Metal Dust Extraction and AQI Monitoring with IoT

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Abstract : The steel manufacturing process releases large quantities of dust and fine particles at multiple stages during raw material handling, sintering and blast furnace activities. Steel dust exposure poses significant health risks for workers with increased risk of respiratory diseases. The commonly experienced symptoms are cough, mucus production, and shortness of breath. These problems can escalate with prolonged exposure and inadequate use of protective equipment. For controlling the airborne pollutants, the metal dust extractions system plays a pivotal role in the manufacturing processes. In this paper, a metal dust extraction system is designed to capture, filter and remove hazardous dust and particulates generated during metalworking operations such as grinding, cutting, welding and machining. This system consist of capture hoods, ducting, high-efficiency filters and exhaust components to return clean air to the workspace or environment. An IoT based AQI monitoring is also incorporated to provide the monitoring of air quality and ensure clean air at the exhaust and assist the corrective action.

***Index Terms* - Pollution, Metal Dust Extraction, Air Quality Index, Filters**

INTRODUCTION

Metal processing industries worldwide are major contributors to environmental pollution, significantly affecting air, water, and soil quality [1]. Facilities involved in smelting and processing metals release substantial amounts of airborne contaminants, such as sulfur dioxide, nitrogen oxides, volatile organic compounds, carbon monoxide, particulate matter, and hazardous heavy metals into the atmosphere [2]. These emissions play a crucial role in forming atmospheric smog, fostering acid rain, increasing respiratory health problems, and driving global greenhouse gas emissions. For example, steel and aluminium manufacturing combined account for over 10% of the world's total CO_2 emissions [3]. The industry demands large volumes of water for cooling and washing purposes. Inadequately treated wastewater can introduce toxic heavy metals and chemicals into natural water bodies, endangering aquatic life and causing bioaccumulation within the food chain, which poses risks to both wildlife and humans [4]. The processes of extracting metals and processing ores also generate hazardous waste and tailings that, if not properly managed, can leach into soils and surface waters, resulting in persistent and widespread environmental harm [5].

Metal dust extraction systems are specialized solutions designed to capture, filter, and eliminate airborne metal particles produced during industrial activities such as grinding, cutting, welding, milling, and CNC machining. These systems are essential for maintaining safe and healthy work environments in metalworking, manufacturing, and fabrication sectors by preventing the buildup of hazardous fine metal dust that can compromise worker health, damage machinery, and degrade indoor air quality. The design and selection of these extraction systems depend on factors including the type and size of dust particles, specific industry demands, and regulatory standards. The primary categories include dry dust collectors, wet dust collectors, and electrostatic precipitators, each offering distinct benefits and limitations suited to various operational needs [6].

Dry dust extraction systems, such as cartridge collectors, bag house filters, and cyclone separators, are widely used in metal processing industries due to their efficiency in capturing fine particulate matter. Cartridge and bag house filters utilize fabric or synthetic media to trap dust particles, offering high filtration efficiency often above 95%. Cyclone separators use centrifugal force to remove larger dust particles and are typically employed as pre-cleaners to prolong the lifespan of filter media. These systems are favoured for their low water usage and ability to handle large dust volumes but require regular maintenance to prevent clogging and ensure pressure drop does not compromise airflow [7].

Wet dust extraction systems use water or liquid sprays to capture dust particles from air streams, forming dust-laden droplets that are then removed from the air. These are particularly effective for handling combustible or sticky metal dusts that might clump or create fire hazards in dry systems. Wet scrubbers, for example, can remove both dust and soluble gases, making them versatile for certain industrial environments. However, wet systems generate contaminated wastewater requiring treatment and disposal, and their use may be limited in cold climates due to freezing risks [8].

Electrostatic precipitators (ESPs) operate by charging dust particles electrically and then collecting them on oppositely charged plates. ESPs are highly effective for submicron-sized particles and can operate continuously with minimal pressure drop, making them energy-efficient. They are common in large-scale operations where air volumes are massive. However, ESPs possess high capital costs, require skilled maintenance, and are less effective with sticky or damp dusts [9].

Selection among these dust extraction systems depends on numerous factors, including dust composition and particle size distribution, facility air volume, environmental regulations, operational costs, and maintenance capabilities. Emerging innovations focus on hybrid systems combining dry and wet technologies, integration of smart sensors for real-time performance monitoring, and development of higher-efficiency, longer-lasting filter media to minimize maintenance and environmental impact [10]. Typical extraction setups include targeted ducting, specially designed container and filtration modules of cartridge filter and HEPA grade fiberglass filters to effectively capture and contain dust at its source before it disperses to the atmosphere [11, 12].

To make the metal dust extraction system efficient and cost effective, this paper discusses implementation of metal dust extraction system with IoT based AQI monitoring. The cartridge filter and HEPA filter are included for extracting micro particles of metal dust. The AQI monitoring system assists for corrective and maintenance actions.

RESEARCH METHODOLOGY

A. Metal Dust Extraction System Hardware Model

The figure 1 shows the block diagram of a metal dust extraction system integrated with an IoT-based AQI monitoring. In this setup, metal dust generated from the metal processing source enters the system and first strikes the baffle plate designed to direct airflow and precipitate larger particulate matter. Baffle plates disrupt and redirect airflow, forcing heavier metal dust particles to lose momentum. As the air changes direction abruptly, the denser particles collide with the plate and fall into a collection basket, separating them from the air stream before reaching filters. The resultant dust-laden air is then drawn into a dust and air cleaning chamber constructed with a cartridge filter to effectively capture fine dust particles and ensuring high filtration efficiency. Cartridge filters are combined with the fiberglass material for ensuring compliance with workplace safety standards set by National Ambient Air Quality Standards (NAAQS) and pollution control board. The larger collected dust particles settle into a dedicated dust collection basket through a unidirectional valve, which prevents re-entry of dust into the clean airflow. Cleaned air subsequently passes through an air cleaning filter constructed with fiberglass and cotton. The filtered air is then released to the atmosphere. The temperature and air quality sensor are positioned near the air outlet. These sensors continuously monitors both ambient temperature and particulate concentrations, enabling real-time AQI measurement.

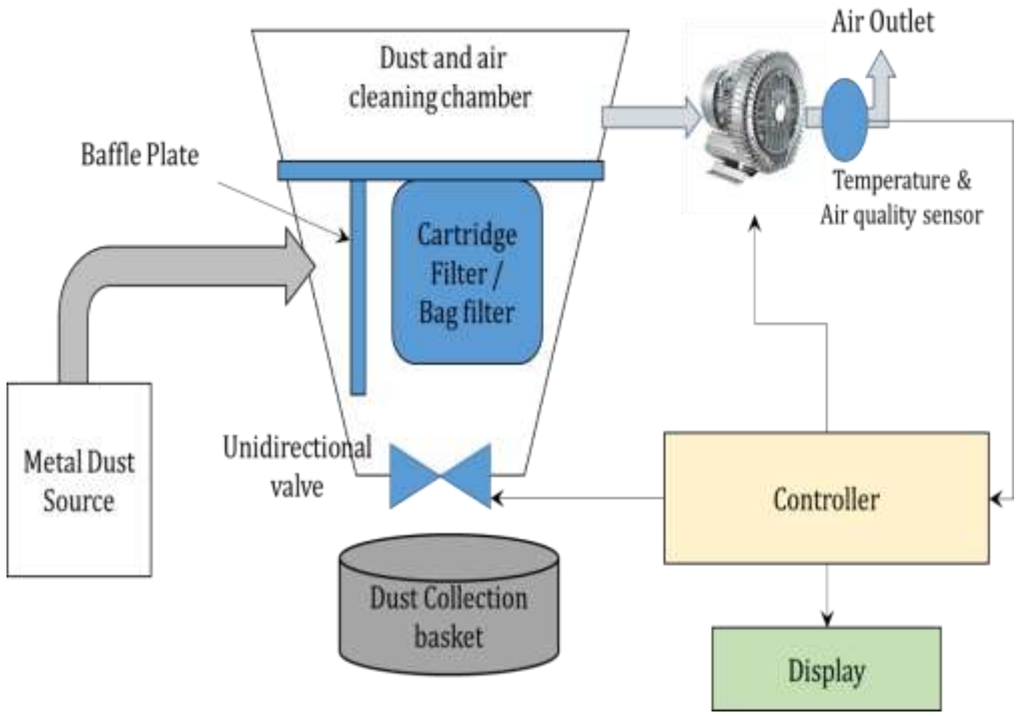

Figure 1: block diagram of Metal dust extraction with AQI monitoring

Table 1: Specifications of the experimental model

Container Volume	30 Litre
Compressor	ELGI Make 230V, 1000W, 1400RPM 20kPa
Filters	Cartridge filter – Polypropylene pleated type HEPA Filter – fiberglass air filter
Baffle plate	Stainless steel 100mm X 100mm X 2mm
Dust collector	Cotton bags
AQI sensors	MQ7 – Carbon monoxide MQ2 – Smoke, CO2 PM – PMS5007 Thermocouple K-type – temperature
IoT Interface	Thing Speak https://thingspeak.mathworks.com/channels/3104790
Controllers	ATMega 328 and ESP8266

The system's intelligent controller receives and processes sensor data, facilitating the continuous assessment of environmental quality within the workspace. The processed AQI data is visualized on a connected display, providing immediate feedback to operators and ensuring compliance with occupational health standards. Through its IoT connectivity, sensor readings are remotely accessed, logged, or used for predictive maintenance with. The data logging is achieved with Thing Speak cloud platform. The integration of a high-efficiency filter, real-time monitoring and IoT-based data monitoring ensures that this dust extraction framework not only minimizes the occupational exposure to hazardous metal particulates but also aligns with requirements for safety, automation and process transparency in industrial environments.

B. AQI Monitoring with IoT

Air quality index (AQI) is a dimensionless number that reflects the overall air quality at a particular location and time. It is used to communicate the air quality to the public in a simple and easy-to-understand manner [13]. Higher AQI values indicate higher levels of air pollution and greater potential health risks. AQI is usually reported on a scale of 0 to 500, with higher values indicating worse air quality [14]. The exact ranges and health effects associated with different AQI values can vary depending on the country or region. According to the Indian Government (CPCB), Indian AQI range is from 0-500, from 0 being good and 500 being severe. There are eight major pollutants to be taken into account for AQI calculation, viz. particulate matter (PM 10 and PM 2.5), carbon monoxide (CO), ozone (O3), nitrogen dioxide (NO2), sulphur dioxide (SO2), ammonia (NH3), and lead (Pb). To calculate AQI, data for a minimum of three pollutants must be present, of which one should be either PM10 or PM2.5 [15, 16]. The calculation of AQI is done with equation (1).

$$I_p = \left[\frac{I_{Hi} - I_{Lo}}{BP_{Hi} - BP_{Lo}}\right](C_p - BP_{Lo}) + I_{Lo} \qquad \textbf{... (1)}$$

Where,
I_p = index of pollutant
C_p = Concentration of pollutant
BP_{Hi} = Higher concentration breakpoint
BP_{Lo} = Lower concentration breakpoint
I_{Hi} = AQI value corresponding to BPHi
I_{Lo} = AQI value corresponding to BPLo

AQI ranging from 0-500 has different concentrations for each pollutant and has health effects accordingly. AQI in the range 0 – 50 defines air quality as good as it shows minimal or no impact on health. AQI in the range 51-100 is a satisfactory air quality range and it can show effects such as breathing difficulty in sensitive groups. The 101-200 AQI range shows moderate air quality with impacts such as breathing discomfort for children and elderly people, and people already suffering from lung disorders and heart disease. AQI in range 201-300 communicates that the air quality is poor and shows health effects on people when exposed for the long term. People already suffering from heart diseases can experience discomfort from short exposure. The very poor category AQI fall in 301-400 range causes respiratory illness for a longer duration of exposure. The severe range 401-500+ of AQI causes health impacts to normal and diseased people. It also causes severe health impacts on sensitive groups [17, 18].

RESULTS AND DISCUSSION

The experimental model of the metal dust extraction system is shown in figure 2. The specifications of the hardware model are mentioned in table 1. The experimental model is tested in two scenarios. At first the air quality is tested at the input side of the metal dust extraction system which gives indication of air pollution that could have been caused by disposing the metal dust effluent directly to the atmosphere. The values of temperature, carbon monoxide, sulphur dioxide, smoke and particulate matter are recorded in the table 2 in both scenarios. The evaluation of air quality index is carried out with formula of equation (1) and the air quality index at the input side of the metal dust extraction system is observed to be 157.45. For calculation of the air quality index, values of particulate matter, carbon monoxide and sulphur dioxide are considered.

Table 2: AQI Sensors observations

Parameters	Before filtration	After Filtration
Temperature	49	43
Particulate Matter	128	28
Carbon Monoxide	34	18
Carbon Dioxide	28	19
Sulphur Dioxide	14	9
AQI	157.45	68.58

Figure 2: Photograph of the experimental setup

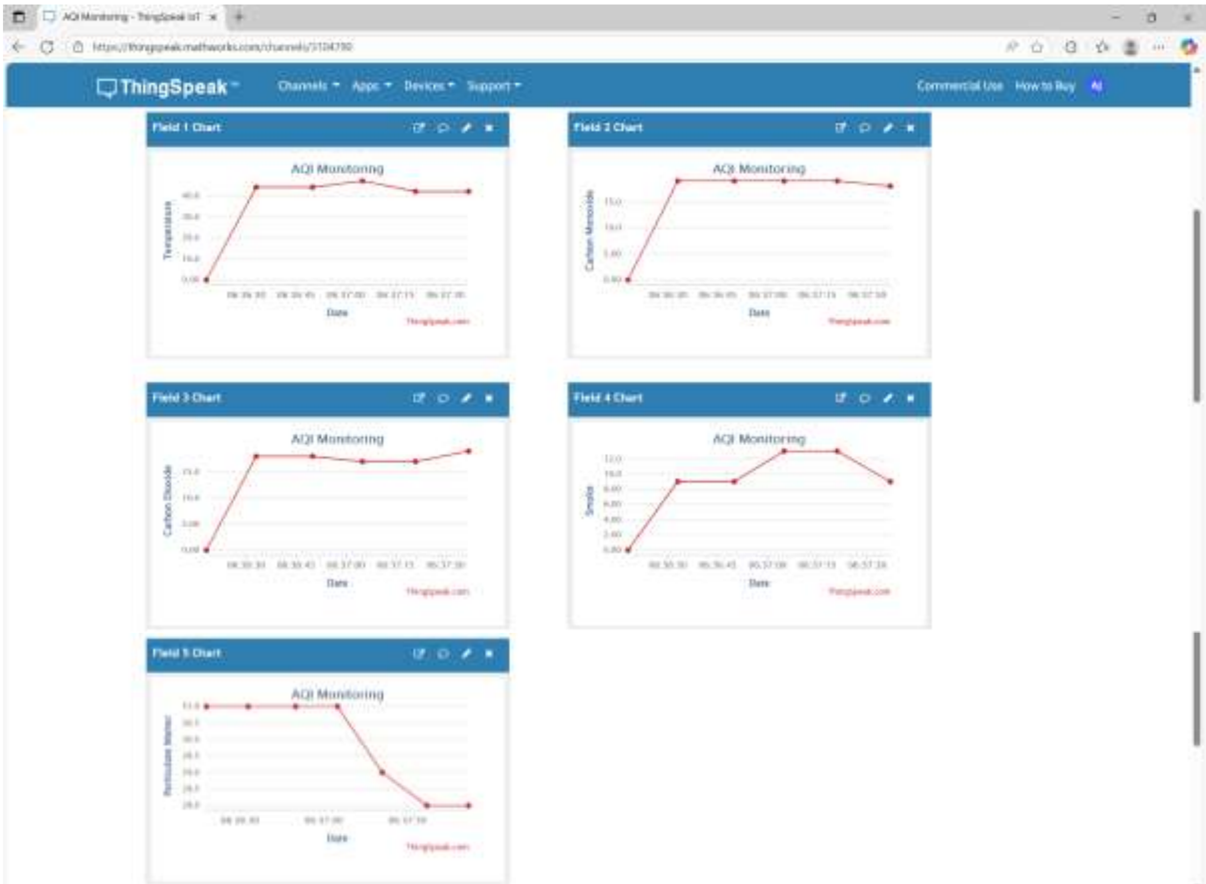

Figure 3: Thing Speak IoT display screenshots after filtering

The AQI sensor data is updated at every 15 seconds on thing speak as seen in figure 3. The AQI is evaluated with four pollutants. The major contributing pollutants in metal industry (metal dust extraction) being particulate matter, CO2, CO and SO2 are considered for AQI calculation. The data collected through IoT can be accessed remotely for initiating the corrective actions and performance maintenance related tasks. In ensuring safe air quality, the cartridge filters and HEPA filter need periodic cleaning or replacements. The dust collection bag is also required to be emptied to ensure safe and correct functioning of the system. The size of metal dust fall in the range of 2.5µM – 100 µM. As seen in table 2, the contents of the particulate matter constituted by the hazardous metal dust are significantly reduced after filtering.

Conclusion

The proposed metal dust extraction and Air Quality Index monitoring system demonstrates an efficient, IoT-enabled approach for maintaining safe industrial environments. By integrating real-time sensing, data acquisition and filtration mechanisms, the system effectively reduces airborne metallic particles, thus mitigating health and equipment hazards. The IoT-based monitoring framework enables continuous tracking of AQI and pollutant trends through the Thing Speak cloud platform, facilitating the decision-making for maintenance activities. Experimental results shows that a significant reduction from 157.45 to 68.58, in air quality index is achieved by implementing the metal dust extraction unit. The AQI level (68.58) after the processing metal dust through the filtering unit fall within the safe levels of AQI standards.

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