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Development of a dust minimization system for the coal wagon tippler section for a coal power plant

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Abstract

This work study looked at coming up with a dust minimization system for the coal wagon tippler section in the coal handling plant. The proposed design sought to reduce the spread of dust at the offloading point by at least 60% of the initially observed level. There had been high incidence of operators affected by black lung disease caused by the inhalation of airborne coal dust. The study developed an optimum design system which included a hood, duct, fan and a cyclone separator to separate solid dust particles from the air stream.

Key words

Coal handling, dust minimization, cyclone separator, coal dust

1. Introduction

Approximately 60% of total electrical power production in Zimbabwe is generated by coal fired thermal power plants. These facilities are equipped with corresponding large coal handling plants where the coal transported from the respective mines is stored and processed before it is sent to boiler and steam generation section (ACGIH 2004). During the offloading process of coal by the wagon tippler there is a large amount of dust that is released into the air. The dust adversely affects the operators working in the yard as well as flora and fauna in the neighbouring surroundings. It is against this background that an effective system needs to be put in place to mitigate coal dust at this point (Ankush 2011). The development of a coal dust collection system at the wagon tippling section would have a merit of decreasing the probability of dust explosion and fire outbreaks thereby protecting machinery and environment. The dust minimization system would as well eliminate health and safety hazards to workers such as irritation to eyes, ears, skin, nose and occupational respiratory diseases such as silicosis and coal workers' pneumoconiosis (BBE 2004). The same measure enhances the company image, in an effort to get ISO 14001 and ISO 18001 certifications by putting in place a system that seeks to protect employees and the environment.

2. Literature review

Dust is defined as small dry solid particles suspended in air for some time due to natural forces (Brown 2012). Dust formation is generated by working processes such as mining, drilling, grinding, crushing and material conveying. Dust particles vary in diameter from less than 1µm to at least 100µm, and they travel long distances before settling (Christopher 2003).

Table 1. Types of industrial dusts (Chen 2012)

TYPE OF DUST	EXAMPLES
mineral dusts	free crystalline silica, coal and cement dusts
metallic dusts	lead, cadmium, nickel, and beryllium dusts
other chemical dusts	many bulk chemicals and pesticides
organic and vegetable dusts	flour, wood, cotton and tea dusts, pollen
biohazards	viable particles, moulds and spores

2.1 Main dust size categories

Particles above 100µm: These are coarse particles which can be seen by a naked eye. They travel a long distance in air before settling down, and they fall to the ground due to gravitational forces. In still air, they settle to ground with increasing velocity. Typical examples are heavy industrial dusts such as coal dust and cement dust.

Particles between 0.1µm to 100µm: These particles are responsive to any electrical force and they can only settle down with constant velocity thus obeying Stroke's law. Their speed of travel depends on several factors such as density, size of particles and medium viscosity.

Particles between 0.01µm to 0.1µm: The particles are always in air, and they never settle down. This includes fine oil mist particles and metallurgical dust. These particles are too fine such that they cannot be seen by a naked eye.

2.2 Coal handling plant processes

In a thermal power plant, a coal handling plant entails the initial coal process operations such as unloading, storage, screening and filling into bunkers before the coal is send to the boiler for steam generation. If adequate measures are not taken, the coal handling plant can turn out to be a very dusty environment (Fox 2012). Enough care and regulatory measures have to be considered so as to improve the working conditions and safety of employees in the plant through developments of a dust minimisation system. The main coal handling plant processes include coal delivery, coal unloading, preparation, transfer and stacking (Jerry 2009).

2.3 Coal dust

Coal dust accumulates when small solid coal particles are suspended in air for some time before settling down. A wide range of particle sizes is produced during dust generation. Coal dust is produced during coal processing. The amount of coal dust produced is measured in microns. Coal dust particles ranges in diameter from 10µm to 75µm. Particles with small diameter takes a long time in air before settling down to the ground. In the coal handling plant, coal dust is generated through cola crushing and grinding; when coal is unloaded, transferred and stored; and movement of machinery in the plant (Josh 2012).

2.4 Dust minimization systems

The four dust minimisation systems used in controlling dust generated during coal handling processes are: dust collection, ultrasonic dust suppression, plain water dust suppression and chemical dust suppression. Dust collection system consists of five basic components. Exhaust hoods are used to capture dust from the dust generation source. A far fan system is used to create high suction pressure which is used to capture the dust into a hood. Dust collection system also consists of ducts which are used to transport dust from the hood to the air cleaning device. A motor is used to power the fan. A dust collection system requires sufficient power and ongoing maintenances for it to operate effectively. A typical centrifugal dust collector is given in Figure 1 below (Mbohwa 2002).

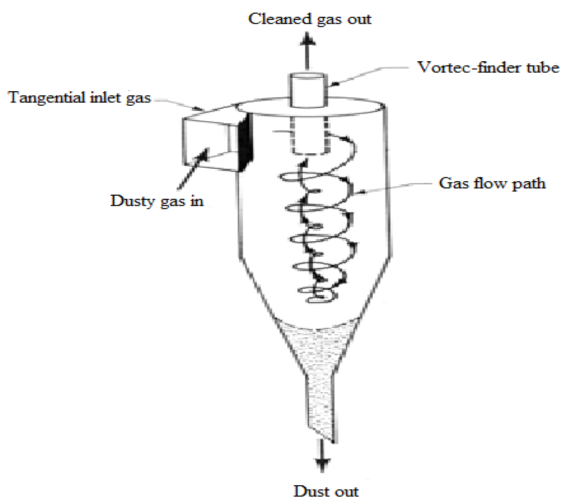


Figure 1. Centrifugal dust collector [9]

A centrifugal collector is a dust control mechanical device which is used to separate dust from fluids by means of centrifugal forces. The dust particles enter near the top cyclone in a tangential direction and at high velocity. As a result of the conical shape of the cyclone and the tangential entry of dust particles, the dust particles are forced to flow helically downwards in a vortex pattern. Inertia and centrifugal force will force the dust particles to move outwards towards the walls of the cyclone, and then descend downwards through the central pipe towards the discharge receiver. The cleaned air is forced out through the top of the cyclone. The most commonly designed cyclones are reverse flow cyclones (Raja 2006).

2.5 Fan selection

A fan operates by providing a pressure to move air against resistance caused by different fan system components such as blowers, ducts and electric motor. A rotating shaft is used to transmit energy to the fan and the fan transmits it into the air (Ramakrishma 2006). In the selection of fan size and fan type, air-flow and the outlet pressure required are the most important factors to be determined. The pressure drops across the bends, length, expansion and contraction in the ducting system are also required. Once the pressure drop and system flow requirements are obtained, the fan type and impeller type are decided on. The operation fan speed varies with the application. Fans operating at high speeds are more economical, more efficient and relatively cheaper (Chen 2012).

3. Methodology

Industrial visits were conducted at the case study coal handling plant to gather information on coal dust is produced during the handling processes. Consultations were conducted with the plant engineers and operators in the plant to appreciate the processes and current measures taken to suppress the dust. Taking into account the technical considerations the concept was generated to develop an effective dust minimisation system. Various system components were designed in detail through use of AutoCAD and solid works. Bill of quantities and economic evaluation of the proposed system were put in place assess the viability of the system.

4. Case study operation

4.1 Operation overview

The study was done on coal handling plant for Harare Power Station which is a coal fired thermal plant which falls the under the administration of Zimbabwe Electricity Supply Authority (ZESA). The station is currently equipped with nine steam boilers and six turbo generators. The plant uses washed peas coal to heat up the boilers. It has a production capacity of 50MW. The coal which is used at the plant is transported from the mine by means of rail transport. The plant is equipped with one wagon tippler for off loading the coal wagons into storage hoppers which have a maximum storage capacity of up to 500 000 tons. The major coal preparation processes which are carried out in the coal handling plant entail coal screening, weighing, feeding and sampling. Coal is transported by conveyor belts from the coal handling plant to the storage bunkers and finally to the steam boilers. The amount of dust concentration produced in the coal plant per annum is 280 $\mu g/m^3$ which is way above the expected maximum dust concentration limit of 100 $\mu g/m^3$ per annum according to Environment Management Agency (EMA). In the boiler plant, demineralised water is heated up into steam which would in turn drive the nine turbines. The water is heated to 420˚C and pressurised to 190 bars by means of pulverised coal which is burnt in the furnace to produce heat. The steam is then further heated by secondary super heaters into saturated steam.

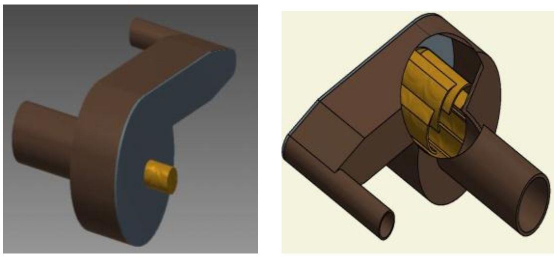
4.2 Dust minimization system development

The dust system design was based on the parameters in Table 2 below which were given as the summary of the findings on the case study coal handling plant.

Table 2. Summary of data collected

Coal dust particles diameter	10 – 75 µM
Height of free fall	0.5 m
Feed open area	300m³
Coal dust concentration per annum	280 µg/m³
Hours of unloading per day	12 hrs
Coal handled	10 000 tons per day
Shape of coal dust	circular
Temperature of coal dust	400 °C
Length of the wagon tippler	6 m
Height of the wagon tippler	2.5 m
Width of the wagon tippler	3.5 m
Speed of wagon during unloading	0.5 m/s

Using the above findings as the basis for technical specifications, the cyclone separator design in Figure 2 was selected based on the weighting evaluation on aspects of functionality, reliability, simplicity, efficiency, cost effectiveness, and ease of manufacture and maintenance.



Outside view *Cut away view*

Figure 2. Cyclone separator

The cyclone separator concept operation is based on simple components – which are the exhaust hood, duct, cyclone separator, fan and electric motor. The dusty air is sucked by high suction pressure produced by a fan and enters in the dust collection system through the hood. The air is then transported to the cyclone through the duct system. The centrifugal force created by the circular flow throws the dust particles toward the wall of the cyclone. After striking the wall, these particles are collected into the coal dust bins located below the cyclone separator. The exhaust hoods would capture the airborne respirable coal dust from the working environment. The duct then transports captured dust from a hood to a dust collector and to discharge clean air into the atmosphere. The cyclone separator – is the air cleaning device which is used to separate solid coal dust particles from the airstream. This system of dust minimisation works well for high loads of dust loads, with minimal capital and operational costs. It is simple to design and involves low maintenance cost.

4.3 Detailed design of components

The general assembly of the cyclone separator is shown in Figure 3 below.

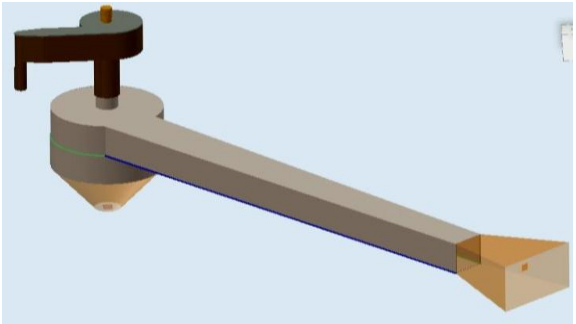


Figure 3. Cyclone separator assembly

Key consideration is the required rate of air flow through the hood. The location of the hood should not exceed 1.2m away from the dust generation source. Its size should exceed the cross section of flow entering the hood for effectiveness in dust capturing. A canopy hood with a flange opening is recommended so as to improve the effectiveness of the hood. Mild steel could be used for hood construction for non-corrosive dust emissions. Design parameters of a ducting system entail the volumetric flow of air as well as the required shape and size. Galvanised steel would be used for ductwork construction as it is both fire and corrosion resistant as well as strong and flexible. Circular ducts are chosen over rectangular ducts as they have lower costs, less leakage, lower energy loss, occupy lees space and can withstand high static pressures.

The basic components of a cyclone are the inlet duct, outlet duct, cylindrical section, conical section, upper outlet and lower outlet. Stairmand method is used to develop an efficient cyclone separator which has high through put. The cyclone separator is considered to be a thin vessel cylinder. Stainless steel would be used for the cyclone construction as it is easy to weld as well as resistant to rust and fire. Cyclones are subjected to both internal and external pressures during service. The design is made such that the cyclone would be capable to withstand the maximum pressure to which the cyclone would be subjected to in service, this is taken to be 5 – 10 % above the normal working pressure (40bars). Conical sections are used to lead the solid dust particles to the discharge opening. There is a gradual reduction in diameter from the cylindrical section to the conical section. The walls of the conical section (Figure 4) are essential in providing smooth flow of the solid particles as they fall due to gravity into a collection hopper.

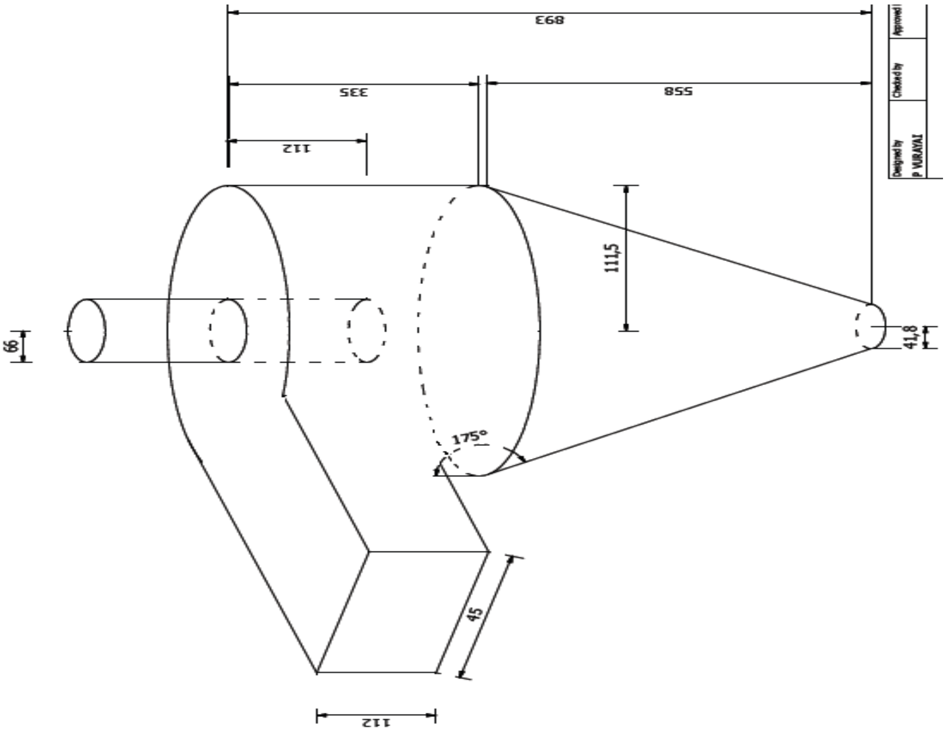


Figure 4. Coal dust separator configuration

The motor rotates the fan which delivers air to the system as it develops a pressure in the ductwork that causes the air to move through the system. A 19.5kW, AC single phase 220V, 50Hz servo motor is recommended for this application as it has high operational speed. It can also send back an error feedback signal to control the performance of the system.

Overall costs to be incurred would include equipment, material and field installation costs. Cost estimates also constituted a budget for the installation of the developed system. This was done by providing the price rates against each items and the grand total was calculated and the coal dust collection system cost is estimated to be $11 523.

5. Recommendations

The coal dust minimisation proposed for the coal handling plant should be complemented by other efforts such as spraying of water and reducing unnecessary handling of coal in getting the required peas coal. The hood should be adequately large enough to capture dust emitted during rail tippling, and minimise errant dust into the surroundings. The motor and fan housing should be sealed so as to keep them away from the coal dust, which would otherwise shorten their service life. The fan blades and housing should be regularly cleaned twice a week so as to avoid build-up of dust, which would otherwise interfere with fan operations. It is recommended that a daily cyclone operation checklist should be carried out to ensure high operational efficiency of the dust minimization system by taking early corrective action for any potential mechanical fault that may occur.

6. Conclusion

The centrifugal dust collection system was designed for the case study coal handling plant to eliminate potential health and safety hazards to workers such as occupational respiratory diseases. The work managed to size up the design components of the centrifugal dust collector, and the theoretical results obtained were satisfactory as they met the standard design requirements. The efficiency of the configured system was calculated and found to be around 65%. It could therefore be concluded that the firm could benefit if it implements the system as evidenced by the economic evaluation analysis which showed that the design option is feasible and viable in long term. This would also enhance the company's image, as the company was making efforts to become ISO 14001 and ISO 18001 certified, putting together this system which would protect employees and as well as the environment are basic requirements for the certifications.

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Biography

Ignatio Madanhire is a PhD student in Engineering Management at the University of Johannesburg, SA. He is also a lecturer with the Department of Mechanical Engineering at the University of Zimbabwe. He has research interests in engineering management and has published works on cleaner production in renowned journals.

Charles Mbohwa is a Professor of Sustainability Engineering and currently Vice Dean Postgraduate Studies, Research and Innovation with the University of Johannesburg, SA. He is a keen researcher with interest in logistics, supply chain management, life cycle assessment and sustainability, operations management, project management and engineering/manufacturing systems management. He is a professional member of Zimbabwe Institution of Engineers(ZIE) and a fellow of American Society of Mechanical Engineers(ASME).