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Design of Fogging Nozzles as Alternative Stock Pile Dust Suppression Medium at Gold Mining Sites

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Abstract: The aim of this study is to design fogging nozzles as alternative stock pile dust suppression medium at gold mining sites. Furthermore, this fogging medium helps to arrest the dust without getting the area wet and without any substantial expenditure. Emission of dust, which is one of the main contributors to the pollution of the environment, has been associated with mining industries for years, especially in the mining towns of Ghana and Liberia. The emission of dust takes place mainly around the haul roads, ore drilling, blasting and trafficking areas, crushers and, and especially, the stock pile unit. The intensity of the emissions of the dust is such that all the plants, objects, living things, gadgets, instruments and structures in the area are engulfed in the dust. Residents, who are hard hit by this phenomenon, backed by their traditional rulers often take the mining companies to task through legal or unlawful actions, which, many a time, become violent and confrontational. Sprinkling of water has been done to alleviate the situation but this process rather creates more problems in that, the area, especially roads, once wet becomes dry again, and the emission of dust gets intensified and aggravated.

Key words: Dust, environment, fogging, nozzles, pollution, stock pile

INTRODUCTION

Dust is referred to as solid particles which can be readily dispersed into the atmosphere.

Dust consists of very tiny dry particles of a substance such as sand or coal, either in the form of a deposit or a cloud. (Microsoft® Encarta®2007.©1993-2006 Microsoft Corporation). Dust is a general name for minute solid particles with diameters less than 500 μm. (www. wikipedia,thefreeencyclopaedia).

In any minerals processing environment, dust is generated when ore is shattered or broken. In a mine site almost all activities in mining - drilling, blasting, grinding, crushing, scraping, hauling of ore and traffic in the mine site - all produce or generate dust (Duncan and Levit, 1990).

Studies have shown that dust particle sizes ranges between 0.001 to 100 μm (Fig.1). Dust occurs in the atmosphere from various sources, such as soil dust lifted up by wind, volcanic eruptions, and pollution. Particles are present everywhere, but high concentrations and/or specific types of particles have been found to present a serious danger to human health.

Dust particles are basically formed from weathered rocks. They have different sizes, shapes and structural features. Formation and movements of these dust particulates depends on the brittleness, the hardness and the force applied in the breaking of the rocks (Stout, 1980). Dust emissions from stockpiles is due to:

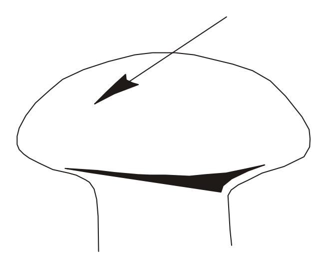

Fig. 1: A micron size dust particle on a pin head (www.osha.gov)

- The formation of stockpiles
- Wind erosion of already formed piles

During formation of stockpiles by conveyors, dust is generated by wind blowing across the stream of falling material and separating fine from coarse particles. Additional dust is generated when the material hits the stockpile. Wind erosion on the already formed piles also generates dust.

Research at mining sites has shown that fresh rocky/ hard rocks, when crushed, generate more dust than oxide

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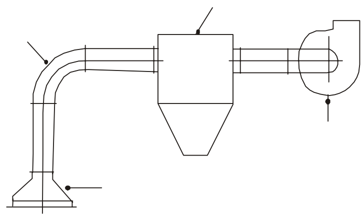

Fig. 2: Dust collection system (www.osha.gov)

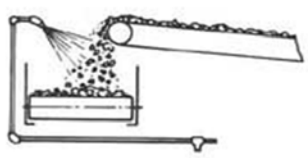

Fig. 3: Wet dust suppression system (www.osha.gov)

Fig. 4: Airborne dust capture through water sprays

or weathered rocks. Dust formation depends on other factors such as the weather condition and the time of the day (Gentry and O'Neil, 1992). To elaborate further:

- In rainy seasons there is little or no dust formation in the air
- During dry and hazy conditions, like the dry season, there is severe formation of dust in the air
- With low temperature and high humidity conditions in the night, dust formation is very small
- In windy and high temperature conditions the formation of dust is very high

All these and a few others which have not been stated, determine how dust is generated. Some of the characteristics of dust are:

- They are easily dispersed in a gaseous medium (air) and so they have a high surface area to volume ratio
- They are able to remain suspended in the atmospheric medium for a relatively long time. These are normally referred to as respirable dust

Dust particles in the air are basically classified into two (2) different types, namely (Stout, 1980):

- Nuisance
- Health hazard

Nuisance dust at a mine site is that which causes poor visibility and machine malfunctioning. Poor visibility can easily lead to accident, unsafe working environment, and, eventually slowdown productivity. Machine malfunction may lead to increase in maintenance cost or cost for new replacement which will eventually affect productivity. However, excessive concentrations of nuisance dust in the workplace may cause unpleasant deposits in eyes, cars, and nasal passages, and may cause injury to the skin or mucous membranes by chemical action.

Health hazardous dust particles are classified as respiratory dust and non-respiratory dust particles. The respiratory dust particles are less than 7 μm whiles the non-respiratory dust particles are greater than 7 μm. Some of the hazardous respiratory dusts are:

- Fibrogenic dust which is harmful to the lower respiratory system
- Carcinogenic dust which is harmful to the upper respiratory system
- Toxic dust which is poisonous to human body organs and tissues

Factors that contribute to dust harmfulness:

- The number of hours to which a person is exposed to dust particles in the air contributes to the extent to which dust related illness will affect him / her.
- The concentration of dust in the environment also contributes to its harmfulness.
- The particulate size of dust determines the number of hours for which the particles will remain suspended in the air, the manner in which it will settle down and the velocity of the ventilating air required to remove the dust from the environment.
- Chemical and mineralogical compositions of dust also contribute to its harmfulness on living organisms.

Dust control is the science of reducing dust emission by applying sound engineering principles (www.osha.gov). There are several existing methods of controlling dust but many are ineffective, costly and have detrimental effects on the plant (conveyor system) and machinery. Properly designed, maintained, and operated dust control systems can reduce dust emissions and, thus exposure of workers to dust Dust control systems can also reduce equipment wear, maintenance, and downtime; increase visibility and productivity (Sassos, 1985).

An effective system for the control of fugitive dust in industry should meet the following objectives and criteria. It must:

- Be efficient to meet health and safety requirements
- Be practical and simple in operation

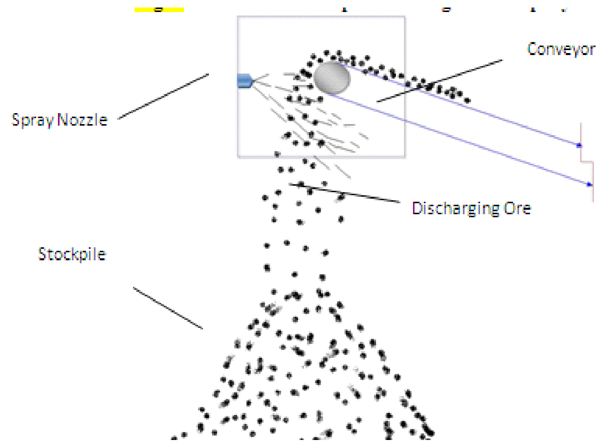

Fig. 5: Water spray system

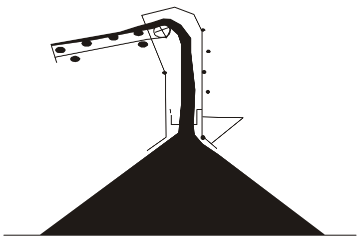

Fig. 6: Stone ladder (www.osha.gov)

Fig. 7: Telescopic chute (www.osha.gov)

- Have low initial cost
- Have low operating costs

Also, no adverse effects on product quality or plant (conveyor system) and machinery should be created.

There are several ways of controlling dust in the work place. One or more of the following techniques can be employed: dust collection systems, wet dust suppression systems, airborne dust capture through water sprays, dilution ventilation and isolation of workers.

Dust collection systems use industrial ventilation principles to capture airborne dust from the source (Fig.2). The captured dust is then transported to a dust collector, which cleans the dusty air (Tcho’rzewski, 2003).

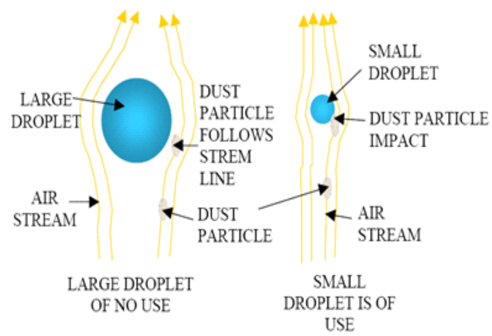

Fig. 8: Theory of dust suppression (Makarand and Joshi, year)

Wet dust suppression systems use liquids (usually water) to wet the material so that it has a lower tendency to generate dust. Keeping the material damp immobilizes the dust, and very little material becomes airborne.(Fig. 3)

This technique suppresses airborne dust by spraying fine droplets of water on the dust cloud. The water droplets and dust particles collide and form agglomerates. Once these agglomerates become too heavy to remain airborne, they settle down from the air stream (Fig. 4).

Dilution ventilation: This technique reduces the dust concentration in the area by diluting the contaminated air with uncontaminated fresh air. In general, dilution ventilation is not as satisfactory for health hazard control or dust collecting systems; however, it may be applied in circumstances where the operation or process prohibits other dust control measures (Tcho’rzewski, 2003).

Isolation: Isolation is another means to protect workers from exposure to harmful dust. In this technique, the worker is placed in an enclosed cab and supplied with fresh, clean, filtered air.

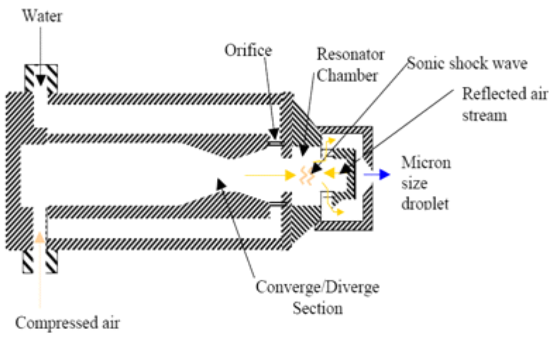

Fig. 9: Fogging nozzle (Makarand and Joshi,)

Stockpile dust control systems: The most commonly used stockpile dust suppression systems in the world are:

- Water spray system
- Screening system
  - Stone Ladder
  - Telescopic chutes
- Stacker conveyors
- Minimizing wind erosion

Water spray system: Regulated water is sprayed at the discharging ends of the stockpile conveyor. Water spray system is the most commonly used dust suppression system found in most of the mining companies in Ghana (Fig. 5).

Screening system:

Stone ladder: This consists of a section of vertical pipe into which stone is discharged from the conveyor (Fig. 6). At different levels, the pipe has square or rectangular openings through which the material flows to form the stockpile. In addition to reducing the height of free fall of material, stone ladders also provide protection against wind.

Telescopic chute: In this process, the material is discharged to a retractable chute. As the height of the stockpile increases or decreases, the chute is raised or lowered accordingly. Although some free fall of material from the end of the chute to the top of the stockpile occurs, proper design of the chute can keep the drop to a minimum (www.osha.gov) (Fig. 7).

The screening system is one of good ways of suppressing dust around the stockpile. But the only disadvantage is that not all conveyors can bear the weight of the chute.

Stacker conveyor: This operates on the same principle as telescopic chutes. The conveyor has an adjustable hinged boom that raises or lowers it according to the height of the stockpile.

Minimizing wind erosion: Minimizing wind erosion of the stockpile is done by:

- Locating stockpiles behind natural or manufactured windbreaks
- Locating the working area on the leeward side of the active piles
- Covering inactive piles with tarps or other inexpensive materials

Benefits of dust control:

- It reduces dust-related human respiratory health problems like asthma, bronchitis, emphysema, hay fever, and allergies
- It reduces vehicle accidents and human injuries due to poor visibility and road conditions
- It reduces impacts on vegetation, agricultural crops, and water quality due to dusting, turbidity, and sedimentation
- It reduces vehicle and equipment wear and damage due to mechanical abrasion, road impact, and intake of particles in operating equipment
- It reduces unpaved road maintenance costs by reducing frequency of grading, decreasing loss of fine-grained surface material, and lowering re-graveling costs
- It reduces liability for damage caused to property or people
- It improves property values and quality of life.
- It reduces complaints from employees and the public

Hence, the objective of this study is to design fogging nozzles as alternative stock pile dust suppression medium at gold mining sites Furthermore, this fogging medium helps to arrest the dust without getting the area wet and without any substantial expenditure.

MATERIALS AND METHODS

Consider a water droplet about to impinge on a dust particle, or what is aerodynamically equivalent, a dust particle about to impinge on a water droplet, as shown in the Fig. 8. If the droplet diameter is much greater than the dust particle, the dust particle simply follows the airstrip lines around the droplet, and little or no contact occurs. This study is conducted in a mining industry in Ghana and Liberia in 2010. If, the water droplet is of a size that is comparable to that of the dust particle, contact occurs as the dust particle tries to follow the streamlines. Thus the probability of impact increases as the size of the water spray droplets decreases.

The theory behind the fogging nozzle is based on research considering a water droplet from a spray that is about to impinge on a dust particle. The probability of impaction increases as the size of the water spray droplet decreases (Kingman and Rowson, 1998).

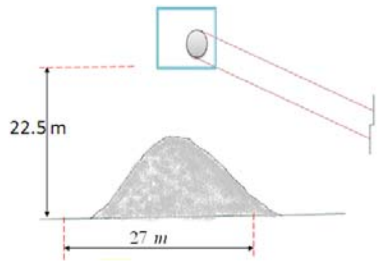

Fig. 10: Assumed dimensions of existing stockpile

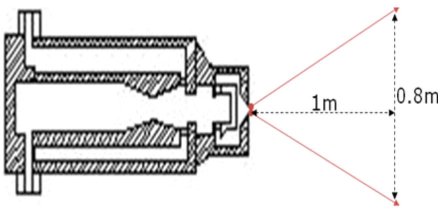

Fig. 11: Diameter of emitted fog to its distance

This explains why conventional hydraulic water sprays are not effective on respirable dust. With typical diameters of 200-600 microns the droplets are much larger than the particles of the dust they are attempting to suppress. The fogging nozzle generates droplets averaging 1-10 micron in size and is capable of suppressing sub-micron dust particles. In addition to this particle size theory, the results of additional research indicate there is another significant phenomenon that occurs when fog is used in dust suppression. The effect can be compared to an electrostatic precipitator in which dust particles are charged and then collected on plates of opposite charge. It was found that dust particles generally carry certain negative potential depending on the nature of the dust and the ambient conditions. Water droplets produced by the nozzles carry a charge that is strongly positive in relation to the dust particles. This proves that, the smaller the droplets, the more effective they are in knocking small dust particles out of the air. The result is that the probability of collision between a droplet and particle is greatly increased from the spatial probability, implying the need for fewer water droplets to ensure the desired efficiency.

RESULTS AND DISCUSSION

Working principles of the fogging nozzle: This system uses water and compressed air to produce micron - sized droplets that are able to suppress respirable dust without adding any detectable moisture to the process (Fig. 9).

The fogging nozzle takes the form of a whistle. The fogging nozzle is an air driven acoustic oscillator for fogging liquids by passing them through a field of high frequency sound waves. This is accomplished by compressing air upstream of a specially designed converge section of the fogging nozzle. To further enhance the fogging capabilities, a resonating chamber in the path of the air stream reflects the air stream back at itself to amplify and complement the primary shock wave. Once this standing shock wave is generated, water is delivered through annular orifices where it is first sheared into relatively small droplets (Kingman and Rowson, 1998). These small droplets are then carried by the primary air stream into the intense shock wave where the sound energy is converted into work by exploding the droplets into thousands of micron size droplets. After having done its work, the air then escapes around the resonating chamber and carries the droplets downstream in a soft, low velocity fog. The whole process is simplified in the next paragraph.

Compressed air is accelerated through a converge section and expands to a diverge section into a resonator chamber. This produces a powerful sonic shockwave. Water droplets delivered to this sonic area is shattered into droplets. Droplets produced by sonic atomization are small and relatively uniform in size, in the order of 1 micron, with a low mass and low forward velocity. The fogging nozzle produces a very dense fog of 1-10 micron size water droplets which literally blanket the dust source and keep the dust particles from becoming airborne (Miller, 2005).

Fogging nozzle parameters: For a higher efficiency, the fogging nozzle to be use has the following parameters:

- Fogging nozzle outlet diameter of 2.42 mm
- Speed of compressed air is mach 2.4
- Jet diameter after 1m is about 80 cm (with no back wind)
- Standard working air pressure above 110 psi (7 bar)
- Standard working water pressure is 103.1 kN/m^2 (1.031bar)
- Air consumption 2 cfm (55 L/h)
- Water consumption at atmospheric pressure is 1.6 gal/h (6 L/h)

Effectiveness of the fogging nozzle: Vertical height of the stockpile conveyor from the base of the stockpile is given as 75ft =22.5 m (Fig. 10). Diameter of stockpile is also given as 90 ft = 27.0 m. The Area (*A*) occupied by the base of the stockpile is given as:

$$A = \frac{\pi d^2}{4} = \frac{\pi \times 27.0^2}{4} = 572.79 m^2$$

where *d* is the diameter of the stockpile.

It has already been established that the ratio of the diameter of the diverging artificially created fog to its distance from the emitting source (nozzle) is 0.8 m: 1 m as depicted in the Fig. 11:

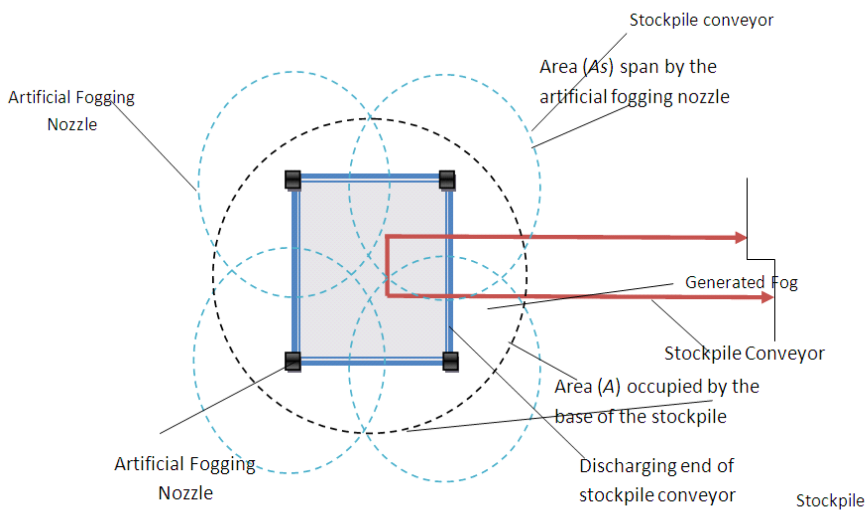

Fig. 12: Plan of proposed modification

Therefore, the diameter (D) of the diverging artificially created fog at the base of the stockpile which is at a distance, l = 75ft = 22.86 m from the fog source (nozzle) can be determined as:

$$D/l = 0.8/1 = 0.8$$
$$\Rightarrow D = 0.8\ L = 0.8\times 22.5 = 18.0\ m$$

Therefore, the Area (*As*) spanned by the artificial fogging nozzle at the base of the stockpile can be determined as:

$$As = \frac{\pi D^2}{4} = \frac{\pi \times 18.0^2}{4} = 254.57 m^2$$

Four nozzles will be used for the dust suppression. These nozzles will be placed at the four corners of the discharging end of the stockpile conveyor.

Therefore, the total area (*At*) span by the four nozzles will be approximately calculated as:

$$At \approx 4\times 254.54 = 1030.28\ m^2$$

The four nozzles positioned at different points at discharge end of the stockpile conveyor, will achieve four times as large as the area of dust suppression as will be achieved by one nozzle. It can clearly be seen from the calculations above that the total area, At, spanned by the artificial four fogging nozzles at the base of the stockpile is greater than the area A, occupied by the base of the stockpile, ie 1030.28 m^2 >572.79 m^2. This shows that the four artificial fogging nozzles will be very effective in absorbing/suppressing most of the dust generated at the stockpile.

Working pressure of the nozzle: The working pressure of the artificial fogging nozzle as derived by Makarand and Joshi is as follows:

- Air Pressure is at least 7 bar (700 kN/m^2)
- Water Pressure is at least 1.031bars (103.1 kN/m^2)

At various plant sections in mining companies where stockpiles are located, the compressed air used for instrumentation is normally at a pressure of 7.5 bar (750 kN/m^2). Comparing this pressure (7.5 bar) to the minimum working pressure of the fogging nozzle (7 bar), it can be agreed that when losses are considered in the piping system, then the compressed air for instrumentation can be used for the fogging nozzle.

The working pressure of the clean/drinkable water is slightly above 1.75 bar. This implies that the clean/drinkable water circulating through the plant can be connected to the artificial fogging nozzle.

Efficiency of fog formation: Factors affecting the efficiency of fog formation are Particle size, Particle solubility, Particle Charge, Air Temperature, Relative humidity, Air Pressure. The efficiency of fog dust capture will increase by increasing the probability of fog formation and respirable dust particle contact. It is increased by increasing the nozzle pressure.

Advantages of the artificial fogging nozzle:

- It is extremely reliable from a maintenance standpoint.

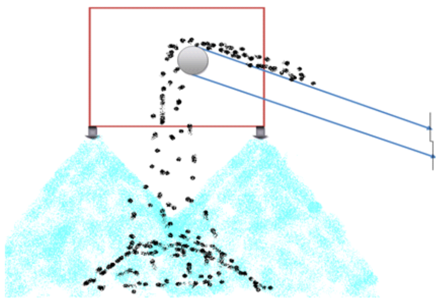

Fig. 13: Front view of proposed modification

- Since the artificial fogging nozzle does not rely on high pressure of the water to achieve maximum atomization, wear problems are virtually eliminated, as there is no need for high-pressure water pumps.
- The artificial fogging nozzle cleans itself while operating with high frequency sound waves.
- The nozzle has no moving parts and is constructed of 100 % stainless steel. This eliminates wear and corrosion and ensures years of maintenance free service even with poor water quality.

Observations: It is observed that if the existing dust suppression systems are employed at the dust generating areas of the mines and related companies:

- They will not be effective enough as to suppress or stop the emission of dust to the bearest minimum level.
- They can not be accommodated or incorporated in the structure of the stockpile conveyer system because of their weight and amorphous shapes.

CONCLUSION

The design of this artificial fogging nozzle will have obvious benefits regarding the control of respirable dust. Some of these benefits are that, there will be

- A reduction in health hazards
- A decrease in atmospheric pollution
- An improvement in working conditions of the workers
- Efficient operation of the equipment with minimum use of water which will not saturate the product or plant and equipment

For a new installation, most conveyor structures can accommodate. This makes the modification efficient and less expensive when compared with other types of Stockpile dust suppression system.

RECOMMENDATION

It is recommended that the active stockpile dust suppression system which is here by modified in this project by using artificial fogging nozzle should be adopted in the mine and the related companies to put an end to this menace of dust emission.

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