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Comparative Study of Air Pollutant Emissions from Cement, Ready-Mix Concrete, Brick Kiln and Steel Industries

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Abstract

Industrial activities associated with construction and infrastructure development contribute to ambient air pollution through material handling, fuel combustion and high-temperature processing. This review compares the principal sources and control approaches for air pollutants associated with four sectors: cement manufacturing, ready-mix concrete (RMC) production, brick kilns, and iron and steel production. The discussion focuses on particulate matter (PM), including PM_{10} and $PM_{2.5}$, sulphur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), and carbon dioxide (CO_2). A narrative review approach was used to synthesise the technical literature, regulatory material and guidance documents cited in this paper. The comparison indicates that fugitive and process dust is a major concern in cement and RMC operations; combustion-related emissions are particularly important in brick kilns; and the integrated iron and steel production route has multiple emission-generating stages, including coke making, sintering, ironmaking and steelmaking. The review also shows that emission profiles vary with fuel, raw-material composition, production technology, operating conditions and the effectiveness of pollution-control equipment. Accordingly, no single control strategy is suitable for all four sectors. Source enclosure, dust extraction, fabric filters, electrostatic precipitators, improved combustion, flue-gas treatment, energy efficiency and regular monitoring are among the measures relevant to specific processes. Because this paper is based on secondary sources and does not report original stack measurements, its comparison is qualitative rather than a ranking of measured emission rates.

Keywords: *Air pollution; brick kilns; cement industry; emission control; iron and steel industry; ready-mix concrete.*

1. INTRODUCTION

Industrial production is an important contributor to air pollution, particularly where processes involve the handling of dry materials, combustion of fossil fuels or high-temperature chemical reactions. Cement, ready-mix concrete (RMC), brick manufacturing and iron and steel production are closely connected with the construction sector, but their production processes and emission profiles differ substantially.

Cement manufacturing involves quarrying, crushing, raw-material preparation, clinker production, cooling, grinding and packing. Dust may be released at several material-handling points, while kiln combustion and limestone calcination contribute gaseous emissions and carbon dioxide. Studies of cement production have examined particulate matter, SO_2, NO_x, CO and CO_2 emissions and have shown that technology and kiln configuration influence the emission profile [1], [2].

RMC plants generally receive cement as a finished product and combine it with aggregates, water and admixtures. Unlike an integrated cement plant, an RMC plant normally does not operate a clinker kiln. Its principal air-quality concern is therefore fugitive dust from cement transfer, aggregate storage and handling, batching, vehicle movement and related activities. Combustion emissions may also arise from trucks, loaders and diesel generator sets [3], [4].

Brick kilns use thermal energy to fire moulded clay bricks. Their emissions depend on kiln design, fuel type, fuel quality, firing practice and operating conditions. Measurements from Indian and South Asian brick kilns have documented differences in particulate and gaseous emissions between kiln technologies, including improved performance from some zig-zag and other improved kiln designs [5], [6].

The iron and steel sector includes several production routes and process stages. In an integrated route, coke making, sintering, ironmaking, steelmaking and finishing can all contribute to air emissions. The pollutant mix varies with the process route, raw materials, fuels and pollution-control systems [7], [8].

A comparison of these sectors is useful because it links pollutants to their points of generation and helps identify process-specific control measures. However, a meaningful comparison must distinguish between the presence of a pollutant, its emission rate, and its concentration in ambient air. These are different measures and cannot be treated as interchangeable.

2. REVIEW METHODOLOGY

This paper adopts a narrative literature-review approach based on the technical studies, regulatory documents and industry guidance cited in the reference list. The source material includes peer-reviewed research on cement, brick-kiln and steel-sector emissions; government and pollution-control guidance; and technical documents describing industrial processes and emission-control practices. The review was organised around four sectors cement, RMC, brick kilns, and iron and steel and the recurring pollutants identified in the source material.

For each sector, the review identifies (i) the production stages associated with emissions, (ii) the principal pollutants reported in the cited literature, and (iii) control measures relevant to those sources. The findings are then compared qualitatively. No new field sampling, stack monitoring, laboratory analysis or emission-factor calculation was undertaken for this paper. The comparison therefore does not claim to establish absolute emission quantities or to rank the four sectors by total pollution load.

The manuscript does not describe a systematic database search, a fixed search period or a formal screening protocol. Consequently, it should be interpreted as a narrative review of the sources listed, rather than a systematic review or meta-analysis. Any journal-required details about databases and search dates should be added only if the authors actually performed those searches.

3. MAJOR AIR POLLUTANTS AND THEIR RELEVANCE

The pollutants discussed in this review differ in their formation mechanisms and environmental effects. Particulate matter is generated by mechanical handling, crushing, grinding, transport and combustion. PM_{10} refers to particles with aerodynamic diameters generally at or below 10 µm, while $PM_{2.5}$ refers to finer particles at or below 2.5 µm. Fine particles can penetrate deeper into the respiratory system and are associated with adverse respiratory and cardiovascular outcomes [9], [10].

Sulphur dioxide is mainly associated with the combustion or processing of sulphur-containing fuels and materials. Nitrogen oxides are formed mainly during high-temperature combustion and certain industrial processes. Carbon monoxide is associated with incomplete combustion. Carbon dioxide is released through fuel combustion and, in some industries such as cement production, through process chemistry as well. CO_2 is primarily discussed here as a greenhouse gas rather than as a conventional local air-quality pollutant [2], [11].

The presence of a pollutant does not by itself indicate the magnitude of exposure or health risk. Actual risk depends on emission rate, dispersion, exposure duration, background concentrations and population characteristics. Health evidence on particulate air pollution and ambient air pollution is summarised in the literature by [9], [10], [12].

3.1 National ambient air quality standards in India

The values below are the Indian National Ambient Air Quality Standards (NAAQS) notified in 2009 for industrial, residential, rural and other areas. They are ambient-air concentration standards, not stack-emission limits for individual industrial chimneys. The standards include different averaging periods and should be interpreted accordingly [13].

Table I. Selected Indian National Ambient Air Quality Standards (NAAQS).

Pollutant	Annual standard (µg/m³)	24-hour standard (µg/m³)
$PM_{2.5}$	40	60
PM_{10}	60	100
Sulphur dioxide (SO_2)	50	80
Nitrogen dioxide (NO_2)	40	80

Note: The table reproduces selected NAAQS values for the general industrial, residential, rural and other area category. The NAAQS notification also specifies standards for additional pollutants, measurement methods and special provisions for ecologically sensitive areas. Compliance assessment should refer to the complete notification.

4. EMISSION SOURCES IN THE FOUR INDUSTRIES

4.1 Cement industry

Cement manufacturing includes quarrying and crushing of limestone and other raw materials, raw-meal grinding, preheating, clinker formation in the kiln, clinker cooling, cement grinding and packing. Particulate emissions may arise from crushers, mills, conveyors, transfer points, storage areas, clinker coolers and packing operations. Effective capture and filtration are therefore required at several points rather than only at the kiln stack.

The principal stages of cement manufacture are illustrated in Fig. 1.

Combustion in the kiln and associated thermal equipment contributes NO_x and other combustion-related pollutants. SO_2 emissions depend on the sulphur content of fuels and raw materials, as well as process conditions. CO can indicate incomplete combustion. CO_2 is generated both by fuel combustion and by the calcination of limestone, making cement production a significant industrial source of greenhouse-gas emissions [1], [2], [14].

Relevant control measures include enclosed conveyors and transfer points, local dust extraction, fabric filters (bag filters), electrostatic precipitators where appropriate, effective kiln operation, low-NO_x combustion systems and suitable flue-gas treatment. Energy efficiency, alternative fuels and materials, clinker substitution and carbon-capture options are discussed in the wider decarbonisation literature [14], [15].

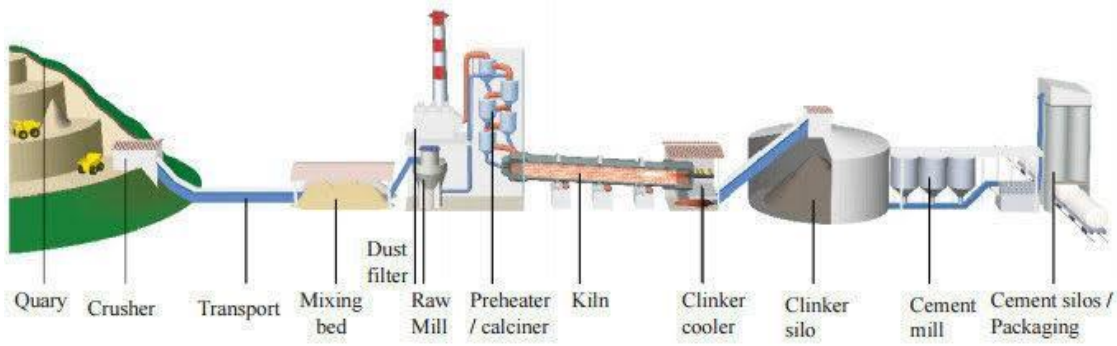


Fig. 1. Layout of a cement manufacturing plant.

4.2 Ready-mix concrete plants

RMC plants proportion and mix cement, aggregates, water and, where required, chemical admixtures to produce concrete. The principal air-pollution issue at these facilities is generally fugitive dust rather than kiln emissions. Dust may be generated while filling cement silos, unloading and storing aggregates, transferring materials by conveyor, batching, loading concrete mixers and moving vehicles over unpaved or dusty surfaces.

A representative RMC plant arrangement is shown in Fig. 2.

Cement silo vents can release fine dust if suitable filtration is absent or poorly maintained. Aggregate stockpiles and transfer points can also generate particulate matter, particularly in dry and windy conditions. Diesel-powered trucks, loaders and generators may contribute NO_x, CO, particulate matter and CO_2. The relative importance of these sources depends on plant layout, throughput, equipment, vehicle activity and housekeeping practices [3], [4].

Practical controls include properly maintained silo filters, covered or enclosed conveyors, controlled material transfer, covered aggregate storage where practicable, water spraying or other dust-suppression methods, paved and regularly cleaned internal roads, speed control and maintenance of diesel equipment. Water spraying should be managed to avoid excessive runoff and should be matched to site conditions.

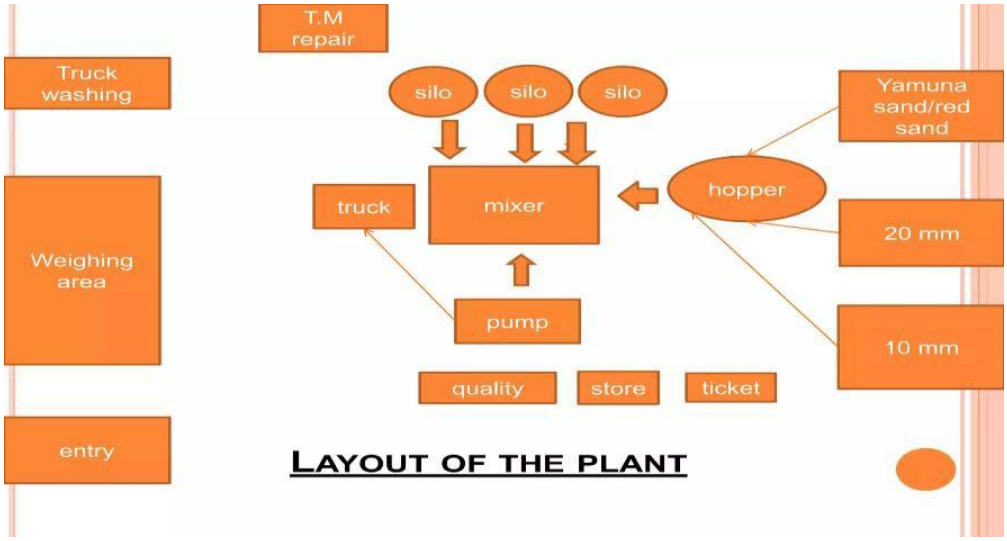


Fig. 2. Layout of a ready-mix concrete (RMC) plant.

4.3 Brick kilns

Brick production generally involves clay preparation, moulding, drying and firing. The firing stage is the principal source of combustion-related emissions. The pollutants reported in the literature include particulate matter, SO_2, CO and CO_2; NO_x and light-absorbing carbon may also be relevant depending on fuel and combustion conditions. Fuel type, kiln geometry, firing practice, maintenance and operator skill influence the emission profile.

The general arrangement of a brick kiln is shown in Fig. 3.

Field measurements at brick kilns in India have shown differences in emission factors across kiln technologies and operating conditions [5]. Research on South Asian brick production has also reported substantial variation between kiln types and identified improved technologies, including appropriately operated zig-zag kilns, as potential lower-emission options compared with some traditional configurations [6]. These findings do not imply that every kiln using a particular design will achieve the same performance; operation and maintenance remain important.

Control strategies include upgrading kiln design, ensuring correct firing practices, improving combustion and fuel feeding, using suitable cleaner fuels where feasible, maintaining kiln structures and monitoring emissions. Technology selection should consider local fuel availability, production requirements, technical capacity and regulatory requirements.

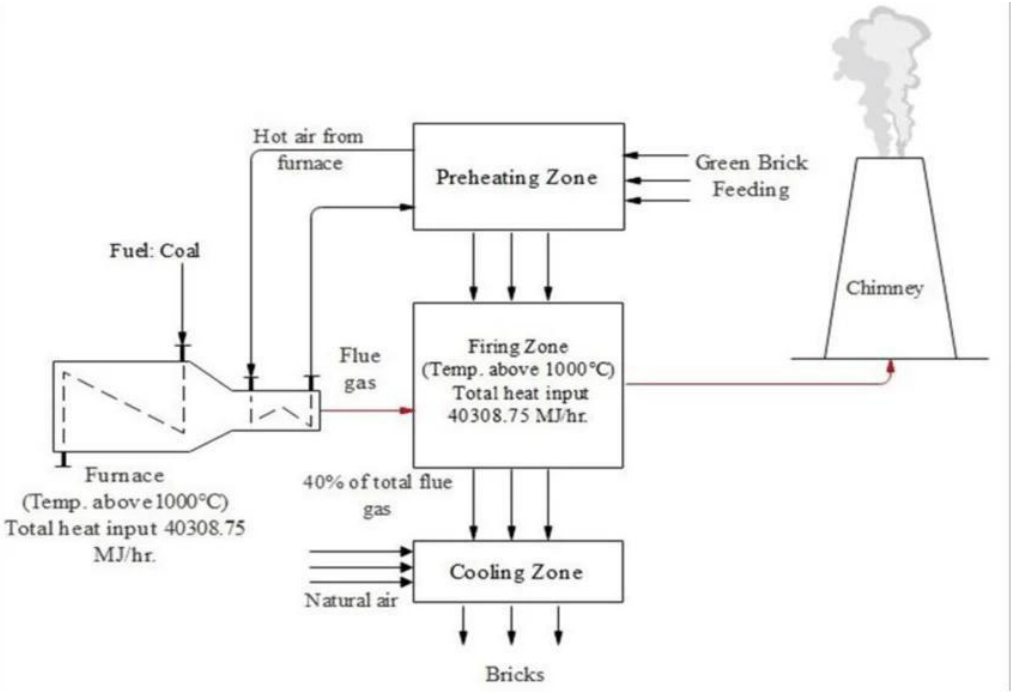


Fig. 3. Schematic/layout of a brick kiln.

4.4 Iron and steel industry

The iron and steel industry contains several potentially emission-intensive operations. In an integrated production route, these may include coke ovens, sinter plants, blast furnaces, basic oxygen steelmaking, casting and rolling. Electric arc furnace routes have a different process configuration and emission profile. Dust and particulate matter may arise from material handling, furnaces, sintering, tapping and finishing operations. Combustion and process gases can contribute SO_2, NO_x, CO and CO_2; the specific pollutants depend on the process route and input materials.

A representative iron and steel plant layout is presented in Fig. 4; the facility photographs are provided in Figs. 5–7.

Because emissions originate at multiple stages, pollution management requires process-specific capture and treatment. Measures can include enclosure and extraction at dusty operations, fabric filters, electrostatic precipitators, wet or dry gas-cleaning systems, desulphurisation where appropriate, combustion optimisation, improved coke-oven practices and continuous or periodic emissions monitoring. Best-available-technique guidance for iron and steel production provides a framework for evaluating process and control options [7], [8].

Technologies such as electric arc furnaces, direct reduced iron, waste-heat recovery and increased use of scrap can influence energy use and emissions, but their environmental performance depends on electricity sources, feedstock, fuel and plant configuration. They should not be described as universally emission-free alternatives [8].

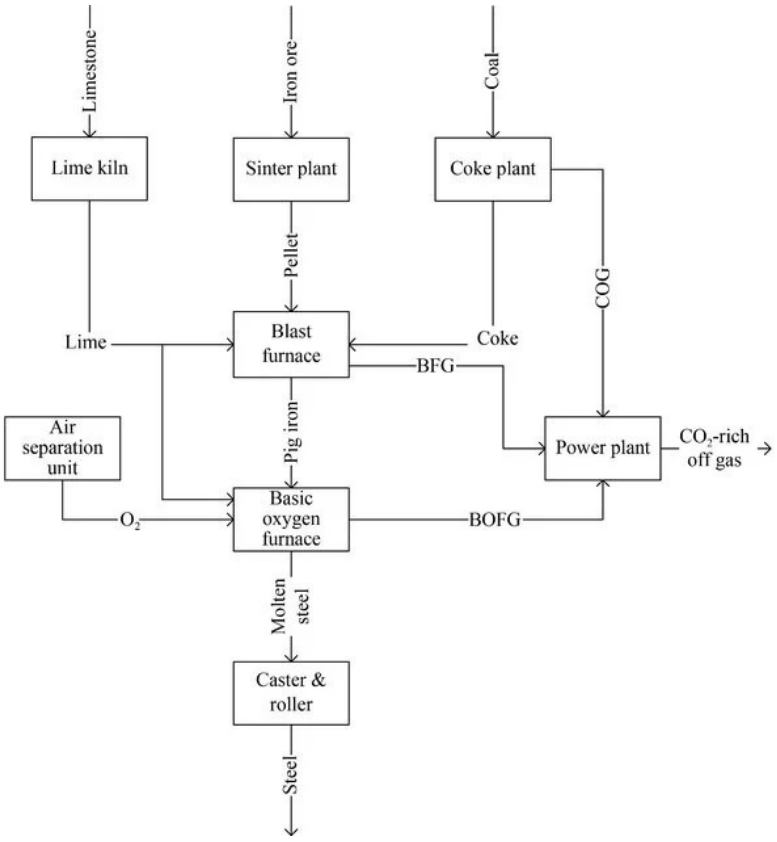


Fig. 4. Layout of an iron and steel manufacturing facility.

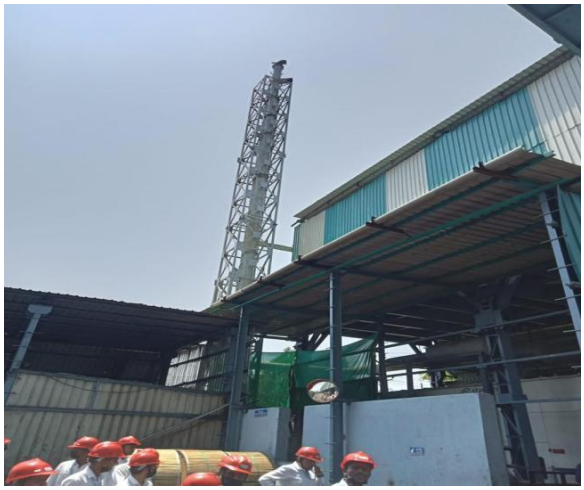


Fig. 5. Photograph of the steel-industry facility Kalika Steel Industry.



Fig. 6. Steel-industry photograph



Fig. 7. Steel-industry photograph

5. COMPARATIVE ANALYSIS

The comparison below identifies the main types of emission sources and the pollutants of concern in each sector. It is a qualitative synthesis of the cited literature and technical guidance; it does not represent measured emission rates or a ranking of the industries.

Table II. Qualitative comparison of emission sources and control priorities across the four industries.

Industry	Main emission-generating activities	Pollutants commonly discussed	Priority control focus
Cement	Crushing, grinding, kiln and clinker operations, cooling, packing and material transfer	PM, PM_{10}, $PM_{2.5}$, NO_x, SO_2, CO, CO_2	Dust capture and filtration; kiln and combustion optimisation; gas treatment; energy and process efficiency
RMC	Silo filling, aggregate storage and unloading, conveyors, batching, loading and vehicle movement	Fugitive PM and dust; vehicle-related NO_x, CO, PM and CO_2	Silo filters; covered/enclosed transfer; dust suppression; road cleaning; vehicle maintenance

Brick kiln	Fuel combustion and firing; fuel and brick handling	PM, $PM_{2.5}$, SO_2, CO, CO_2; other pollutants depending on fuel and kiln	Improved kiln design and operation; combustion control; appropriate fuels; monitoring
Iron and steel	Coke making, sintering, ironmaking, steelmaking, casting, rolling and material handling	PM, PM_{10}, $PM_{2.5}$, SO_2, NO_x, CO, CO_2; process-specific pollutants	Capture at multiple process stages; filtration and gas cleaning; process optimisation; monitoring

The comparison highlights three broad distinctions. First, fugitive dust is especially relevant to RMC operations because cement and aggregates are handled in dry or partially dry form, while cement and steel production also generate dust from numerous process stages. Second, combustion conditions and fuel quality are central to the emission profile of brick kilns and are also important in cement and steel production. Third, integrated steel and cement plants have complex process chains in which effective control requires coordinated measures across several operations. These distinctions are more informative than assigning a single high, medium or low emission rating to each industry without comparable measurements.

6. POLLUTION-CONTROL TECHNOLOGIES

6.1 Particulate matter control

Fabric filters (bag filters) remove particles by passing dusty gas through filter media. They are widely used for dust collection at silos, mills, transfer points and industrial exhaust systems, subject to suitable design and operating conditions. Electrostatic precipitators use electrical forces to collect particles from gas streams. Cyclones use centrifugal action and are generally more effective for larger particles or as a pre-cleaning stage. Enclosures and local exhaust ventilation reduce the release of dust at its source, while water spraying and good housekeeping can reduce fugitive dust from roads and stockpiles [3], [15].

6.2 Sulphur dioxide control

SO_2 control can begin with the selection and management of lower-sulphur fuels and raw materials. Where required and technically suitable, flue-gas desulphurisation or other gas-treatment systems can remove sulphur compounds before exhaust gases are released. The appropriate method depends on fuel composition, process chemistry, gas characteristics and applicable emission requirements.

6.3 Nitrogen oxides control

NO_x formation can be reduced through combustion optimisation, suitable burner design and control of combustion temperature and air-fuel mixing. Selective non-catalytic reduction (SNCR) and selective catalytic reduction (SCR) are post-combustion technologies that can reduce NO_x under appropriate operating conditions. Their selection depends on gas temperature, process configuration, required removal performance and operating cost.

6.4 Carbon dioxide reduction

CO_2 reduction requires a distinction between energy-related emissions and process-related emissions. Energy efficiency, waste-heat recovery, lower-carbon fuels, renewable electricity and process optimisation can reduce energy-related emissions. In cement production, reducing the clinker-to-cement ratio and considering carbon capture may also address process emissions. The feasibility and benefits of each option depend on material availability, plant design, energy supply and economic conditions [2], [8], [11], [14].

6.5 Monitoring and maintenance

Pollution-control equipment must be correctly designed, operated and maintained. A bag filter that is damaged or poorly maintained, for example, may not provide the intended dust-removal performance. Monitoring of stack emissions, fugitive sources and ambient air—using methods prescribed by the relevant regulatory authority—helps identify operational

problems and assess compliance. Ambient-air standards should not be substituted for industry-specific stack-emission standards.

7. DISCUSSION

The reviewed material indicates that the four sectors share some pollutants but differ in the processes that generate them. Particulate matter is relevant across all four sectors, although its sources differ: crushing and grinding in cement production; storage, transfer and batching in RMC plants; fuel combustion and firing in brick kilns; and several material-handling and high-temperature operations in iron and steel production.

The distinction between RMC plants and cement manufacturing plants is particularly important. RMC plants generally do not manufacture clinker and therefore do not have the same kiln-related emission sources as cement plants. Their control priorities are mainly fugitive dust management and emissions from mobile or auxiliary equipment. By contrast, cement plants need controls for both particulate emissions and combustion- or process-related gases.

Brick-kiln emissions are strongly influenced by kiln technology and operation. The cited field studies demonstrate that emission factors can vary between technologies, supporting the need to evaluate actual kiln performance rather than relying only on the technology label. In the iron and steel sector, the number and diversity of process stages make integrated pollution management essential.

A limitation of many broad industry comparisons is that they list pollutants without specifying the measurement basis. Stack concentration, emission factor per unit of product, total annual emissions and ambient concentration answer different questions. A rigorous quantitative comparison would require harmonised data for production capacity, fuel use, process route, operating conditions, control-equipment performance and measurement methods. Such harmonised primary data are not available in the present review.

8. LIMITATIONS OF THE STUDY

This study is based on secondary literature and technical or regulatory documents; no original field measurements or laboratory analyses were conducted. The review is narrative rather than systematic, and it does not claim that all available studies have been exhaustively identified. The source material also includes studies conducted in different countries and under different process, fuel and regulatory conditions. Therefore, their findings cannot be transferred directly to every plant in India.

The paper does not calculate emission factors, total sectoral emissions or exposure concentrations, and it does not rank the four industries by pollution load. Such a ranking would require comparable quantitative data collected or reported using consistent methods. Plant counts and industry-capacity figures from the earlier draft have been omitted because their dates, definitions and source documentation were not sufficiently established in the supplied manuscript.

9. CONCLUSION

Cement, RMC, brick-kiln and iron and steel industries contribute to air pollution through different combinations of material handling, combustion and industrial processing. Particulate matter is a common concern, but the dominant sources and appropriate control measures vary by sector. Cement production requires control across crushing, grinding, kiln, cooling and material-handling operations. RMC plants primarily require effective management of fugitive dust from silos, aggregates, batching and vehicle movement. Brick-kiln emissions are closely related to fuel, kiln technology and operating practice. Iron and steel production requires emission capture and treatment across several interconnected process stages.

The review therefore supports a process-specific approach to pollution prevention. Dust extraction, fabric filters, electrostatic precipitators, enclosures, improved combustion, gas treatment, energy efficiency and regular monitoring can contribute to emission reduction when correctly selected and maintained. A quantitative ranking of the four sectors cannot be established from the secondary information reviewed here. Future work should use comparable plant-level measurements and clearly defined emission factors to assess differences in actual emission performance.

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