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Dust Suppression and Collection Unit for Crusher Areas

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Abstract - This project examines the complex relationship between design and fabrication techniques intended to reduce dust emissions in crusher areas, which is essential for improving environmental stewardship and worker safety. It explores innovative methods to reduce airborne particulate matter through an interdisciplinary lens, combining cutting edge materials, engineering concepts, and automation technologies. Throughout the conceptualization stage, the discussion emphasizes the incorporation of efficient ventilation systems, enclosure designs, and particulate filtration mechanisms. It also clarifies the complexities of fabrication, focusing on material selection and precision engineering to guarantee efficiency and durability. In the end, the passage emphasizes the necessity of creative design paradigms in promoting long-term solutions for dust collection and suppression.

Key Words: Air-Borne Dust, Crusher areas, Dust suppression and collection

1. INTRODUCTION

When materials are handled, processed, or transported in industrial, construction, agricultural, or mining operations, dust generation is a common problem. When inhaled, airborne dust can contain dangerous particles like silica, asbestos, or other toxic substances. Strict regulations pertaining to airborne dust emissions are enforced by numerous regulatory agencies. Penalties such as fines and legal actions may follow noncompliance with these regulations. Industrial dust can negatively impact the surrounding ecosystem and neighboring communities. Air pollution, soil contamination, and other environmental problems may result from it. By penetrating moving parts and causing abrasion, dust can hasten the deterioration of machinery and equipment. Workers exposed to high levels of airborne dust may experience respiratory issues such as chronic bronchitis, silicosis, and other respiratory diseases. Excessive airborne dust not only creates an unhealthy working environment but also reduces visibility, accelerates equipment wear, and contributes to environmental pollution.

A Dust Collection Unit is designed to address these challenges by controlling dust at its source and capturing the remaining airborne particles. Dust suppression methods traditionally follow water spraying, misting, or the application of chemical agents to prevent dust from becoming airborne. Dust collection systems, on the other hand, use mechanical filters, cyclones, or extraction fans to remove particulates from the air. When the temperature increases, the previously suppressed dust tends to rise and mix back into the air, resulting in the generation of a significant amount of wastewater during the process.

The development of an efficient Dust Collection Unit is essential for industries seeking sustainable, safe, and cost-effective dust management. With growing awareness of occupational health and stricter environmental standards, such systems play a vital role in maintaining clean operations and protecting both workers and the surrounding environment.

2. Background

Crusher Machine

A crusher machine is a mechanical device used to reduce large rocks, stones, ores, or waste materials into smaller pieces for further processing at the crusher plants. It applies compressive force, impact force, or shear force to break materials into smaller sizes. The smaller sized rocks are then majorly used for construction and in the cement industry. Different sizes are used for different purposes such as stone aggregates for roads, cement raw material preparation and mining ore processing. Working principle starts with the raw material entering/ fed into hopper. The raw material then enters crushing chamber where the crushing force is applied (compression/impact). The reduced material exits through the discharge gap and the oversized material recirculates.

Types Of Dust

Crusher areas, or stone crushing plants, are typically located on the outskirts of cities, near quarries, or on major construction sites to process raw materials like stone and rock into aggregate.

I. Fugitive dust

Fugitive dust refers to particles that escape into the atmosphere during crushing, conveying, screening, and loading operations. It is not captured by any enclosure or collection system and spreads freely in the surrounding environment. This dust particles can be of various sizes.

II. Respirable dust

Respirable dust consists of very fine particles, typically less than 10 microns in diameter, that can penetrate deep into the lungs. Continuous exposure may cause serious respiratory diseases such as silicosis and chronic bronchitis.

II. PM10 and PM2.5

PM10 refers to particulate matter with an aerodynamic diameter of 10 micrometres or smaller. These particles can enter the upper respiratory tract and cause irritation and breathing discomfort. PM2.5 consists of extremely fine particles (2.5 micrometres or smaller). These particles are highly dangerous as they can penetrate deep into the lungs and enter the bloodstream, causing long-term health effects.

Sources of Dust in Crusher Plants

Dust generation happens mainly near the crusher at the hopper feeding point, primary crusher, conveyors, screening unit, truck loading zone and minorly at other points.
Dust is generated when raw materials are fed into the **hopper** due to impact and material displacement. During crushing**, material breakage** produces fine particles because of high compressive and impact forces. Dust is released at **belt transfer locations** due to material drop, vibration, and spillage. Significant dust generation occurs during **loading of aggregates into trucks** due to free fall and wind disturbance. **Vibratory screens** generate dust as fine particles pass through mesh openings and become airborne. Dust is produced when crushed material exits the crusher or conveyor and falls into storage bins or stockpiles.

Open-Space Vacuum System

The open-space vacuum system is a dry dust control method in which airborne dust particles are captured directly from open environments. It refers to specialized apparatus designed to create, maintain, and simulate the extremely low-pressure, airless conditions of outer space on Earth to create suction. And this can also be used as locations such as crusher discharge points, conveyor transfer areas, and loading zones using suction hoods connected to a vacuum source. The working principle is based on creating a negative pressure zone using a high-capacity blower or fan, which draws dust-laden air through ducts into a filtration unit such as a Baghouse Filter or Cyclone Separator. Inside the filter chamber, dust particles are separated from the air stream and collected in a hopper, while clean air is discharged into the atmosphere. The major advantages of this system include high efficiency in capturing fine particles (including respirable dust), no increase in material moisture content, suitability for dry climates, and better compliance with environmental norms. I In comparison with water spray systems, open-air vacuum systems provide more controlled and efficient dust removal without causing slurry formation or corrosion; however, they involve a higher initial cost and energy consumption, whereas water spray systems are simpler and cheaper but less effective for very fine particulate matter and may increase maintenance issues due to moisture.

Conveying Velocity

Conveying velocity is the minimum air velocity required inside a duct to transport dust particles without allowing them to settle. Sufficient conveying velocity is very important to pick up the dust from the pickup hoods and transport the material through the dust collector for separation from the air stream. If systems do not work properly & effectively convey the dust, then it's not possible to collect the dust particles, which are sticky, have high moisture content, are heavy or oddly shaped, or are very fine, and can present conveying difficulties in the dust collection system. This is important when considering a vacuum system, as a proper validation prevents dust settling inside ducts and ensures smooth material transport while also reducing the maintenance frequency.

Cyclone Separator

Cyclone separators, or simply cyclones, are separation devices (dry scrubbers) that use the principle of inertia and centrifugation to remove particulate matter from the provided gas intake, dust-borne air in this case. Cyclone separators is one of many air pollution control devices known as precleaners since they generally remove larger pieces of particulate matter. This prevents finer filtration methods from having to deal with large, more abrasive particles later on.

Working principle of a cyclone separator

A **cyclone separator** operates on the principle of centrifugal force and is commonly used for removing particulate matter from contaminated air streams. In this system, dirty flue gas is introduced tangentially into a cylindrical chamber, creating a high-velocity spiral vortex similar to a tornado.
The suspended particles are subject to centrifugal force as the gas rotates. Larger and heavier particles are driven downward toward the collection bin because they have more inertia and cannot follow the gas's tight spiral motion. To enable effective particle collection, the chamber is usually shaped like a cone. In the meantime, the cleaner, lighter air rises through the central vortex and leaves the separator through the top because it is less affected by centrifugal force.

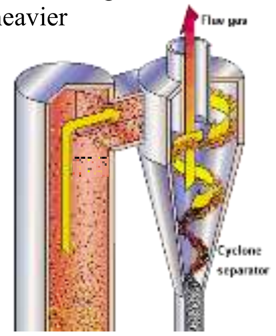

Fig 1. Cyclone Separator [8]

Centrifugal Blower

A centrifugal blower has three important parts, namely, fan, the volute casing and the inlet duct. When the fan rotates, it creates low pressure zone at the inlet, thus drawing in air from atmosphere. The air goes radially and is then circulated in the volute casing and comes out orthogonally. The primary factor is the volume of air that needs to be moved, measured in cubic feet per minute (CFM). Static pressure the resistance the airflow encounters as it moves through ductwork, filters, and collection devices, must also be evaluated. Additional variables such as ambient temperature, particle abrasiveness, humidity, and the physical characteristics of airborne substances affect proper fan or blower sizing. The blower or fan is a critical component that generates the suction necessary to draw dirty air into the ductwork and onward to the filtration and dust disposal sections. The two main types of industrial fans used in dust collection are centrifugal blowers featuring impellers enclosed within a housing and axial fans, which utilise propeller blades. Centrifugal blowers are favoured for high static pressure scenarios and general dust handling, while axial fans are used where high airflow at low pressure is appropriate. Correct selection ensures proper dust extraction, filtration efficiency, and safe operation in demanding plant or facility environments.

3. LITERATURE SURVEY

Crushing operations naturally generate dust due to material impact, air entrainment, and turbulence during processing. To control this dust, Local Exhaust Ventilation systems are widely recommended. These systems create a controlled negative pressure zone near the points where dust is produced by using suction hoods and ducting connected to a centralized vacuum or dust collection unit. According to MSW Stone Crushers [1], the efficiency of a vacuum-based dust control system depends on several factors such as hood placement, capture velocity, duct design, and airflow rate. When properly designed, LEV systems can significantly reduce airborne particulate concentrations compared to conventional water spray methods. Zaman Huiyan [2] discusses the limitations of water-based dust suppression systems. Although water spraying can reduce visible dust, it often leads to excessive water consumption, slurry formation, difficulties in material handling, and the re-entrainment of dust once the surface dries, especially at higher temperatures. In contrast, vacuum-based dry dust collection systems eliminate wastewater generation and reduce the chances of dust re-suspension. Studies show that sealed crusher cabins equipped with strategically positioned suction inlets can achieve dust removal efficiencies exceeding 90% for both coarse and fine particles. Pneumoconiosis is a general term for pulmonary fibrosis caused by prolonged inhalation of suspended dust, particularly respirable particles with aerodynamic diameters below 7.07 µm. Dust with an aerodynamic diameter of around 5 µm has a collection efficiency of about 50% [3]. Such conditions are commonly observed among coal miners and workers exposed to high dust concentrations. Research conducted by R. Sivacoumar [4] reported that the daily average ambient concentrations of total suspended particles (TSP) and PM10 near the dust source ranged from 342 to 2,470 µg/m³ and 90 to 1,200 µg/m³, respectively. In the surrounding ambient air, the average concentrations ranged from 86 to 257 µg/m³ for TSP and 39 to 138 µg/m³ for PM10. The average PM2.5 concentration near the source varied from 41 to 388 µg/m³, while ambient concentrations ranged between 17 and 48 µg/m³. Personal sampling conducted in the workplace environment showed TSP levels ranging from 22.5 to 80.5 mg/m³ and respirable particulate matter (RPM) levels between 13.5 and 53.7 mg/m³. Both ambient and occupational exposure levels were found to exceed Indian National Standards at most monitoring locations. Further studies [5] reported that particulate fractions PM2.5, PM10, PM15, and PM30 accounted for 14.3%, 36.6%, 45%, and 73.5% of total dust respectively. Settled particulate matter constituted approximately 45% of the total dust, with the highest proportion of particles (8%) occurring in the size range of 3–5 µm. The impact zone for measured concentrations ranged from 211 to 1350 m with an average distance of 784 m. In a cyclone separator, the radial velocity distribution within the central vortex core along the axisymmetric line is eccentric, meaning that one side exhibits positive velocity while the other side shows negative velocity. This results in the formation of a flow dipole near the cyclone axis due to the combined effects of flow sources and sinks. The dipole orientation tends to extend upward along the central axis of the cyclone. This behavior is mainly attributed to the vortex rotating with the flow around the cyclone's geometric axis, creating a pronounced helical flow structure. The interaction and compression of gas flow, represented by velocity vectors, can also cause instability within the cyclone. Additionally, a region exists just below the vortex finder where gas flows directly into the vortex finder instead of descending into the conical section and then moving upward [6]. Pham et al. [7] studied the effect of bell-mouth radius on the performance of centrifugal blowers and found that it has a moderate influence on airflow performance. A radius that is too small negatively affects the flow rate; therefore, the optimal bell-mouth radius ratio is approximately 9%. Design of Experiments (DoE), or experimental design, refers to the structured planning of experiments where variation is present, whether fully controlled by the experimenter or not. According to research [5], particle sizes measured using laser beam technology were compared with PM10 and PM2.5 concentrations obtained from samplers at the site. The results showed equivalence to aerodynamic particle size depending on particle density and shape. To prevent undercounting smaller particles, the collected dust samples were completely subjected to particle size analysis. The respirable particulate matter (PM10), defined as particles with aerodynamic diameters less than 10 µm, constituted 36.6% of the total dust, while fine inhalable particulate matter (PM2.5), defined as particles smaller than 2.5 µm, accounted for 14.3%. Another dust control technology is the **d**ry fog dust suppression system, which uses atomized water droplets to capture and suppress fine airborne dust particles, thereby preventing their dispersion into the surrounding environment [9]. Within a cyclone separator, the internal flow consists mainly of external vortices with downward gas movement and internal vortices with upward gas movement. In addition, several secondary flows affect cyclone performance, including recirculation flow in the annular space, short-circuit flow near the lower end of the vortex finder, and eccentric circumferential flow near the discharge outlet.[10]

4. BLOCK DIAGRAM

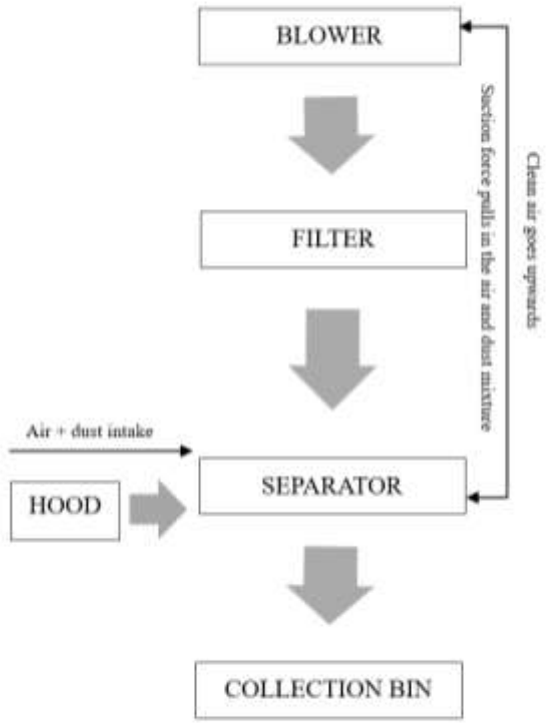

Fig 2. Illustrates the conceptualization of the dust collection unit only depicting the main components

5. THEORETICAL CALCULATIONS

Assumptions

1. The effective dust spread zone around the crusher machine is approximately 4 m³ (localized emission region).
2. The suction hood covers an equivalent capture face area of 4ft × 4ft.
3. The system is designed for continuous operation in a crusher environment generating medium to heavy dust.
4. Recommended capture velocity for crusher dust is taken as 200 feet per minute (fpm).
5. Overall system efficiency (fan + mechanical losses) is assumed to be 60%.
6. A typical inlet velocity range for high-efficiency cyclones handling crusher dust is 12-20 m/s. And hence let's assume an inlet velocity of $V_i = 15$ m/s

Area Volume Calculation

With the assumption of the dust spread area from the crusher machine being 4ft face area,
Area Volume = 4 ft × 4 ft × 4 ft = 64 cubic feet
Convert to m³ for standard engineering calcs:
64 ft³ ≈ 1.81 m³

Airflow Requirement

Let's use a capture velocity of ~200 fpm (feet per minute), good for dusty environments like crusher zones. Therefore,

$$Q = A \times V$$

Where, Q is the Airflow rate (CFM)
A = face area of hood = 4 ft × 4 ft = 16 ft²
V = Capture velocity = 200 fpm

→ Q = 16 ft² × 200 fpm = 3200 CFM

But this is a overkill for a 4 ft cube. We're actually sucking from a localized area, not the whole open volume like a room. For a more realistic requirement,
Target airflow: 400–600 CFM
This ensures air turnover ~6–10 times/min within that space and hence 500 CFM = ~850 m³/hr is selected.

Cyclone Sizing (Ballpark)

From previous calculation, Q = 850 m³/hr = 0.236 m³/s
Inlet Area Calculation,

$$Q = A_I \times V_i$$
$$A_i = \frac{Q}{V_i}$$
$$A_i = \frac{0.236}{15}$$
$$A_i = 0.0157 \text{ m}^2$$

For Stairmand high-efficiency cyclone, inlet dimensions are proportional to body diameter (D). Standard ratios are:

Inlet width (a) = 0.2D
Inlet height (b) = 0.5D
So inlet area:

$$A_i = a \times b$$
$$A_i = (0.2D)(0.5D)$$
$$A_i = 0.1D^2$$

Cyclone Diameter
Equating $A_i = 0.1D^2$,

$$0.1D^2 = 0.0157$$
$$D^2 = 0.157$$
$$D = \sqrt{0.157}$$
$$D = 0.396 \text{ m}$$
$$D \approx 400 \text{ mm}$$

Other Cyclone Dimensions (From Stairmand Ratios)

Once D is known, all other dimensions are derived proportionally.
Inlet width (a) = 0.2D = 0.08 m = 80 mm
Inlet height (b) = 0.5D = 0.20 m = 200 mm
Vortex finder diameter = 0.5D = 200 mm
Vortex finder length = 0.5D = 200 mm
Cone height ≈ 2D = 800 mm
Overall height ≈ 4D = 1600 mm
Suitable for medium- heavy crusher dust

Fan & Motor

To maintain 500 CFM through a cyclone:
Static pressure loss: ~1000–1500 Pa Required motor:
P = (Q × ΔP) / (η × 3600)
P = (850 × 1200) / (0.6 × 3600) ≈ 0.4 kW
So a 0.5 HP centrifugal fan (preferably backward-curved impeller) should be enough.

6. COMPONENTS

Component Name	Specifications / Material
Centrifugal Blower	0.5HP, 400-1500 CFM
Cyclone Separator	Ceramic lined
Inlet Hood	80 × 200 mm²
Collection Tray	Volume - 2 L
Dust Filter	-

Table 1. List of components

7. METHODOLOGY

This report focuses on innovative and cost-effective solution for some of the problems faced by the surrounding environment in a crusher area. Therefore, the objective of this project is to,
i) Collect and suppress the dust at crusher generation points
ii) To keep the machine parts safe from dust accumulation at joints and keep the repair costs under control
iii) Prevent respiratory diseases among workers.

Implementation of the proposed solution

Block diagram of the proposed solution is given at figure 1. First, the dust emission zone around the crusher is identified and approximated as a localized spread volume of 4 m³. A suction hood of size 4 ft × 4 ft is positioned strategically above the crusher discharge and feeding region to ensure maximum capture efficiency.

The hood is connected to a ducting system designed to maintain a conveying velocity of 15–20 m/s to prevent dust settlement. The duct transports contaminated air to a 400 mm diameter cyclone separator designed using Stairmand high-efficiency proportions.

The cyclone is mounted vertically with a sealed dust collection hopper at the bottom. A 0.5 HP centrifugal blower is installed downstream of the cyclone to create the required negative pressure (~1000 Pa). Cleaned air is discharged into the atmosphere at a safe height.

Proper sealing, clamp joints, and vibration isolators are provided to minimize leakage and mechanical stress. The system is designed as a modular unit for easy installation and maintenance.

Operation process of the project

The system operates on the principle of induced draft and centrifugal separation.

- When the blower is switched on, negative pressure is created inside the ducting system.
- Airborne dust particles generated during crushing are drawn into the suction hood.
- The contaminated air travels through the duct at the designed conveying velocity.
- The air enters the cyclone separator tangentially, generating a high-speed vortex.
- Due to centrifugal force, heavier dust particles move toward the cyclone wall and fall into the conical hopper.
- The cleaned air exits through the vortex finder at the top.
- Collected dust is periodically removed from the bottom hopper through a sealed discharge mechanism.

The system operates continuously during crusher operation and requires periodic inspection of seals, ducting, and hopper.

Results

A prototype model of the proposed open-air vacuum dust collection system was successfully fabricated and assembled to validate the theoretical design. The fabricated model was tested near a controlled dust-generating setup simulating crusher discharge condition. Upon operation of the blower unit, negative pressure was successfully established within the ducting line, and visible airborne dust was effectively drawn into the suction hood. The tangential entry of air into the cyclone created a stable vortex motion, enabling centrifugal separation of particulate matter.

Visual Assessment

Based on visual assessment and theoretical cyclone efficiency models:

- Approximate dust removal efficiency: 70–85% for medium and coarse particles (>10 microns).
- Effective control of fugitive dust near crusher discharge area.
- Improved localized air clarity within the 4 m³ dust spread zone.

Overall Outcome

The prototype testing confirms that the proposed open-air vacuum cyclone-based dust collection system is technically feasible, energy-efficient, and suitable for implementation in small to medium-scale crusher units. The results validate the theoretical design calculations and demonstrate effective dust suppression at the source.

Fig 3. Top view of the Dust Collection Unit

Fig 4. Left side view of the Dust Collection Unit

Fig 5. Right side view of the Dust Collection Unit

8. CONCLUSIONS

A dust collection system performs most effectively when integrated into a comprehensive air quality management strategy that includes multiple supporting control measures. As these systems are composed of various interconnected components that can differ significantly in design and function, they offer a high degree of flexibility for customization and future upgrades compared to many other types of industrial equipment.

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