Performance of Synthesized Novel Polymers in Preventing Moisture Evaporation from Coal Mine Haul Road Dust under Laboratory Condition

Thesis submitted in partial fulfillment

for the Award of Degree of

Doctor of Philosophy

By

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“Dedicated with devotion to my

Mataji & Pataji

for their love and everything they have done

behind my grooming”

CERTIFICATE

It is certified that the work contained in the thesis titled ***"Performance of Synthesized Novel Polymers in Preventing Moisture Evaporation from Coal Mine Haul Road Dust under Laboratory Condition"*** by ***"Vivek Kumar Kashi"*** has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

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I, ***"Vivek Kumar Kashi"***, certify that the work embodied in this thesis is my own bona fide work and carried out by me under the supervision of ***"Prof. N. C. Karmakar"*** and ***"Prof. S. Krishnamoorthi"*** from ***"December 2015" to "July 2021"***, at the ***"Department of Mining Engineering"***, Indian Institute of Technology (BHU), Varanasi. The matter embodied in this thesis has not been submitted for the award of any other degree/diploma. I declare that I have faithfully acknowledged and given credits to the research workers wherever their works have been cited in my work in this thesis. I further declare that I have not willfully copied any other's work, paragraphs, text, data, results, *etc.*, reported in journals, books, magazines, reports dissertations, theses, *etc.*, or available at websites and have not included them in this thesis and have not cited as my own work.

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It is certified that the above statement made by the student is correct to the best of my knowledge.

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(Vivek Kumar Kashi)

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LIST OF ABBREVIATIONS

Abbreviation	Full form
OCM	Opencast mine
UGM	Underground mine
CIL	Coal India Limited
MT	Million Tonne
SPM	Suspended particulate matter
TMS	Total particulate matter
PM	Particulate matter
PM_{10}	Particulate matter (aerodynamic diameter smaller than 10 μm)
$PM_{2.5}$	Particulate matter (aerodynamic diameter smaller than 2.5 μm)
DIF	Dust intensity factor
CAN	Ceric ammonium nitrate
FRP	Free radical polymerization
AM	Acrylamide
AP	Amylopectin
GG	Guargum
AMPS	2-Acrylamido-2-methylpropane sulfonic acid
PPM	Parts per million
TMS	Trimethylsilyl

EDX	Energy dispersive x-ray spectroscopy
ASTM	American Society for Testing and Materials
^{1}H NMR	Proton nuclear magnetic resonance
FTIR	Fourier Transform Infrared Spectroscopy
TGA	Thermogravimetric analysis
KBr	Potassium bromide
PAM	Polyacrylamide
H-PAM	Hydrolyzed Polyacrylamide
AP-g-PAM	Amylopectin-grafted-Polyacrylamide
H-AP-g-PAM	Hydrolyzed Amylopectin-grafted-Polyacrylamide
GG-g-PAM	Guargum-grafted-Polyacrylamide
H-GG-g-PAM	Hydrolyzed Guargum-grafted-Polyacrylamide
PAMPS-co-PAM	Poly(2-acrylamido-2-methyl-1-propanesulfonic) acid -co-Polyacrylamide
H-PAMPS-co-PAM	Hydrolyzed poly(2-acrylamido-2-methyl-1-propanesulfonic) acid -co-Polyacrylamide

Preface

There has been a gradual increasing trend of coal production using opencast mining technique since last two decades in India as well as around the globe. In India, share of opencast coal mines in 2018-19 has reached up to 93.8% (631 MT) of the total production, whereas only 6.2% (42 MT) is from underground mines. Various unit operations that take place in opencast mining are drilling, blasting, transportation of overburden/coal through haul road to the dump yard / stock yard / coal handling plant. Out of these operations, coal and overburden transportation through haul truck generates a huge quantity of dust which directly or indirectly leads to the air pollution. Research done by the United States Environmental Protection Agency (US EPA) found that 78–97% of total dust emission is contributed by the haul road transportation system. If such a tremendous amount of dust emission goes unabated, then it will blur the visibility of the operators and may lead to accidents. Main concern of dust emission is health related issues like pneumoconiosis, emphysema and bronchitis.

Thus, it is necessary to adopt sound mitigative measures against generation of haul road dust. However, so far, there is no well-defined method of reducing the haul road dust emission that can be widely adopted as an effective alternative to the conventional technique of water spraying i,e. sprinkling of water through mobile tanker over the haul road in a periodic manner.

Three major techniques, as alternatives to water application, are available to minimize the fugitive dust emissions from haul roads. They are: (i) improving the haul road surface material by paving, (ii) limiting vehicle speed and traffic density, and (iii) application of dust suppressing agents on the surface of haul road. Out of these, paving is cost prohibitive. And, limiting the traffic density and/or speed of vehicle would reduce the mine productivity. Surface treatments include control techniques that require application of chemical stabilization and dust suppressant in place of using only water.

Several published research reports have shown that different chemical dust suppressants, when applied upon mixing with water or without water, result in more effective dust control. Many chemical dust suppressants have been tried for controlling the haul road dust generation. But most of them are either hazardous to the environment or damaging to haul truck at varying degrees. It is thus expected that identification and implementation of a concrete dust control plan in haul roads would be a welcome contribution.

Application of water soluble polymers has wide prospect to control haul road dust emission. But no systematic study has been reported to reduce the haul road dust emission by enhancing the moisture retention efficiency through environment-friendly and biodegradable dust suppressing polymers.

In this study, a laboratory work was carried out to control the emission of fugitive dust of haul roads from opencast coal mine by application of eight different laboratory synthesized polymers as chemical dust suppressants – four are unhydrolyzed polymers, and rest four are their hydrolyzed products. The effectiveness of all the synthesized polymer solutions were tested experimentally on haul road dust samples for their moisture retention efficiency under three different atmospheric temperatures, namely 25 °C, 35 °C and 45 °C for a duration of 8 h and, was compared against tap water application without adding any chemicals. Using an empirical equation, dust emission rate has also been estimated.

Haul road dust sample was collected from an opencast coal mine in Dhanbad district of Jharkhand State, India. For conducting experiments, the sample was prepared by sieve analysis of mesh sizes 10, 12, 20, 35, 50, 100 and 200 of ASTM standard. The major elemental composition of haul road dust was identified by EDX spectroscopy. The polymers were synthesized in the laboratory by free radical polymerization reaction mechanism. The synthesized polymers are named as : (i) Polyacrylamide (PAM), (ii) Hydrolyzed Polyacrylamide (H-PAM), (iii) Amylopectin grafted Polyacrylamide (AP-g-PAM), (iv) Hydrolyzed Amylopectin grafted Polyacrylamide (H-AP-g-PAM), (v) Guargum grafted Polyacrylamide (GG-g-PAM), (vi) Hydrolyzed Guargum grafted Polyacrylamide (H-GG-g-PAM), (vii) Poly(2-acrylamido-2-methyl-1-propanesulfonic) acid-co-Polyacrylamide (PAMPS-co-PAM), and (viii) Hydrolyzed poly(2-acrylamido-2-methyl-1-propanesulfonic) acid-co-Polyacrylamide (H-PAMPS-co-PAM).

Characterization of the polymers was done by ^{1}H NMR spectroscopy, FTIR spectroscopy, Thermogravimetric analysis (TGA), intrinsic viscosity measurements, and neutralization equivalent (NE). ^{1}H NMR spectroscopy and FTIR spectroscopy help identifying whether polymerization, hydrolysis, grafting and co-polymerization have taken place or not. TGA helps to identify the thermal stability of the polymer. Measuring intrinsic viscosity helps to get an idea about the molecular weight of the synthesized polymer. Neutralization equivalent technique is useful to know the number of partial hydrolysis of hydrolyzed polymers.

The results for 25 °C shows that evaporation of moisture is slow. With the application of only water, 29.82% of moisture was retained by the dust sample after 8 h of exposure. For all the polymers, moisture retained by polymer added water was higher than water-alone system. Estimated dust emission rate was 6.49 mg m^{-1} s^{-1} for water-alone application after 8 h. Moisture retention efficiency was higher and, consequently dust emission was less for all the polymers. After 8 h, moisture retention by dust was the highest (52.69%) in case of H-PAM-co-PAM, and corresponding dust emission rate was 3.0 mg m^{-1} s^{-1}.

At 35 °C, moisture retained by water treated dust is 12.32% and estimated dust emission rate is 15.72 mg m^{-1} s^{-1} after 7 h of exposures. After 8 h, no more moisture was present in the water treated sample. Therefore, dust emission rate increased exponentially and could not be estimated. It was observed that the polymer solutions performed better than only water in respect of water holding capacity as well as emission rate. In case of H-PAM-co-PAM, after 7 h, moisture retained by dust was 40.3%, and dust emission rate was 4.48 mg m^{-1} s^{-1}.

At 45 °C, after 2 h, moisture retained by water treated dust was 15.82%, and after 3 h it was negligible. In case of water application, estimated dust emission rate is 12.46 mg m^{-1} s^{-1} after 2 h of exposure. All the polymer solutions performed better than only water application. In case of H-PAM-co-PAM (after 2 h), moisture retained by the dust was 51.26% and corresponding dust emission rate was 3.14 mg m^{-1} s^{-1}.

The polymer solution that can hold the highest level of moisture compared to only-water application for haul road dust sample, is said to be the best performing polymer. From the experimental results it is observed that H-PAMPS-co-PAM polymer is able to retain the highest level of moisture than other the polymers - for all temperatures under study. For the best performing polymer, naturally dust emission rate is minimum. At high temperature of 45 °C (after 2 h), application of H-PAMPS-co-PAM can retain 3.24 times moisture and reduce 3.97 times dust emission against water-alone system.

A PAMPS-co-PAM unit contains two amide groups and one sulfonic group. Due to this, its accumulating capability of water molecules increases. Amide group present in the PAM chain has affinity to make hydrogen bond with four molecules of water. On the other hand, amide group present in PAMPS chain, has capability for formation of three H bonds i.e. three molecules of water can attach with this functional group. Sulfonic group has also tendency to hold four molecules of water by making H bond. Thus, a single unit of PAMPS-co-PAM molecules can hold 11 molecules of water at a time. This will support PAMPS-co-PAM to hold more water molecules for longer duration as compared to other polymers under the study.

In addition, by hydrolyzation of polyacrylamide in presence of NaOH solution, the *carboxylate group* ($-COO^{-}Na^{+}$) is fixed in the end product. This $-COO^{-}Na^{+}$ group is *ionic in nature* and is responsible for high solubility of hydrolyzed PAM (in short, H-PAM) in water. This ionic terminals of H-PAM will hold the water molecules more strongly than the amide group in simple PAM.

With the application of the synthesized polymers, one can develop a sound dust control system, maintaining its efficacy for longer durations in comparison to water-alone system. A close look to the mechanism of water as a dust suppressant for haul road reveals that it binds dust particles by making bond between the particles in presence of moisture. If the duration of moisture retention on road surface can be enhanced, then generation of dust will automatically reduce. The approach for significant control of fugitive dust generation is thus through improving the moisture retention efficiency of the haul road surface using polymers. Therefore, it is a better option than the other available methods - not only due to its application and handling process are similar as water spraying system, but also from operational as well as maintenance point of view. Also, these polymers are water soluble, non-toxic and biodegradable, therefore, not harmful to the environment. Especially in the summer seasons, it would be possible to save water through application of the developed polymeric solution, since the number of water sprinkling per shift will be reduced.