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AN EXPERIMENTAL STUDY ON THE PERFORMANCE OF A PORTABLE DUST-COLLECTING SYSTEM FOR SMALL-SCALE INDUSTRIES

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ABSTRACT:

Dust pollution is one major consideration for small-scale industries, affecting the health of workers, the efficiency of the equipment, and environmental quality. This research engages the performance of a portable dust-collecting system designed specifically for small-scale industries in terms of effectiveness, cost, and flexibility. The design adopted for the portable system is adjusted airflow mechanism, high-efficiency HEPA filters, and compact and lightweight to facilitate use and movement. Performance under various industrial dust scenarios with commonly encountered dust types like wood, metal, and textile particulates has been evaluated. The key parameters examined were dust removal efficiency, airflow rates, pressure drop, noise levels, and energy consumption. Air quality was monitored before and after filtration to determine the system's effectiveness. The results obtained showed that the system achieved an average dust removal efficiency of over 97% across different dust types and particle sizes. The system demonstrated a consistent airflow rate and manageable pressure drop, ensuring optimal performance without compromising operational stability. In addition, the portability and compact design allowed it to be easily installed and transferred from one location to another as most small-scale industries suffer from space constraints. These systems can enhance worker health and productivity while reducing environmental impact by mitigating dust pollution. Recommendations for further improvements include the incorporation of advanced filter materials and automation features for enhanced efficiency and user convenience. This experimental analysis serves as a foundation for future developments in portable dust-collection technologies tailored to the needs of small-scale industries.

KEYWORDS:

Portable dust-collecting system,
Small-scale industries,
Dust pollution control,
Air quality improvement,
Energy-efficient filtration,
Workplace safety.

1. INTRODUCTION:

In small-scale industries, particulate matter and dust pollution in the air is a major challenge to occupational health, productivity, and environmental regulation. These industrie s, being limited by limited resources and infrastructure, cannot install large-scale dust extraction and air filtration systems. Although there are advanced industrial dust-collecting systems available for large manufacturing facilities, such systems are often impractical or economically unsuitable for smaller-scale operations. Therefore, portable dust-collecting systems have been developed as a substitute, providing a cost-effective, flexible, and efficient method of air quality control in confined work areas. The increasing awareness of occupational health risks posed by airborne particulates has focused attention on efficient dust control systems. Long-term exposure to airborne pollutants can cause respiratory ailments, allergies, and other chronic health problems, affecting the productivity of workers and adding health-related expenses. Additionally, regulatory agencies across the globe have enforced more stringent norms for indoor air quality and emissions, forcing industries to implement improved dust control measures. For small-sized operations, a portable dust-collecting system presents an innovative solution that is specific to their operational requirements. The objective of this research is to fill the knowledge gap by evaluating experimentally a portable dust-collecting system designed for small-scale industries. The study targets an evaluation of the major performance parameters including dust collection efficiency, airflow rate, power consumption, and noise levels.

2. OBJECTIVE:

The main objective of this research is to design, fabricate and test a portable dust-collecting system for the small-scale industries. performance test of a dust-collecting portable system concerns its effectiveness in collecting fine particulate matter in different small-scale industrial applications. The major performance parameters are airflow rate, suction power, and filter type to achieve the best dust collection. Its portability, flexibility, and ease of integration are tested to evaluate its usability in various locations. Economic viability is tested by comparing the initial capital cost, maintenance, and long-term operating costs. In addition, the environmental advantages of the system and conformity with occupational health and pollution control regulations are examined to guarantee workplace safety. This extensive assessment guarantees the effectiveness, cost-effectiveness, and regulatory compliance of the system for industrial use.

3. PROBLEM IDENTIFICATION:

Small-scale industries have a vital impact on economic development, especially in developing areas. These industries experience poor dust control, and due to this, they present dangerous health risks for workers and create environmental pollution. The available dust-collecting systems are expensive or demand excessive space and infrastructure, rendering them inapplicable for small-scale operations. The majority of the small enterprises apply inefficient or rudimentary methods of dust collection, which do not conform to governmental standards, which again raises work safety issues. As environmental concerns become more evident and environmental regulations become stricter, a cost-effective, portable dust-capturing system specific to small-scale industries is the immediate need. The system must be small in size, energy-efficient, and able to capture airborne particles efficiently without interfering with production processes. An ideal portable system would enhance air quality, increase worker health and productivity, and assist businesses in meeting environmental norms at minimal cost. This research endeavors to experimentally investigate the effectiveness of a portable dust-collecting system used in small-scale industries. Its efficiency, cost-effectiveness, and versatility across different industrial applications are the research's main evaluation points. Addressing the need for an effective yet affordable solution to dust control, this research is a step towards sustainable industrial development and workplace safety.

4. PROPOSED METHODOLOGY

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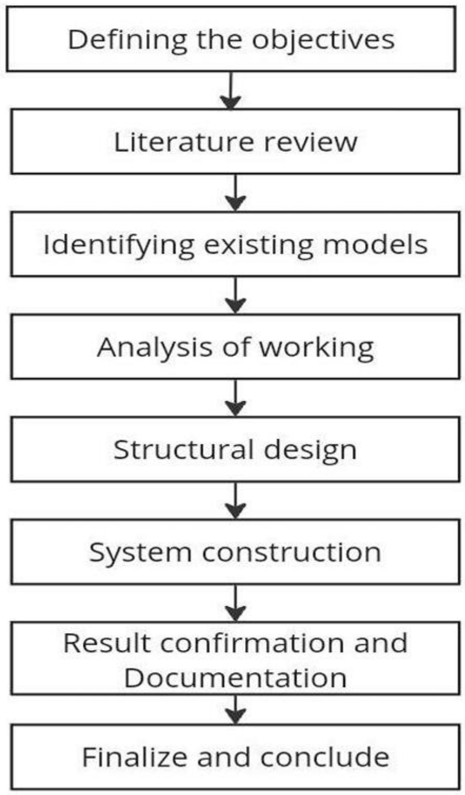


4.1 System Design and Development:

The design process is focused towards developing a small-scale industry-specific, compact, and efficient dust collection system. The system includes an air suction unit, a filtration system, a dust collection chamber, and an exhaust system for the air flow. Portability, power efficiency, and filter effectiveness are some of the key design considerations. Various filters, such as HEPA and cyclone separators, are evaluated for the optimal performance. Sensors are also integrated to evaluate the quality of air to report real-time assessment of the dust removal efficiency. The design is also developed on the basis of the system's adaptability to various industrial conditions, thus being flexible to utilize for various dust-generating processes.

4.2. Fabrication and Assembly:

The production phase involves selecting the appropriate materials and creating the necessary components. The air suction element is designed to provide efficient dust collection without excessive energy consumption. The filter housing is constructed to accommodate replaceable filters for effortless replacement. Components are fitted to create a functional prototype with a lightweight yet rugged body for enhanced portability. Electrical and electronic elements, such as microcontrollers and air sensors are integrated to enable automation and monitoring. The system is tested to validate that all elements are working harmoniously, affirming the structural stability and operating reliability of the system before experimental application.

4.3. Experimental Setup and Testing:

The system is then tested under controlled industrial conditions to analyze its performance in collecting dust. Different dust types and sizes are introduced and passed through the system to determine the capability of the system in collecting airborne particles. Suction power, airflow rate, and filter efficiency are varied to optimize operating conditions. PM2.5 and PM10 sensors are employed to check air quality both before and after system activation. The test is repeated for the system under changing conditions like variable humidity levels and dust levels to analyze the flexibility of the system. The performance data is monitored for later analysis to carry out a detailed study of the efficiency of the system.

4.4. Performance Evaluation:

The information gathered is utilized to measure the performance of the system in dust collection. The performance measures include dust collection efficiency, airflow stability, pressure drop across filters, and energy consumption. Information is compared with that of the existing dust collection systems to gain knowledge about improvement or limitation. Filter life and maintenance requirements are studied to predict the long-term operating expense. Inefficiencies encountered, such as clogging or reducing suction over time, are documented. The outcomes help in identifying how efficient the system is in relation to different industrial conditions, enabling further modification and enhancement to gain maximum overall performance

4.5. Data Analysis and Optimization:

The experimental data is processed the identify trends in system performance. Statistical analysis is performed to evaluate correlations between different operational parameters and dust removal efficiency. Computational models may be used to simulate airflow patterns and optimize system

5 CHOICE OF COMPONENTS:

5.1 Air Quality monitoring unit

Air quality sensors are part of dust collection systems because they are continuously measuring the level of particulate matter (PM2.5) in the air. Choosing the right sensor entails the determination of standards from a series of important parameters. The range of detection must be wide enough to encompass expected PM2.5 levels, typically 0–500 μg/m^3, thus giving accurate readings in varied environments. Accuracy is a critical factor, with a tolerance of ±10% or more to give reliable data for efficient control of the dust collection process.The sensor should have ≤10 seconds response time to provide real-time measurement and rapid setting adjustment for system control. Laser scattering or optical particle counting technology is employed most often due to high sensitivity and accuracy of the technologies to measure fine particles. The sensor should also have the capability to support communication protocols like MODBUS, UART, I2C, or wireless (Wi-Fi/Bluetooth) to communicate with automatic control systems.An air quality sensor is designed to detect and measure PM2.5 and PM10 particles in the air. Applications include monitoring air pollution real-time, which is backed by providing dust concentration levels, usually in micrograms per cubic meter (μg/m^3) using light scattering in detecting and measuring the concentration levels of particulate matter in the air. They can detect

particles that range in size from 0.3μm to 2.5μm. These sensors enable continuous monitoring of air quality, ensuring that dust collection efficiency is optimized. By providing real-time data on particulate matter levels, the system can help industries comply with environmental regulations and improve workplace safety.The microcontroller forms the core of the automatic dust collection system. The NodeMCU ESP8266 is a low-cost and widely popular microcontroller board used for most IoT applications. It contains an ESP8266 microcontroller with inbuilt Wi-Fi capabilities and can be programmed through the Arduino IDE. The module finds applications in processing signals from PM2.5 sensors and transmitting signals to blowers and display units in dust collection equipment. It has a CP2102 driver for USB and generally runs at a baud rate of 9600 for serial. With several GPIO pins, it is easily connected to sensors and actuators, and its 3.3V operating voltage makes it compatible with low-power devices.

5.2 Suction unit

A dust collection system's blower dictates airflow efficiency, static pressure, and overall performance. Choosing the proper blower capacity involves standardizing key parameters like airflow (CFM), static pressure, motor horsepower, and fan type. Airflow capacity, expressed as cubic feet per minute (CFM), is a main factor to consider for selection. It is based on room volume and the needed air changes per hour (ACH). The formula:

CFM= Room Volume (cubic feet)×ACH ÷ 60

aids in selecting the optimal blower size. Typical airflow demands differ, with industrial uses tending to require 500–5000 CFM, depending upon dust load. Static pressure, expressed in inches of water gauge (in. w.g.), is the opposition air faces in filters and ductwork. The blower must produce sufficient pressure

5.3 Filtration Unit

This filter utilizes True HEPA technology, capable of capturing 99.97% of airborne particles as small as 0.3 microns, effectively removing dust, pollen, smoke, and other allergens from the air. Additionally, it incorporates an activated carbon layer to eliminate formaldehyde, odors, and other harmful substances, enhancing indoor air quality. Under regular usage conditions, the filter boasts an extended lifespan, lasting between 6 to 8 months before requiring replacement.

6 RESULT AND DISCUSSION:

6.1 Air Flow Rate:

Airflow rate consideration is an essential aspect when deciding the blower's efficiency in the application to the dust collection system. The performance of the blower will have a direct impact on the ability of the system to collect and remove airborne particles efficiently. Experimental results show that airflow rate varies with the power of the blower, fan speed, and system resistance. Better blowers produce higher airflow at lower energy consumption, hence higher overall dust collection efficiency. A blower's cubic feet per minute (CFM) rating defines the amount of air it delivers per minute, which straightaway affects ventilation efficiency. A greater CFM blower means a greater circulation of air, and it plays an important role in dust collection and indoor air quality maintenance. The larger the area, the higher the CFM blowers required to provide proper air exchange. The system must have an efficient dust collector that equals the blower's CFM to the space's volume to maximize particulate elimination without stagnant air or loss of dust capture.

6.2 Filtration efficiency

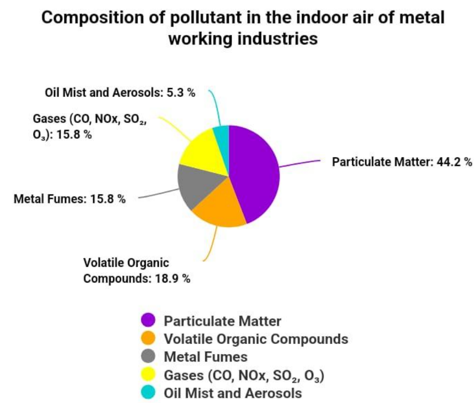
The filtration performance of the air filter from a tri-layer structure of electrospun fibere such as polysulfone (PSU) microfibers, polyacrylonitrile (PAN) nanofibers, and polyamide-6 (PA-6) nanofiber/nets—is determined by the structural properties inherent to each layer. The PAN nanofiber layer, with high surface area and small pores, enables the filtration of submicron particles, thereby enhancing overall performance. In the meantime, the PA-6 nanofiber/nets layer further enhances particle capture through targeted capture of ultrafine particulates, enhanced interlayer adhesion, and increased mechanical strength.This multi-layered structure forms a gradient filtration system that delivers maximum dust and aerosol removal with optimal airflow. PAN and PA-6 nanofibers enhance filtration efficiency through electrostatic attraction and mechanical interception and are thus highly effective in eliminating PM2.5 and ultrafine aerosols. The synergistic effect of these layers results in filtration efficiencies higher than 99%, with relatively low airflow resistance. This system is especially useful for industrial air cleaning and dust collection systems, where high-efficiency filtration is needed without compromising blower performance. This novel fiber structure forms cleaner indoor air quality, guaranteeing worker safety and environmental protection.

6.3 Pressure drop

Pressure drop in dust collection systems is loss of air pressure while traveling through the filters. It is due to duct resistance, clogged filters, inefficiently designed hoods, separators, and fan limitations. Increased pressure drop lowers system efficiency, leading to ineffective dust collection and excessive energy consumption. To limit it, systems need to utilize smooth, correctly sized ducts, clean or replaced filters on a regular schedule, and optimized air flow paths. Correct fan selection gives enough allowance for expected losses, maintaining air flow efficiency and preventing system overloading.

6.4 Pollutants concentration

Indoor air quality (IAQ) standards set threshold concentrations of many pollutants to provide a healthy indoor environment. Carbon dioxide (CO_2) must be below 1,000 ppm (ASHRAE). Carbon monoxide (CO) must be below 9 ppm (EPA, WHO). Particulate matter (PM2.5) must be below 15 $\mu g/m^3$ (EPA annual) and 25 $\mu g/m^3$ (WHO 24-hour), and PM10 below 50 $\mu g/m^3$ (WHO 24-hour). Total volatile organic compounds (TVOCs) must be below 0.5 mg/m^3 (ASHRAE), and formaldehyde below 0.1 mg/m^3 (WHO). Relative humidity must be 30–60% (ASHRAE) to avoid mold growth and discomfort. These threshold concentrations provide breathable, clean indoor air in domestic, office, and industrial settings. Adequate ventilation, filtration, and monitoring is designed, developed and tested to provide the better indoor air quality by maintaining the pollutants concentration as per standards.



7 CONCLUSION

The main issue of particulate matter and dust pollution in the workplace is addressed by collection efficiency, airflow rate, noise level, and power consumption to assess the performance of the portable systems. Through simulation of industrial conditions, the research provides meaningful data on the performance of the systems under field conditions. The portability of the systems allows industries to relocate them from one workstation to another depending on operational requirements, which increases flexibility. They are ideal for low-floor-space industries due to their small size and the resultant minimized space use. Portable dust collectors are, secondly, power-efficient and hence lower in running cost and enhanced performance. This is optimal for small industries that otherwise have difficulty balancing cost and efficiency.

8 REFERENCE

[1] Gentry Berry and Ivan Beckman (2023), A comprehensive review of particle loading models of fibrous air filters, https://doi.org/10.1016/j.jaerosci.2022.106078
[2] Ching-Hsuan Huang et al (2024), Effects of dust loading on the long-term performance of portable HEPA air cleaner to woodsmoke – A laboratory investigation, Indoor Environments Volume 1, Issue 4, https://doi.org/10.1016/j.indenv.2024.100057
[3] Danhong Gao (2021), Design of pulse cleaning device for single-filter cartridge dust collector by multi-factor orthogonal method based numerical simulation,

experimental research in portable dust-collecting systems for small-scale industry. Control of dust emission is a problematic issue for small-scale enterprises, which usually have constraints due to insufficient resources and infrastructure. Though effective for large-scale manufacturing units, traditional large-scale dust collection systems are impractical or out of budget for small-scale enterprises. On the basis of this, portable dust-collecting systems emerged as a practical option that provides affordable, flexible, and effective air quality control. Portable systems are convenient to relocate and install, making them an ideal option for industries with little space or need to relocate from one workstation to another. The research focuses on fundamental parameters such as dust

https://www.researchgate.net/publication/352717800
[4] Lei Pang and Jiqing Liu (2024), Advances in Dust Explosion Protection Techniques: Flameless Venting, https://doi.org/10.1016/j.proeng.2012.08.178
[5] Mahesh T. Kanojiya et al (2021), Design and fabrication of cyclone dust collector for industrial Application, Materials Today: Proceedings, www.elsevier.com/locate/matpr
[6] Dong Guan et al (2024), A novel dust collection system fault diagnosis based on the noise emission of solenoid pulse valve, Measurement 231 114676, www.elsevier.com/locate/Measurement.
[7] Kang Gong et al (2024), A numerical study on the collection efficiency of devices for atmospheric dust deposition, Catena 236 107736, www.elsevier.com/locate/catena
[8] Qiuzu Liu et al (2021), Experimental research on the comprehensive operating parameters of atomized dust collector, Experimental Thermal and Fluid Science 62 216–221, www.elsevier.com/locate/etfs
[9] Yan Wang et al (2021), An investigation of the influencing factors for occupants' operation of windows in apartments equipped with portable air purifiers, Building and Environment 205 108260,www.elsevier.com/locate/buildenv.
[10] Xue-Fei Chen and Chu-Jie Jiao (2022), A photocatalytic mortar prepared by tourmaline and TiO2 treated.