was equally distributed. The measured solution was applied through a plastic spray bottle. The sample was weighed along with the Petri dish after the application of 10 mL dosage before putting Petri dish into a temperature and humidity controller. 10 mL of solution was applied in a way to avoid under or over usage of the solution. The sample was then put in the temperature and humidity controller chamber. Efficiency of the chemical to retain water was studied up to 8 h. For this, at an interval of 1 h, the sample was weighed and again put in the temperature and humidity control chamber.

The experiment has been done with application of only water to compare the effectiveness of dust suppressant PAM in haul road. The same procedure was applied for knowing the % of moisture retention of water as a dust suppressant for every 1 h of duration up to 8 h. Each test was repeated 3 times to get average results.

RESULTS AND DISCUSSION

Size Distribution

A research has been done by Sinha & Banerjee (1997), on the haul road of Noamundi opencast iron ore mine, located at West Singhbhum, Jharkhand, where 60% of total suspended particulate matter was within the size range of 0 – 10 µm, remaining other 40% of SPM were size of 10 to 100 µm range. For the present experiment, haul road dust sample was screened by sieve size range of 2.04 mm to 74 µm. Particle size below 75 µm is known as silt. In this haul road dust sample, 20.4% of silt was present in total weight percentage. Emission of dust depends on the size of the road surface materials. The probability of dust emission from haul road increases as the percentage of silt increases (Kavouras et al. 2009).

^{1}H NMR spectroscopy: PAM was characterized by ^{1}H NMR spectroscopic study and the respective spectra are shown in Fig. 4. A broad peak observed at 2.07 ppm was attributed to the -CH protons present in acrylamide units and the peak observed at 1.51 ppm was because of the methylene protons present in polyacrylamide. The characteristic signals of N-H protons of amide groups present in polyacrylamide units were exchanged by deuterium present in D_2O and thus no corresponding peak was observed. Thus, the ^{1}H NMR spectroscopic data confirm the formation of polyacrylamide.

IR spectroscopy: Synthesized polyacrylamide was characterized by IR spectroscopy and its spectra are shown in Fig. 5. A broad band at 1660 cm^{-1} and 1613 cm^{-1} were due to the stretching vibrations of the >C=O group and

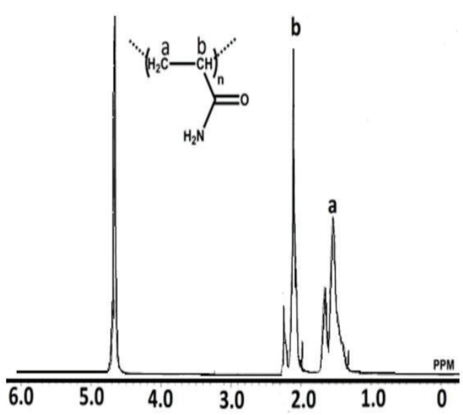

Fig. 4: ^{1}H NMR spectrum for PAM.

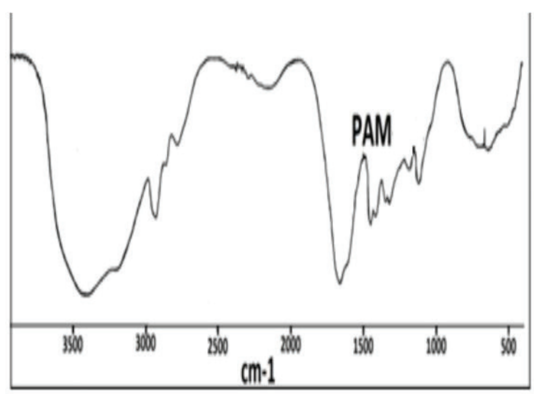

Fig. 5: IR spectrum of PAM.

bending vibration of NH_2 group respectively. Absorption bands at 1451 and 1419 cm^{-1} were due to the scissor and bending vibrations of CH_2 and CH-CO groups, respectively. Furthermore, the absorption band at 2930 cm^{-1} corresponded to the stretching vibrations of CH_2 groups. A broad absorption band at 3419 cm^{-1} was due to the absorption band of N-H group. Finally, the absorption bands at 1350 cm^{-1} region were due to the stretching vibrations of C-N group, while the broad absorption bands in the 600 to 700 cm^{-1} regions were due to out of plane bending vibration of NH_2 group.

Intrinsic viscosity measurement: Flow time of water (t_0) was measured 18 sec with the help of Ubbelohde viscometer. Flow time of PAM solution (t) at various concentrations were measured. Relative, specific, reduced and inherent viscosities were calculated and tabulated in Table 2. From Fig. 6, intrinsic viscosity was calculated and its value was 3.33 dL/g.

The Performance of Water as Dust Suppressant

Performance of water as a dust suppressant was studied at 35°C by varying the humidity level for evaporation of moisture. Low humidity of 40% RH and high humidity of 70% RH have been considered for this study.

Fig. 7 showed the percentage retention of moisture when 10 mL tap water was applied to the haul road sample at 35°C temperature, and 40% and 70% of RH at every 1 h duration respectively. After 1 h, the moisture retention capacity was 90.37 % and 88.30 % for 70% and 40% of RH respectively. However, moisture retention capacity was started to decrease with time continuously in both cases. The retention of moisture was 20.40% and 1.65% after 8 h. The rate of moisture retention was decreasing faster in case of 40% RH compared to 70% of it. As the relative humidity increases, because of the availability of more moisture in the air at the same temperature, the rate of evaporation of water from the surface of the dust sample will be slow. The vapour pressure of moisture is more when RH is 70% as compared to 40%. This helps to reduce evaporation of water from the surface of the haul road.

The Performance of PAM as Dust Suppressant

The % of moisture retention associated with each time interval was plotted corresponding to 40% and 70% of RH of PAM solution of 1000 ppm concentration applied to dust sample at 35°C temperature in Fig. 8. After 1 h inside chamber, the percentage of moisture retention was 92.27%

Table 2: Calculation of reduced and inherent viscosity of PAM.

Concentration (g/dL)	Flow time *t* (sec)	Relative viscosity ($\eta_r = t/t_0$)	Specific viscosity ($\eta_{sp} = \eta_r - 1$)	Reduced viscosity η_{sp}/C (dL/g)	Inherent viscosity [ln (ηr)/C] (dL/g)
1	271	15.06	14.06	14.06	2.71
0.5	87.2	4.84	3.84	7.69	3.16
0.25	44.5	2.47	1.47	5.89	3.62
0.125	27.3	1.52	0.52	4.13	3.33
0.0625	22.2	1.23	0.23	3.73	3.36

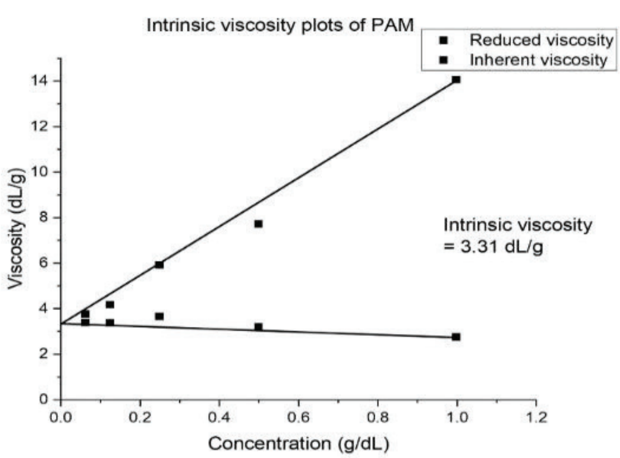

Fig. 6: Intrinsic viscosity plots of PAM.

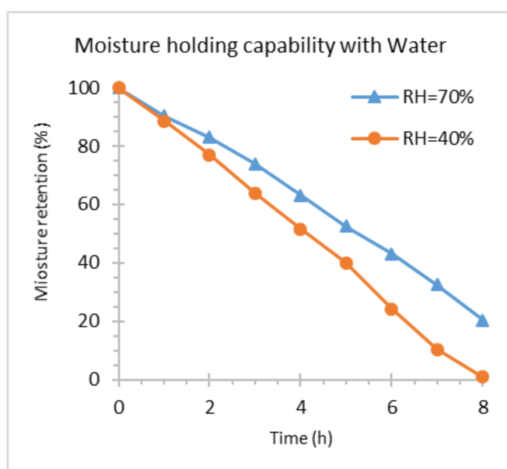

Fig. 7: Trend of moisture loss with duration of time by application of water in haul road dust.

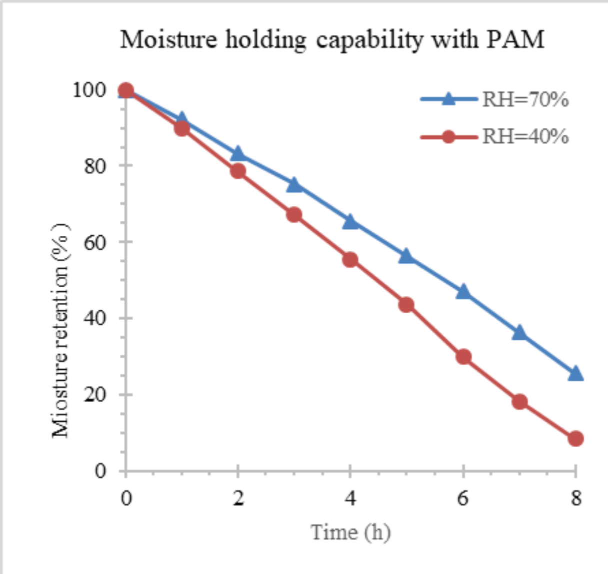

Fig. 8: Trend of moisture retention with duration of time by application of PAM in haul road dust.

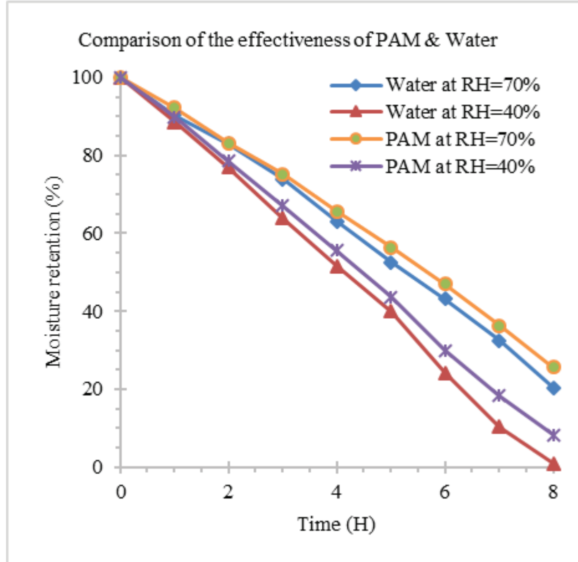

Fig. 9. Comparison of moisture retention with duration of time by application of water and PAM in haul road dust.

and 89.51% at 70% and 40% RH respectively. Fall of moisture present in the dust sample in 40% was at a higher rate than of 70% RH. After 8 h interval, moisture retention in the case of 70% RH was 25.65% which was higher than 7.14% at 40% RH. When RH was 70%, this shows that capacity of moisture holding in the haul road dust was high.

Comparing between the Effectiveness of Water and PAM

A comparative study of the effectiveness of water and PAM can easily be done by analysing Fig. 9. Initially, there is very less variation in moisture evaporation in both the cases. It has happened because a saturated amount of water molecules are present in each of the haul road dust sample. Gradually with an increase of time, the rate of evaporation in case of water spray sample is found to be higher as compared to the PAM spray sample. The deviation of moisture loss in case of 70% RH is lower than 40% RH due to the more amount of moisture present in the surrounding. The moisture retention in case of PAM treated sample is more compared to water treated sample. Every acrylamide group attach in the polyacrylamide chain have one amide group. Each amide molecules have the tendency to hold four molecules of water by hydrogen bond. Thus, water retention capability of PAM increases which facilitates better bonding between dust particles.

CONCLUSIONS

PAM has been synthesized by free radical polymerization process and confirmed through characterization by ^{1}H NMR, IR and intrinsic viscosity measurements. From sieve analysis, 20.4% silt was contented in the haul road. From results, the deviation of moisture loss in case of 70% RH is lower than of 40% RH due to the more amount of moisture present in the nearby surrounding. Also, amide group of PAM has abilities to hold the water molecules. Water molecules release slowly from PAM chain that helps to bind small particles with larger particles for a long period. Thus, PAM solution shows better efficiency than water to reduce dust emission by enhancing moisture carrying capacity of haul road of opencast coal mining. This led to the enhanced mine's productivity through improvement in visibility and health safety of miners.

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