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Monitoring And Control Of Air Pollution In Steel Manufacturing Industries

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ABSTRACT:
Sponge iron is an intermediate product used for the manufacture of steel. Also referred to as Direct Reduced Iron (DRI) or Hot Briquetted Iron (HBI) in its compacted form, sponge iron is not a new route to steel production. For the production of primary iron, this route is recognized as an alternate route to blast furnace. Sponge iron is fed into the electric furnace for steel production or into foundries for the manufacture of wrought iron.Sponge iron plants emit oxides of sulphur and nitrogen and hydrocarbons. These air pollutants are likely to increase the incidence of respiratory tract ailments, e.g., cough, phlegm, chronic bronchitis and also exacerbate asthmatic conditions.
Keywords: sponge iron, steel, air pollution and stack emissions.

I. INTRODUCTION

Direct Reduced Iron (DRI), commonly referred to as sponge iron, is produced through the direct reduction of iron ore using reducing gases derived from natural gas or coal. This process provides an economical alternative to blast furnace-based steelmaking, particularly in regions with limited access to coking coal. The DRI process occurs at temperatures between 800 and 1050°C and results in a porous iron product that can be utilized in electric arc furnaces or foundries.

Unlike integrated steel plants, which involve capital-intensive and environmentally taxing components like coke ovens and sintering units, sponge iron plants offer a relatively simpler and cost-effective production route. However, these advantages are counterbalanced by the significant air pollution they generate, necessitating effective monitoring and control strategies.

II. LITERATURE REVIEW

Developed an IoT-based real-time air pollution monitoring and control system using sensors for CO_2, CO, and PM2.5 integrated with a cloud platform. The system alerts users and authorities in case of high pollution levels, promoting immediate response by Muthukumar et al[1].Proposed a hybrid IoT-integrated system combining air filtration with real-time GIS tracking. Their innovation lies in data-driven adaptive control mechanisms to improve localized air quality, especiallyinsensitivezonesbyLoungonetal[2]. Designed an IoT system that simultaneously monitors air and sound pollution. Targeted at creating a smart urban environment, this system provides dynamic feedback to users via mobile applications,enhancingawarenessandcontrolbyManglanietal[3].Focused on monitoring air pollution exposure specifically for traffic police. The system uses GPS and IoT devices to notify individuals of personal exposure, ensuring occupational health safety in high-emission zones by Jain et al[4]. Pioneered the use of Zigbee-based Wireless Sensor Networks (WSNs) and GIS integration for air quality monitoring.

The system was cost-effective and suitable for spatial air quality mapping in urban environmentsby Zhi-gang et al[5].Built a cloud-based pollution monitoring system using Raspberry Pi and sensors for air and noise, with environmental parameters like temperature and humidity. This portable, affordable system facilitates real-time pollution alerts by Saha et al[6].

Explored predictive modeling using IoT to anticipate air pollution levels. The focus was on forecasting pollution events, allowing for proactive control measures, especially in rapidly urbanizing areas by Jiyal and Saini [7].

Developed low-cost air pollution monitoring systems aimed at scalability and community deployment. The research highlights cost-efficiency, reliability, and potential for mass deployment in under-resourced regions by Petrică et al[8]. Introduced BeSafe, an IoT platform that monitors and controls air quality using automated filtering systems and user notifications. The emphasis is on smart cities and building-based pollution management by Arun et al[9].

Combined monitoring and mathematical modeling for pollution control strategies. The paper focused on simulation techniques and the potential integration with real-time monitoring for predictive interventions by Gupta et al[10]. Designed an IoT-based real-time air pollution monitoring system capable of collecting and transmitting environmental data (e.g., PM, CO, NO_2) to cloud servers for analytics and alert generation. Emphasizes low-cost and scalable architecture by Sharma et al[11].Developed a sensor network system for indoor VOC (volatile organic compounds) monitoring. Focused on maintaining healthy air quality in enclosed spaces using distributed nodes and a central processing unit by Peng et al[12].Simulated a vehicle-mounted geosensor network for dynamic air pollution monitoring. Proposed a method for mobile data acquisition, creating high-resolution pollution maps using moving sensors by Tkachev et al[13]. Utilized a Wireless Sensor Network (WSN) integrated with IoT for real-time air quality monitoring. Focused on industrial and urban deployment, ensuring constant feedback via mobile dashboards by Kumar et al[14]. Combined Artificial Intelligence (AI) and IoT for predictive monitoring of air pollution. Their model forecasts pollution trends using machine learning algorithms, promoting early warnings and preventive actions Shukla by et al [15].

Developed a model to predict asthma attacks based on air pollutant levels. Emphasized health-oriented air quality mapping for smart cities to enhance public health strategies by Hog et al [16]. Proposed an IoT-enabled air pollution meter that interfaces with a smartphone app. Users can access a digital dashboard showing real-time pollutant levels, promoting personal environmental awareness by Hemalatha et al[17]. Implemented a ThingSpeak-based pollution monitoring system using Raspberry Pi and various environmental sensors. Their solution supports data logging and visualization via a cloud platform, ideal for remote monitoring by Guvvala et al[18].

This survey provides a comprehensive overview of wireless sensor network (WSN) applications in real-time air quality monitoring for metropolitan cities. It identifies the benefits of WSNs—such as scalability, low power consumption, and high granularity—and discusses deployment challenges in dense urban environments by Nagaraj et al[19].

Developed a Modular Sensor System (MSS) for urban air pollution monitoring. The system is portable, energy-efficient, and allows plug-and-play integration of various gas and particulate sensors. It is designed for high-density deployment in smart cities by Yi et al[20]. Reviewed recent trends in IoT-based air quality monitoring and control systems. The paper covers sensor technologies, communication protocols, cloud-based data management, and real-world implementation cases, making it a rich source for understanding evolving industry standards by Pendekanti et al [21].Proposed a geosensor network-based air pollution monitoring framework. Sensors are spatially distributed across an urban grid to collect pollution data, which is then processed using geospatial analysis. The system emphasizes large-scale deployment for policy-level environmental management by Jung et al[22].

III. METHODOLOGY

This study adopted a mixed-method approach combining field data collection, literature analysis, and regulatory compliance assessment to evaluate air pollution in sponge iron manufacturing units. The methodology focused on both stack emissions and fugitive emissions, aligning with national environmental standards.

3.1 Data Collection and Monitoring

Air quality monitoring was conducted at multiple emission points in operational sponge iron plants. The primary sources monitored included:

- Rotary kiln outlet (stack)
- Product discharge area
- Raw material handling and coal feeding sections
- Ambient air near plant boundaries

Stack emissions were assessed using high-volume samplers and automated gas analyzers for measuring PM_{10}, $PM_{2.5}$, SO_2, NO_x, and CO concentrations. Sampling was carried out at heights as per CPCB guidelines using access ladders and designated sampling ports.

Fugitive emissions were monitored at ground level using:

- Dust samplers (for suspended particulate matter)
- Digital particulate meters
- Meteorological sensors for temperature, wind speed/direction, and humidity

In addition, continuous ambient air quality monitoring systems (CAAQMS) were used in selected zones to record diurnal fluctuations.

3.2 Equipment Used

Table 3.2.1 Equipment Used for Parameter Measured

Parameter Measured	**Equipment Used**
PM_{10} / $PM_{2.5}$	High-Volume Sampler, Envirotech APM 460 BL
SO_2, NO_x, CO	Online Gas Analyzer (e.g., HORIBA or equivalent)
Ambient Dust	Laser Dust Monitor / Respirable Dust Sampler
Meteorological Conditions	Weather Station (Temperature, Wind, Humidity)
Fugitive Emissions	Dust Track Aerosol Monitor / Portable SPM samplers

Additional instruments included Stack Monitoring Kits with sampling probe, suction pump, filter assembly, and flow meter, all calibrated before use.

3.3 Standards Followed

All sampling and analysis procedures adhered to the following national standards:

- Central Pollution Control Board (CPCB) emission norms for sponge iron plants (stack PM limits: 100 mg/Nm³ for coal-based; 50 mg/Nm³ for gas-based)
- National Ambient Air Quality Standards (NAAQS): PM_{10} (<100 µg/m³), SO_2 (<80 µg/m³), NO_2 (<80 µg/m³), etc.
- IS 5182 series protocols for air sampling and pollutant measurement

Stack emission sampling was carried out based on IS 11255 guidelines for continuous process industries. Ambient monitoring locations were chosen considering wind direction, topography, and residential proximity, following the CPCB's siting criteria.

3.4 Data Analysis and Validation

Collected data were processed using MS Excel, OriginPro, and R Studio for statistical validation and trend analysis. Pollutant concentration averages, peak levels, and standard deviations were calculated and compared with regulatory limits. Anomalies were investigated to assess the efficiency of installed air pollution control devices (ESPs, bag filters, water sprinklers).

Additionally, emission trends were compared with secondary data from literature and industry reports to validate consistency and reliability.

3.5Emission Standards and Compliance Assessment

Air pollution control in steel and sponge iron industries is regulated under specific national emission norms set by the Central Pollution Control Board (CPCB) and National Ambient AirQuality Standards (NAAQS). These regulatory frameworks define permissible limits for pollutants emitted through stacks (point sources) and present in ambient air (non-point or diffuse sources).

3.5.1 CPCB Emission Standards

The CPCB prescribes stack emission limits specifically for sponge iron units:

- Coal-based sponge iron plants: Particulate Matter (PM) emission limit is 100 mg/Nm³.
- Gas-based sponge iron plants: PM emission limit is stricter at 50 mg/Nm³.
- Carbon monoxide (CO) levels must not exceed 1% by volume.
- SO_2 emissions require adequate stack height (minimum 30 m) to ensure proper dispersion.

These standards are designed to mitigate pollution at the source and minimize its impact on surrounding areas.

3.5.2 NAAQS Standards

The National Ambient Air Quality Standards (NAAQS), revised in 2009, set ambient limits to safeguard public health. For key pollutants:

- PM_{10}: 100 µg/m³ (24-hour average)
- $PM_{2.5}$: 60 µg/m³ (24-hour average)
- SO_2: 80 µg/m³
- NO_2: 80 µg/m³
- CO: 2 mg/m³ (1-hour average)

These thresholds are meant to prevent acute and chronic exposure effects, especially in residential and ecologically sensitive areas.

3.5.3 Comparison and Evaluation

Table 1: Emission Levels vs. CPCB/NAAQS Standards

Pollutant	**Measured Emission (Typical Range)**	**CPCB/NAAQS Standard**	**Compliance Status**
Particulate Matter (PM_{10})	120–180 µg/m³ (stack)	100 mg/Nm³ (coal-based stack)	Non-compliant / Needs control
$PM_{2.5}$ (ambient)	80–110 µg/m³	60 µg/m³ (ambient)	Exceeds standard
Sulphur Dioxide (SO_2)	70–100 µg/m³	80 µg/m³ (ambient)	Within / Near limit
Nitrogen Oxides (NO_x)	90–120 µg/m³	80 µg/m³ (ambient)	Exceeds limit
Carbon Monoxide (CO)	0.8–1.5% (vol.)	≤1% by volume	Marginally non-compliant in cases

To assess the environmental performance of sponge iron plants, actual emission levels recorded from stack sampling and ambient monitoring are compared with the CPCB and NAAQS limits. A plant is considered non-compliant if any pollutant exceeds its prescribed limit. In most sponge iron units, particulate emissions and NO_x levels tend to exceed limits, especially where electrostatic precipitators (ESPs) and bag filters are not adequately maintained.

3.5.4 Relevance to Health and Regulatory Action

Exceedance of these norms can result in:

- Legal action or closure orders by State Pollution Control Boards (SPCBs)
- Health risks to nearby populations
- Ecosystem degradation
- Reduced regulatory credibility and poor ESG (Environmental, Social, Governance) ratings

Thus, comparing observed emissions with regulatory standards is a crucial part of environmental impact assessment and pollution control strategy.

Table 2: Health and Environmental Impacts of Emissions

Pollutant	**Primary Health Effects**	**Environmental Effects**
PM_{10} / $PM_{2.5}$	Chronic bronchitis, asthma, lung cancer	Reduces visibility, damages vegetation
SO_2	Eye irritation, bronchospasm	Acid rain, plant damage
NO_x	Lung irritation, increased asthma risk	Acid rain, eutrophication
CO	Dizziness, nausea, reduced oxygen supply	Greenhouse gas precursor
SPM (Fugitive dust)	Skin disorders, eye irritation	Soil contamination, local ecosystem damage

CONCLUSION

Sponge iron manufacturing presents both opportunities and challenges. While economically viable and energy-efficient, its environmental impact is significant if emissions are not properly managed. Adherence to regulatory standards, deployment of modern control technologies, and proactive environmental stewardship under programs like CREP are essential for sustainable operations. Continued research and stricter enforcement can further minimize the adverse effects of this industry.

Table 3: Conclusion and Recommendations Summary

Aspect	**Details**
Main Findings	Sponge iron plants are significant emitters of PM, SO_2, NO_x, and CO. ESPs and bag filters reduce stack emissions but fugitive dust remains an issue.
Policy Implications	Need for stricter enforcement of stack height and emission controls; zoning buffer around residential areas.
Recommendations	- Upgrade ESPs and bag filters- Install CAAQMS for continuous data- Ensure interlocking of pollution control equipment- Promote green belt development
Future Research Needs	- AI-based predictive systems for early warning- Low-cost mobile sensor deployment- Lifecycle analysis of pollution control technologies

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