# Pollution Control in Ferro-Alloys Production

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## 1.0 Background

Industrialisation and pollution control measures go hand in hand for the socio-economic progress of a country since pollution is a sign of inefficiency in industrial production. In recent years, environmental aspects with respect to air and water pollution have assumed special significance in ferro-alloys production both in developed and developing countries [1]. The stringent environment pollution control legislation in developed countries have necessitated the development and adoption of appropiate pollution control systems in the plants, and greater awarenes has been created in developing counttries for pollution control in ferro-alloys production. In the past 25 to 30 years, intense pressure has been put on U.S. Industry to stop polluting air[2]. U.S. Congress has passed the Clean Air Act in 1963 itself. Other laws and regulations are Clean Air Act Amendments of 1966, the Air Quality Act of 1967 and the Clean Air Amemdments of 1970. The stringent emission control standards forced most companies of U.S. to take a hard and realistic look at the viability of existing production facilities. In the United Nation Conference on the Human Environment held in Stockholm in June, 1972, in which India also participated, decisions were taken to take appropriate steps for the presevation of the quality of air and control of Air Pollution [3]. Government of India formulated Act, 1974 for the prevention and control of water and air pollution. The Air (Prevention and Control of Pollution) Act, 1981 was enacted under Art 253 of Indian Constitution and Environment (Protection) Act, 1986 was passed by the Indian Parliament in 1986. According to the act, no person carrying on any industry, operation or process shall discharge or emit or permit to be discharged or emitted any environmental pollutants in excess of such standards as may be prescribed. Elkem Technology, the World's largest producer of ferro-alloys and pioneer in electric smelting technology, is now engaged in solving the mounting problems of industrial pollution and waste, as well as in profitable metal recovery from slags and waste [4]. Filter Media-France is a French Air Pollution Control Company which concentrates its efforts in hot gas filtration and is highly successful in the field of ferro-alloy furnaces fume control and carbon black production filters[5]. The need of the hour is to prevent further degradation of the environment and control air and water pollution. Every ferro-alloy industry should make necessary provision in their capital expenditure for installing pollution control equipments and steps should be taken to keep the manufacturing costs of antipollution equipments as low as possible. The quantities of pollutants can be reduced by treating the effluent streams through beneficiating processes producing useful by products.

## 2.0 Introduction

Of late, there is increased awareness of pollution hazards within the metallurgical industry. The Government of India through various central and state pollution control agencies has taken steps to effectively protect ecology from pollution.

The primary manufacturing processes for most of the bulk ferro-alloys are carried out in submerged arc furnaces. The submerged arc furnaces, used in the manufacturing of ferro-alloys, are now included in "Red Category" as equipments giving rise to high degree of pollution for which immediate action has to be taken for effective control. Much of the atmospheric pollution from ferro-alloys production is smoke, fume and dust. The smoke mostly consists of soot, fly ash and other solid and liquid particles to be about 0.075 or 3 millionth of an inch. Coke smoke contains a high proportion of carbon. Fumes are synonymous with dirt and are mostly composed of solid particles. Fumes are generally less than 1 micron in diameter and commonly consist of metals and metallic oxide and chlorides. For expansion of existing plants and for new plants, installation of pollution control equipments has been made compulsory. This papers provides and overview of the state of pollution in ferro-alloys production and focusses in the main methods of pollution control, with special reference to Indian conditions.

## 3.0 Pollution in Ferro-Alloys Production

The emissions of smoke and fumes are visible from the stacks of submerged arc furnaces and they may be white greyish, brown or black [Tabel I]. The gas emissions from ferro-alloy smelting furnaces contain large size particles of dirt, dust and incompletely combustion wood and/or coal and coke in addition to fine particles. The gas may contain harmful sulphurous products, toxic metal oxide vapours, carbon monoxide and other organic gases. The threshold limits of gaseous pollutants and organic matter and their effects on human body are given in Table II. The quantity of particulates varies on the condition of the charge material, frequency of tap, furnae design and operating practice. Table III shows the particulate emissions from different ferro-alloys production. in a covered furnace, the concentration of particulates ranges from 10 to 70 gms per cubic meter of gas, while in open furnaces only 0.5 to 5 gms per cubic meter of gas due to the dilution of the exit gas. Table IV illustrates the chemical composition of gases and fume concentration from some of the ferro-alloys furnaces and Table V states the chemical composition of fumes from ferro-alloy furnaces.

## 4.0 Assessment of Pollution

A proper assessment of pollution from a ferro-alloy plant is extremely essential before taking up the pollution control measures. It requires the knowledge of the concentration of each substance present in the effluent and an understanding of the after-effects of the emitted substance i.e., how each substance affects everything which it contacts. Chemical tests identify and quantify everything in an effluent stream emitted from a ferro-alloy furnace while bioassays tell us what happens when living matter comes in contact with or exposed to the material contained in the effluent. Different bioassays are required to determine toxicity, carcinogenic and teratogenic characteristics in hazardous effluents. These tests assess whether compounds that could not be identified chemically or for which toxicological data are not availbale are dangerous or antagonistic. The emissions in the ferro-alloy industries generally contribute the oxides of cabon, silicon, manganese, chromium, calcium iron, magnesium, aluminium, nitrogen [NOx], sulphur [SOx] and some hydrocarbons. In several industries fine particles and droplets are left to the atmosphere, in such cases it becomes essential to assess their concentration, particle size distribution, chemical composition and spectral distribution with respect to size. Usually small particles of around 1 to 10 micron in size or even less remain suspended for long periods and are transported over long distances due to air currents. Certain gases and particles undergo changes owing to phase and composition, while some gases in presence of sunlight, moisture or trace elements give rise to photochemical reactions in oxidizing atmospheres producing photochemical smog (liquid particles). In order to assess the pollution, sometimes the measurement is directly made on the original gas stream and in other cases sampling is inevitable. In the latter case, the sample is collected and treated, if required, pollutants are separated from it, the desired properties are measured and the sample is disposed off. In some cases, dust fall observations are made by determining the rate at which particulate pollutants are deposited in an open vessel and the content of dust deposited under the influence of gravity is recorded.

One approach is to analyse the light scattering or staining of smoke from polluted air mass. The light scattering device equipped with an appropriate electro-photometric unit serves as a direct, quick and reasonably accurate method for pollution measurements. it is extremely desirable to measure the exact concentration of the pollutant in a particular atmosphere. When pollutants are emitted from a single source, their concentration is directly proportional to the mass rate of emission, to the square of the source height, and to the wind velocity when other parameters are virtually constant. The pollutants after entering into the atmosphere may undergo various changes namely (i) may get diluted due to decrease in relative concentration governed by the turbulent motion of the air (ii) may get transported due to wind, affected by its speed and direction and characteristic of place and time (iii) physico-chemical changes may occur due to natural phenomena or (v) may get separated to a certain extent due to rain, gravity etc. Analytical methods are applied to obtain actual concentration present and then methods/means are investigated to minimize the concentration suitable to comply with the standards.

The laboratory analysis of the sample is carried out using Orset apparatus and gas chromatographs. Portable gas chromatographs equipped with photoionization detectors offer better air sampling and are efficient on the spot analysis in the range of 0.1 ppb to 100 ppm. In this sample, air sample of about one mililiter quantity is required, air itself is used as the carrier gas. This system provides ambient monitoring of air pollution. Ir provides quick and accurate results with saving in time and cost. Low levels of volatile organics in air can also be analysed accurately on a gas chromatograph/mass spectroscopy. Thus dust content can be measured by the use of open top vessel, smoke by light scattering, odours by personal assessment and volatile organics by portable gas chromatograph or mass spectroscopy.

## 5.0 Selection of a Pollution Control Device

The measurement and analysis of air pollution provide a guideline to select a suitable device to control the pollutants of gaseous streams emitted from ferro-alloy furnaces. Before selecting any control device, it is required to know (i) the type of the source of pollution whether stationary or mobile, effective height of the source and rate of pollutant emission. Generally, the receptors of polution are humans, animals, vegetation and buildings. It is also important to know the total time of exposure to the pollutant, distance from the source, their location relative to the wind direction and wind velocity apart from the mode of transport of the pollutants to the receptors. The efficiency of any pollution controlling device can be judged by the ratio of the pollutant amount collected to the total amount present in the original stream. The pollution controlling device (i) should be cheap and as compact as feasible to fit within a certain space (ii) should be fairly efficient, corrosion resistant and should last at least for ten years (iii) should have minimum maintenance and low noise level (iv) should be operable in harmony with the operation of other devices and plant processes (v) must withstand temperature, pressure, flow rate and humidity of the polluted air stream. The design of the pollution controlling device depends upon the requiremnet of separation efficiency and size in case of particulate pollutants. The combination of two or more control equipments can improve the separation efficiency and can be used as a single unit. With the use of a concentrator also, the efficiency can be improved. The concentrator takes the stream of air and pollutant inside and gives out two streams, one of them is clean and the other dirty, thus helps the control device with many advantages. The control devices can be successfully employed with many stationary sources. Pollution can also be controlled by modification in fuel, modification in process, modification in raw materials and total eleimination through a newer technology. Air pollution control devices can be mainly classified into the following categories:

1. **Condensation Devices** - are used to separate gaseous organic pollutant from a pollutant stream emitted from a ferro-alloy furnace. When a gaseous organic pollutant is of considerable quantity and value, it is recovered by separation from the pollutant stream and collection is done by condensation. The gas loses heat and gets converted into liquid from. The liquid being heavier than gas, gets separated. Surface heat exchangers and direct contact condensers are generally employed for this purpose.

2. **Mechanical Devices** - are generally employed to separate particulate matters from the gaseous pollutants. The particulate matters can be removed by a suitable mechanical force. This force can be gravity, inertia or centrifugal.Based on the type of employment external or internal, mechanical devices can be chosen. A settling chamber is an example of external type of devices, its prime task is to provide preliminary separation of coarse particles to decrease the burden of the next control device. Cyclonic collectors when placed together give better efficiency of particulate collection. In cyclonic collectors the gas stream is made to flow in a curved path and the particles come out of the stream under the effect of centrifugal force.

3. **Combustion Devices** - are generally employed to convert a harmful pollutant into harmless fragments. The burning of such compounds is carried out under controlled conditions called incenerator, after-burner or furnace. Sometimes the combustion is facilitated with certain catalyst. In some cases, where mixed pollutants are involved, a preferential removal is often required. For example, it is preferred to remove gaseous pollutants [which could be harmful to the control device] from solid pollutants. During the process of combustion, heat is generated. It is necessary that the combustion process, involving destruction of harmful chemicals, must be complete. Complete combustion is achieved by maintaining sufficient temperature, sufficient time for combustion, sufficient amount of oxygen and sufficient degree of mixing of oxygen and pollutant. If the combustion is incomplete the pollutant may be converted into intermediary products leaving the problem unsolved. For many organic gases, a temperature between 350°C to 850°C is usually sufficient and the time in the order of a decimal fraction of a second is adequate. Many pollutants which are not combustible are mixed with fuel to promote their combustion. If the pollutant is flammable, it must be treated properly to avoid explosion hazards.

4. **Absorption Device and Adsorption Devices** - are mainly useful for gaseous pollutants. A suitable packing material is packed in absorption tower which facilitates mutual interaction of polluted air stream and the solid. When the gas penetrates a solid material, diffusion occurs. The concentration of a pollutant decreases in the direction of low.

   Adsorption devices are also used for gaseous pollutants. When the polluted air stream contains a mixture of several gaseous pollutants, they get adsorbed preferentially resulting into separation. Both bed adsorber and moving bed adsorber are used. Moving bed adsober offers certain advantages and can be designed in several ways.

5. **Devices Based on Electrostatic Attraction** - are electrostatic precipitators. They remove pollutants by electrostatic attraction. First, an electric charge is applied on the particles and in the next step an electric field is applied on the charged particles. Due to this treatment, charged particles migrate to the oppositely charged electrode, which ultimately collects the pollutants. The electrostatic precipitator, in general, can be employed for both liquid and solid pollutants. Solid particles get accumulated over the collecting electrode, and are then removed by shaking the electrode. Liquid droplets flow down the electrode and get collected at the bottom reservoir. The electrostatic precipitator is useful for almost complete collection of particles. It can collect solid and liquid pollutants even at a relatively high pressure and temperature.

6. **Devices Based on Entrapment Mechanism** - are used where the removal of particulate matter is more important. Scrubbers and filters fall under this category and are used for the removal of particulate matter. Water forms larger particles and sweeps through the polluted gas stream. The common mechanism

for pollutant removal is the attachment of solid substance with water droplets. These droplets are collected and treated separately to reuse the water. The most common scrubber is the spray chamber. In a filter, the polluted stream is allowed to pass through a bunch of fibress, the gas diffuses levaing the particulates on the fibers. These filters are of two types - single layer filter and packed filter. In single layer filter a cloth is used and in packed filter, fibers are loosely packed in random manner.

## 6.0 Equipments Employed for Pollution Control in Ferro-Alloy Production :

1. **Dust Chambers Cyclone Separators and Multiclones** - are employed for collecting coarser particles from the ferro-alloy furnace gases. Dust chambers are used for precleaning of gas from coarse particles having size range from 5-40 microns. In shelved dust chambers, gas velocities can be raised to 2-3 m/sec without impairing collection efficiency. In cyclone separators gases move downwards forming a peripheral vortex throughing dust particles towards the walls. Particles upto 5 microns and over can be adequately separated from gases. Multiclones are employed to handle large quantity of gases with high efficiency. In multiclones, gases [dust laden] are divided among individual cyclone units. As the gases descend, they pass through the guides of units and acquire rotary motion.

2. **Empty Scrubbers, Packed Scrubbers, Wet Cyclones and Venturi Scrubbers** - are employed to coal and clean the gases before their treatment in dust collection equipments. In empty scrubbers, water is sprayed under pressure [1960 $kN/m^2$ , 20 atm. and over] through sprayers with small orifices ranging from 1-2 mm in diameter. Particles 1-2 microns are removed by 25-60% with water consumption 2.5-3.0 cu m/1000 cu m of gas. Packed scrubber houses a packing which offers resistance to the flow of dust laden gases. Particles of 2-5 microns are collected upto 70% and particles greater than 5 microns upto 80-90%. The gas velocity is 1-1.5 m/sec. The longer time of contact between gas and liquid favours dust collection. Wet cyclone consists of vertical cylinder with conical bottom. The dust is cooled moderately from 140-180$^0$C to 40-55$^0$C aand gases leaving wet cyclones are not saturated with water. The mean gas velocity for the cyclindrical part of the wet cyclone is 5.5 m/sec. and specific water consumption is 0.10-0.20 litre/cu m of cleaned gases. As the gases enter cyclone, a portion is diluted upward following inside surface of casing and remaining revolves and descends, rebound from cyclone bottom and rises along a helical line. Dust particles are sprayed towards the surface of the cyclone and water containing dust particles trickles down the casing wall and removed through the bottom of conical part. Venturi scrubber cools down the dust laden gases to a temperature corresponding to full saturation of gases by water vapours. The velocities of dust laden gases are 70-100 m/sec. These dust laden gases disintegrate water into fine droplets, coarse liquid droplets entrap dust particles. The wet scrubber technique, though very effective, poses the problem of water pollution and disposal of sludges from the settling tank or filters etc.

3. **Electrostatic Precipitators and Fabric Filter Bag House** - Electrostatic precipitators can collect both solid and liquid pollutants. They are commonly used for gas cleaning. The use of electrostatic precipitator in ferro alloys industries has been limited due to high resistivity of dust. However, the use of fabric filters has gained popularity over the others for the ease of operation and maintenance as well as effectiveness in obtaining the desired level of particulate control in the environment. The fabric filter bag house is cheaper than wet scrubbers in operation. Synthetic fabric materials have been developed for fabric filters which are heat resistant and have resistance to chemicals, and resistance to wear and elasticity.

## 7.0 Process of Pollution Control in Ferro-Alloys Production

The air pollution control in the ferro-alloy industry is carried out by adopting the application of pollution control equipment, either singly or in combination, depending on the plant and other considerations. Various processes of pollution control are as follows :

1. The smoke gas from a ferro alloy plant is cooled in ambient air coolers and the coarse particles are taken out in a cyclone placed before the main fans. Then the smoke gas is cleaned in standard bag house filters. The filters have proven to be very effective. The dust collected is pelletised with water. In the case of ferro-silicon and silicon metal plant, the silicon dust pellets so formed can be used in a cement plant.

2. In high carbon ferro-manganese, and silico-manganese production, where the furnaces are closed type, the gas is cleaned with venturi scrubbers usually in two stages for either drying off the ores and carbon reductants or preheating the laddles and power generation. The collected dust of manganese ore in the slurry is recovered, pelletised and recycled into the furnace and the clarified water is fed to the existing water circulation system or let out.

3. In ferro-silicon and high carbon ferro-chrome smelting operation, bag filters are used for pollution control. The can withstand the temperatures usually upto 250$^0$C. The operating cost due to filter bag maintenance, electric power etc., is directly proportional to the volumetric gas flow.

4. A simple system consisting of a train of cyclone separators and air separator is illustrated in figure-1, it can remove most of the coarser particulates and fines from the furnace gas. This system can also be employed to recover silicon monoxide and dioxide and the fines of silicon metal in ferro-silicon, calcium silicon and silicon metal plants.

5. For the removal of the fine dust particles various equipments such a bag filters, wet scrubbers, electrostatic precipitators can be used. The wet scrubbers and bag filters effectively meet the clean gas dust content requirements even under fluctuating inlet conditions.

## 8.0 Illustrations of Stack emissions from a Few Ferro-Alloy Plants

8.1. **Stack Emissions from two Ferro-Manganese Plants** - Ferro-manganese plants, amongst other ferro alloys plants, are one of the potential sources of air pollution. Ferro-manganese alloy is produced in a closed smelting electric furnace. The temperature inside the furnace is about 1500°C. The dust laden gases generated during the reaction reaches the top of the furnace and exhausted into the atmosphere through the stack. The gases evolved in the furnace are discharged through the stack and the results of stack emissions from two ferro-manganese plants are as follows :

| Plant | Avg. Stack Temp. (°C) | Flow (Nm³/hr) | Dust Concentration (gm/Nm³) | Dust Loadings (MT/day) | Mn Content (%) |
|---|---|---|---|---|---|
| Plant 'A' | 341 | 4622 | 5.94 | 0.66 | 23.32 |
| Plant 'B' | 293 | 3300 | 12.00 | 1.00 | 27.00 |

The particle size distribution in the dust is as follows :

| Particle Size in microns | Weight Basis (%) |
|---|---|
| < 0.5 | 0.10 |
| 0.5-1.5 | 1.50 |
| 1.5-3.0 | 6.80 |
| 3.0-5.0 | 17.60 |
| 5.0-7.5 | 28.40 |
| > 7.5 | 45.60 |

The average gas flow is about 4000 Nm³/hr at an average temperature of 350°C. Carbon monoxide is about 15% and concentration of sulphur dioxide is negligible. Normal capacity of furnace is to produce 60 MT of alloy per day. The dust is the major pollutant emitting about 14 kg per tonne of product and about one MT of dust every day. CO content can be recoverd and used as fuel in the furnace.

8.2 **Emission of Particulate and Organic Matter from Plants Producing Silicon Metal, Ferro Silicon and Ferro Managanese[6]** : The amounts of particulate and organic generated by various ferro alloy furnaces and escaping to the environment were determined as follows :

**Particulate Matter Generated by Furnaces**

| Product | Furnace Type | Avg. Load During Tests (MW-hr/hr) | Particulate Generated (kg per hour) | Particulate Generated (kg per MW-hr)) |
|---|---|---|---|---|
| Si Metal | Open | 17.3 | 567.2 | 32.55 |
| 50% FeSi | Open | 32.1 | 234.8 | 7.36 |
| 50% FeSi | Covered | 43.0 | 307.0 | 7.14 |
| HC-Fe-Mn | Open | 2.0 | 94.8 | 4.75 |
| HC-Fe-Mn | Covered | 6.8 | 15.5 | 2.37 |

**Organic Matter Generated by Furnaces**

| Product | Furnace Type | Aveg. Load During Test (MW-hr/hr) | Organic matter Generated (kg per hour) | Organic matter Generated (kg per MW-Gr)) |
|---|---|---|---|---|
| Si Metal | Open | 17.3 | 45.7 | 2.64 |
| 50% FeSi | Open | 32.1 | 22.1 | 0.69 |
| 50% FeSi | Covered | 43.0 | 71.1 | 1.65 |
| HC-Fe-Mn | Open | 2.0 | 35.6 | 1.78 |
| HC-Fe-Mn | Covered | 6.8 | 1.69 | 0.26 |

Amount of particulate generated (per MW-hr) during the production of HC Fe-Mn, 50 percent Fe-Si, and Si Metal are in the ratio of respectively, 1:2:9. The relative rate (kg/MW-hr) at which organic matter is generated by the furnaces is somewhat surprising. Open type furnaces generate more organic matter than the covered furnaces.

8.3 **Emissions from Ferro Manganese and Ferro Silicon Furnaces** : The primary emissions from ferro-manganese and ferro-silicon furnaces contain high temperature dust laden gases. The dust primarily contains oxides of iron, silica, calcium and other elements while the chief constituants of gas phases are carbon dioxide, carbon maonoxide and nitrogen. The dust load varies between

10-20 gm/Nm$^3$ of fumes, while the current standard set by pollution control authorities requires that dust emission to atmosphere is kept below 150 mg/Nm$^3$ level. Typical composition of dust in fumes and particle size distribution of dust are as follows :

**Chemical Composition of Dust from Submerged Arc Furnaces**

| Constituent | Percent Composition Fe-Mn Furnace | Percent Composition Fe-Si Furnace |
|---|---|---|
| FeO/$Fe_2O_3$ | 10-12 | 4-6 |
| $SiO_2$ | 4-8 | 75-85 |
| MnO | 42-46 | - |
| CaO | 8-10 | 2-3 |
| $Al_2O_3$ | 8-12 | 1-2 |

**Particle Size Distribution of Dust from Submerged Arc Furnaces**

| Size (Microns) | Weight Basis (%) |
|---|---|
| 0.1-10.0 | 20-30 |
| 10-40 | 25-35 |
| 40-80 | 10-40 |
| Above 80 | 20-40 |

Particle sizes vary considerably depending upon the type of raw materials.

8.4 **Emissions of Particulates and Dust from Ferro-Alloy Furnaces**[7]
When open furnaces are used, a large amount of air flows into the hood. The gas emitted to the atmosphere contains only 0.5-5 percent of gases produced in the furnace itself. Closed and sometimes semiclosed furnaces emit relatively small volumes of gases to be cleaned and the cleaning does not present any technical problems, provided no combustion takes place. The gas contains a high percentage of carbon monoxide and is a valuable fuel.

**Typical Emissions of Particulates from Ferro Silicon Furnaces**

| Operating figure | Semi-closed furnace | Open furnace | Open furnace |
|---|---|---|---|
| Capacity ton/day | 100 | 25 | 21 |
| Gas volume, m STP/ton | 26,000 | 1,16,000 | - |
| Dust (kg/ton) | | | |
| FeSi(99%) | - | 405 | 420 |
| FeSi(90%) | - | - | 288 |
| FeSi(75%) | 215 | - | 160 |
| FeSi(45%) | 45 | - | 27 |
| Dust g/m STP | 7.3-9.1 | 3.5 | 0.42 |

The emitted particles have coarse fraction and fine fraction. The coarse fraction amounts to 10-20 percent of the solid material and contains particles from a few to several hundred micron in size. It contains 40-50 percent of coke and coal and 30-50 percent of silica. The fine fraction is mainly consisting of amporphous silica in the form of particles in the range of 0.01-1 micron. The dust emission figures from ferro-silicon, ferro-manganese, ferro-silicon-manganese and ferro-chromium and ferro-silicon-chromium are shown in the following table :

**Dust Emission from Ferro-Alloy Industries**

| Product | Type of furnace | Gas volume m STP/ton alloy | Dust kg/ton alloy | Dust gm/m STP of gas | Particle size |
|---|---|---|---|---|---|
| Fe-Si | Semi-closed | 26,000 | 215 | 7.3-9.1 | Coarse 100 micron, fine 0.1-1 micron |
| Fe-Mn | Closed | 700-800 | - | 15-40 | 0.1-1 micron |
| Fe-Si-Mn | Closed | 490-830 | 13-40 | - | 0.1-1 micron |
| Fe-Cr & Fe -Si-Cr | Mostly Open | - | 40-270 | - | 0.1-1 micron |

The coarse fraction of dust (10-20% from ferro-silicon industry consists of 40-50% coal and 30-50% of silicon and the fine fraction consists of amorphous silicon. The particulates from ferro-manganese and ferro-silicon-manganese industries constitute 70% fume and 20% manganese. The dust from ferro-chromium and ferro-silicon-chromium industries consists of amorphous silicon, metal oxide of chromium, iron, magnesium, calcium and different slag product. The ambient air around a ferro-alloy plant consists of suspended particulates of FeO, MnO and SiO upto a distance of 2500 meters from the source.

## 9..0 Illustrations of Pollution Control Systems in Ferro-Alloys Production

9.1 **Sealed Covers for Fume Control on Submerged Arc Furnaces[2]** : The special water cooled cover fabircated in 10 sections with special seals was fastened to the furnace shell, the electrode columns penetrate the cover. This sealed furnace cover is fitted with two gas off-takes, one is for start up and emergency use only, when the gas cleaning system is not in use, called raw gas stack and the other is called as clean gas stack. Under normal operating conditions, the unburned reaction gases are pulled from the sealed cover by fans and are ducted to high efficiency fixed throat venturi scrubber which washes the gases and collects the particulate matter, which then exits from the scrubber with the effluent scrubber water. The cleaned gases pass on through the fans and demisters and exit to the atmosphere through the clean gas stack when they are flared. The principle of the SF-venturi combined with a cyclone is shown in Fig. 2. The cleaning process consists of venturi stage, comprised of an inlet duck a mixing chamber and a diffuser. The second stage is connected to a mechanical separator or cyclone. In this two stage venturi, the first stage is normally used as a cooler, humidifier and precollector, while the second stage is the main collecting stage. The dust laden unburned CO gas from the furnace is led through the inlet duct A to the venturi unit C, passes the venturi throat D, the diffuser E and the cyclone F, where particles are separated from the gas. The cleaned gas leaves system at G and is either used for other purposes or burned at the top of the cleaned gas stack.

### 9.2 Two Stage Venturi Scrubbing System for Air Pollution Control from Closed Ferro-Alloy Furnace[7]

The two stage venturi scrubbing system was employed to control pollution from a closed ferro-alloy furnace. In the system unburnt CO gas is exhausted through a suction duct to the venturi scrubbing system. The first stage acts as a quencher and pre-collector whereas the second stage acts as the collector. The installation of this system includes equipment for controlling the furnace pressure. The gas volume to the venturi scrubbing system is kept constant via a differential pressure transmitter for the furnace and PID controller which acts on a control valve placed in the shunt gas path. Gas tight venturi scrubbing system is probably the only solution for pollution control because of unburnt CO gas for covered reduction furnace.

## 10.0 Conclusions and Remarks

During last three decades there is increased awareness of pollution hazards among the people and various measures are being taken to effectively protect ecology by pollution control from ferro-alloy plants also. It is extremely essential to have the knowledge of the process of ferro-alloy production, that produces pollutants, for an efficient selection of the control equipment. Emissions from ferro-alloy furnaces can be extracted by various ways. Fumes can be captured right at the source or when they come out of the furnace. Varieties of combinations of different pollution contnrol equipments have been tested to control pollution by various ferro-alloy industries. Generally wet scrubbers, electrostatic precipitators and fabric filter bag house are being employed either singly or in combination depending on the operating conditions of a particular ferro-alloy plant. The cleaned gas from ferro-alloy furnaces can be used for either drying off the ores and carbon reductants or preheating the laddles and power generation. In India the technology to recover silicon metal, oxides of silicon, ore fines and particulates is to be adopted in almost all the ferro-alloy plants employing closed or open suberged arc furnaces.

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TABLE I

COLOUR AND CONSTITUENTS OF FUMES IN FERRO ALLOY OPERATIONS

| Type of Ferro-alloy | Colour of fumes | Constituents of fumes Major | Minor |
|---|---|---|---|
| Manganese alloys FeMn and SiMn | Brown | $SiO_2$ & MnO | Carbon |
| Chromium alloys charge chrome, FeCr & SiCr | Grey | $SiO_2$ & $Cr_2O_3$ | Tar & Carbon |
| Silicon alloys, FeSi, Si metal | Grey | $SiO_2$ | Tar and Carbon |

TABLE II

THRESHOLD LIMITS OF POLLUTANTS RELATED TO FERRO-ALLOY INDUSTRIES, THEIR SOURCE OF EMISSIONS AND EFFECTS ON HUMAN BODY

| Name of Pollutant | Threshold Limit values (TLV)(ACGIH) | Effect on human | Main source |
|---|---|---|---|
| Sulphur dioxide (a colourless gas with distinctive odour) | 2 ppm | Irritates respirator system, causes bronchitis | Ferro alloy industries, more if 's' is present in excess quantity in raw materials and reductants. |
| Nitrogen dioxide (a red brown gas) | 3 ppm | Severe irritation of respiratory system. It's danger lies in delay before its full effect upon lungs is felt | Ferro-alloy industries in general. |
| Phosgene (a colourless gas with musty smell) | 0.1 ppm | Severe pulmonary oedema. There may be delay of several hours before effect develops | Ferro-alloy industries in rare cases only |
| Carbon monoxide (a colourless, | 50 ppm | Deprives body cells of oxygen, | In all ferro alloy industr- |

| | | | |
|---|---|---|---|
| odourless gas) | | causes unconsc iousness, carbon monoxide combines with haemoglobin | ies |
| Hydrogen sulphide (a colourless gas with offensive odour | 10 ppm | Respiratory paralysis, causes immediate unconsiousness. In low concentration causes irritation of all parts of respiratory system | Ferro - alloy industries in rare cases only |
| Hydrocarbons | 100 ppm to 1000 ppm | Affects central nervous system | In all ferro-alloy industries. The degree differs depending upon the content of volatile matter in the reductants used for reduction. |

TABLE III
PARTICULATE EMISSIONS FROM FERRO-ALLOY PRODUCTION

| Type of ferro alloys | Emissions, kg/tonne |
|---|---|
| FeMn | 20.0 |
| SiMn | 90.0 |
| FeSi (75% Si) | 165.0 |
| Silicon metal (97% Si) | 265.0 |
| FeCr (65% Si) | 90.0 |
| Charge chrome (50% Cr) | 75.0 |
| SiCr | 165.0 |
| FeP | 90.0 |
| FeSi (45% Si) | 100.0 |
| FeSi (90% Si) | 210.0 |
| CaSi (30% Ca) | 290.0 |
| FeCrSi (30% Si) | 100.0 |
| FeCrSi (50% Si) | 110.0 |
| Low Carbon FeCr | 100.0 |

TABLE IV
CHEMICAL COMPOSITION OF WASTE GASES AND FUME CONCENTRATION FROM FERRO-ALLOY FURNACES

| Type of ferro-alloy | Type of furnace | Chemical composition of gases (%) | | | | | | Fume concentration |
|---|---|---|---|---|---|---|---|---|
| | | CO | CO2 | CnHm | H2 | O2 | N2 | |
| Ferro-chrome | Closed | 78.3 | 8.27 | 0.08 | 6.42 | | | 4.91 at 200°C |
| | Open | 1.0 | 8.5 | 1.03 | 8.8 | 0.5 | 80.0 | 0.3 to 2.45 at 200-250°C |
| FeSi75 | Closed | 94 | 0.49 | 4.97 | 0.13 | 0.41 | | 185 to 350 at 810°C |
| | Open | 0.2 | 2.6 | | | 18 | 78.8 | 1.7 at 590-650°C |
| FeSi45 | Closed | 92.5 | 2.78 | 0.58 | 4.14 | | | 10.9 to 30 at 600-800°C |
| SiMn | Closed | 57-60 | 30-32 | 1.8 | 3.5 | 0.2-0.6 | | 8-19 at 400°C |
| | Open | | | | | | | 3.0 at 250-290°C |
| SiCr | Open | 0.7 | 1.0 | | | 14.3 | 83.0 | 0.1-0.5 at 75-200°C |
| FeSiCr | Open | | | | | | | 0.84 at 120°C |
| FeCrSi | Open | | | | | | | 3.28 at 260-300°C |

TABLE V

CHEMICAL COMPOSITION OF FUMES FROM FERRO-ALLOY FURNACES

| Type of ferro-alloy | Type of furnace | Chemical composition (%) SiO2 | FeO | Al2O3 | CaO | MgO | MnO | C | S | P | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FeCr | Closed | 10.5 to 20.96 | 10.92 to 13 | 2.5 to 7.12 | 1.84 | 15.4 to 20.5 | 2.84 | 13 | 1.241 | 0.075 | $Cr_2O_3$ = 23.56 29.27% |
| | Open | 15.83 to 20 | 5 to 7.44 | 5 to 10.0 | 0.84 | 15 to 20.48 | | 3 to 9.72 | 1.51 | 0.025 | $Cr_2O_3$ = 20-26.13% |
| FeSi75 | Closed | 94.8 | | 1.43 | | | | | | | SiC=6.99% and $Fe_2O_3$ =1.107 |
| | Open | 80-95 | 4.0 | [illegible] | 2.0 | 1.0 | | 3.0 | | | SiC=2.0% |
| FeSi45 | Closed | 72-91 | 0.9-7.00 | .56-2.5 | 0.6-23 | 2.3 | 0.7-1.49 | 0.65 | 3.70 | 0.21 | |
| SiCr | Open | 10.15 | 13.24 | 1.8 | 18.4 | 15.30 | | | | | $Cr_2O_3$ = 26.4% |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SiMn | Closed | 14.6 to 45 | 4.60 to 6.75 | 2.4 to 5.55 | 0.1 to 3.11 | 0.76 to 3.78 | 20.3 to 31.92 | 2.86 | 0.47 to 2.12 | 0.1 to 0.2 | Fe2O3 = 1 to 1.46% |
| CaSi | Open | 5-74 | 0.8 to 1.0 | 0.3 to 3 | 10 to 30 | 3 to 3.4 | | 3.0 | | | CaC2 = 2.4% & SiC 1.4% |
| FeMn | Open | 7.5 to 25 | 5.96 | 8.38 | 2.24 to 7.8 | 1 to 3.7 | 33.6 to 35.6 | | 13 | | Fe2O3 = 3.1% |
| FeSiCr | Closed | 76.48 | 12.4 | 3.57 | 3.9 | 1.09 | | 11.44 | 0.14 | 0.03 | Cr2O3 = 4.5% & SiC = 1.44% |
| FeMn | Blast Furnace | 9 to 19 | | 3 to 11 | 8 to 15 | 4 to 6% | 19.4 to 32.3 | 1.2 | | 5 to 7 | Fe2O3 = 0.91 to 1.52% |

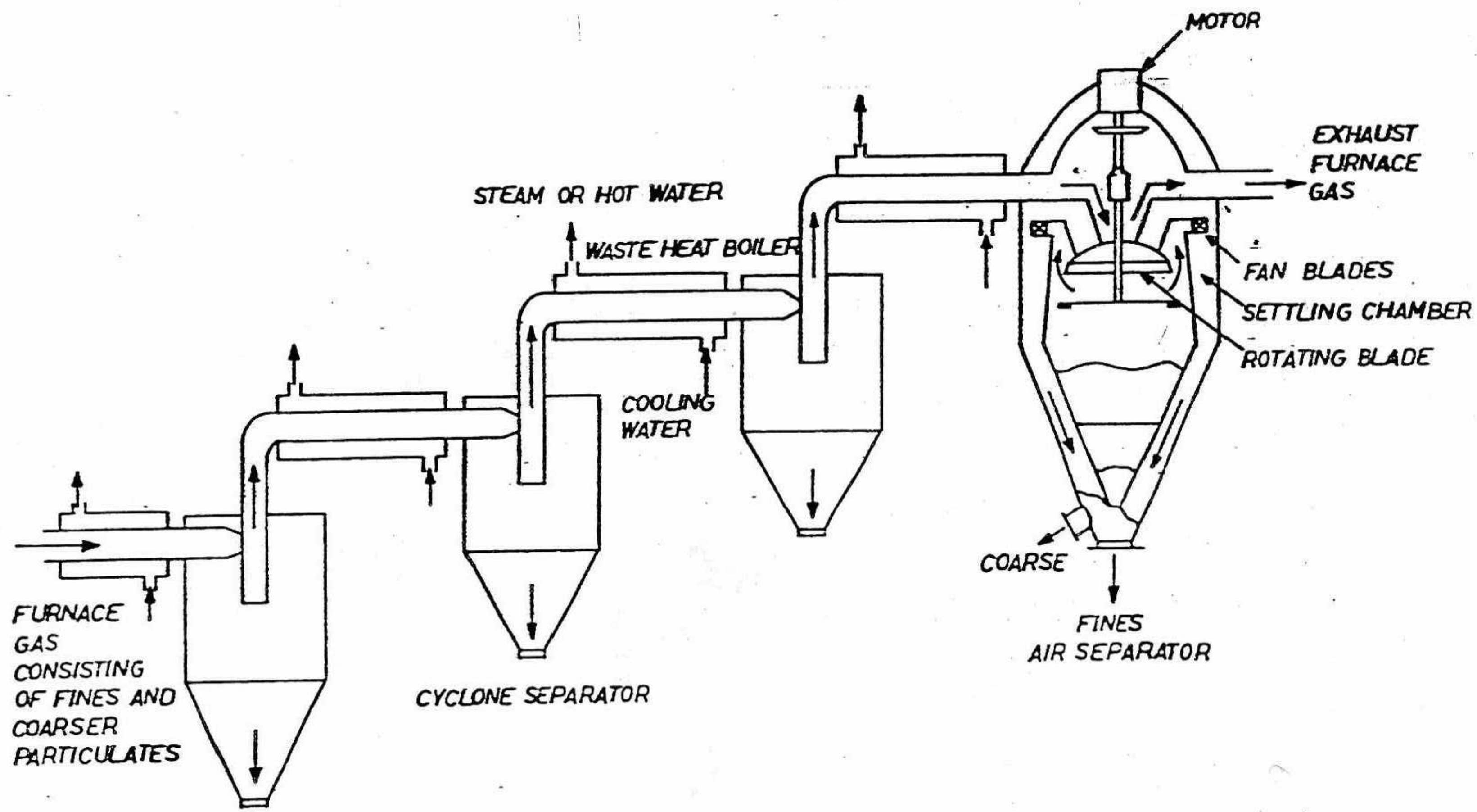


FIG. 1. SCHEMATIC REPRESENTATION OF FINE PARTICLES / COARSER PARTICULATES RECOVERY SYSTEM.

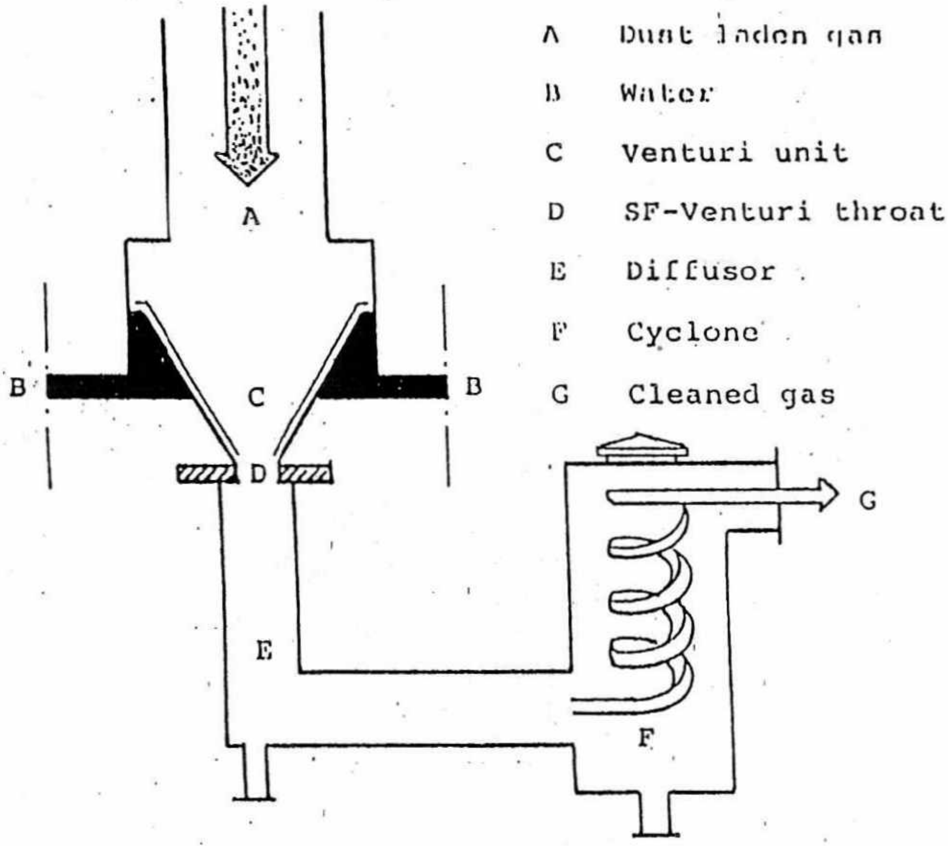


**Fig. 2—The principle of a SF-Venturi combined with a cyclone**