AIR CONTAMINANTS CONTROL IN VENTILATION SYSTEMS

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For the Degree of
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IN
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(Refrigeration & Air Conditioning)

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CERTIFICATE.

Certified that the thesis entitled " Air Contaminants Control in Ventilation Systems" which is being submitted by Shri P.K.Arora, in partial fulfilment for the award of the Degree of Master of Engineering in Applied Thermodynamics (Refrigeration and Airconditioning) of the University of Roorkee , is a record of student's own work carried out by him under my supervision and guidance. The matter embodied in this thesis has not been submitted for the award of any other Degree or Diploma.

This is further to certify that he has worked for a period of 4½ months for preparin this thesis for Master of Engineering Degree at the University.

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CHAPTER I

AIR CONTAMINANTS AND THEIR SOURCES.

Air contaminants are classified into natural and artificial type, or particulate matter and gaseous substances. The particulate matter is sub-divided into solid and liquid type or suspended and settleable type. Under each division, various air contaminants are dealt along with their sources.

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1.1. GENERAL

Air is a mechanical mixture of many gases among which Oxygen and Nitrogen are paramount ones. Trace amounts of other gases being Orgon, Carbondioxide, Hydrogen, Neon, Krypton, Helium, Ozone and Xenon, plus varying amount of water vapour and small quantities of microscopic and submicroscopic solid matter called permanent impurities. Variations in the percentage of normal constituents may render the air unfit for use. Also the presence of other foreign material called contaminants may pollute the air thus rendering it unfit for use.

1.2. CLASSIFICATIONS:

Broadly speaking, the air contaminants can be classified into two groups viz. Natural and Artificial contaminants. The atmosphere is continuously exposed to both Natural and Artificial contaminants. Aircontaminants may also be classified as Organic or Inorganic, visible or invisible, submicroscopic, microscopic or macroscopic, particulate or gaseous, toxic or harmless. Every individual contributes to natural contamination by his metabolism and to artificial contamination by his activities. Fig. 1.1. shows the chief sources of air pollution and the main constituents of many effluents.

1.2.1. Natural Contaminants

The sources of natural pollution are many. The permanent atmospheric impurities can arise from such natural processes as erosion , wind storm, sea-spray evaporation and volcanic eruption. Also as a result of natural phenomenon the atmosphere contains gases from the decomposition of animal and vegetable matter, products of weathering action and metoric disintegration, spores, pollens and bacteria. Nature plays a share in promoting chemical reactions in the presence of sunlight which converts innocuous compounds to irritating vapours and to small droplets which limit visibility ~~of~~ by scattering of light. Generally the natural contaminants are absorbed or stabilized by the atmosphere. The concentrations in the air will very considerably but will range far below the concentrations caused by man-made activity.

1.2.2. Artificial Contaminants:

Current technical data supports the idea that the contaminants which cause serious pollution are those that result from man's own activity. Man-made contaminants

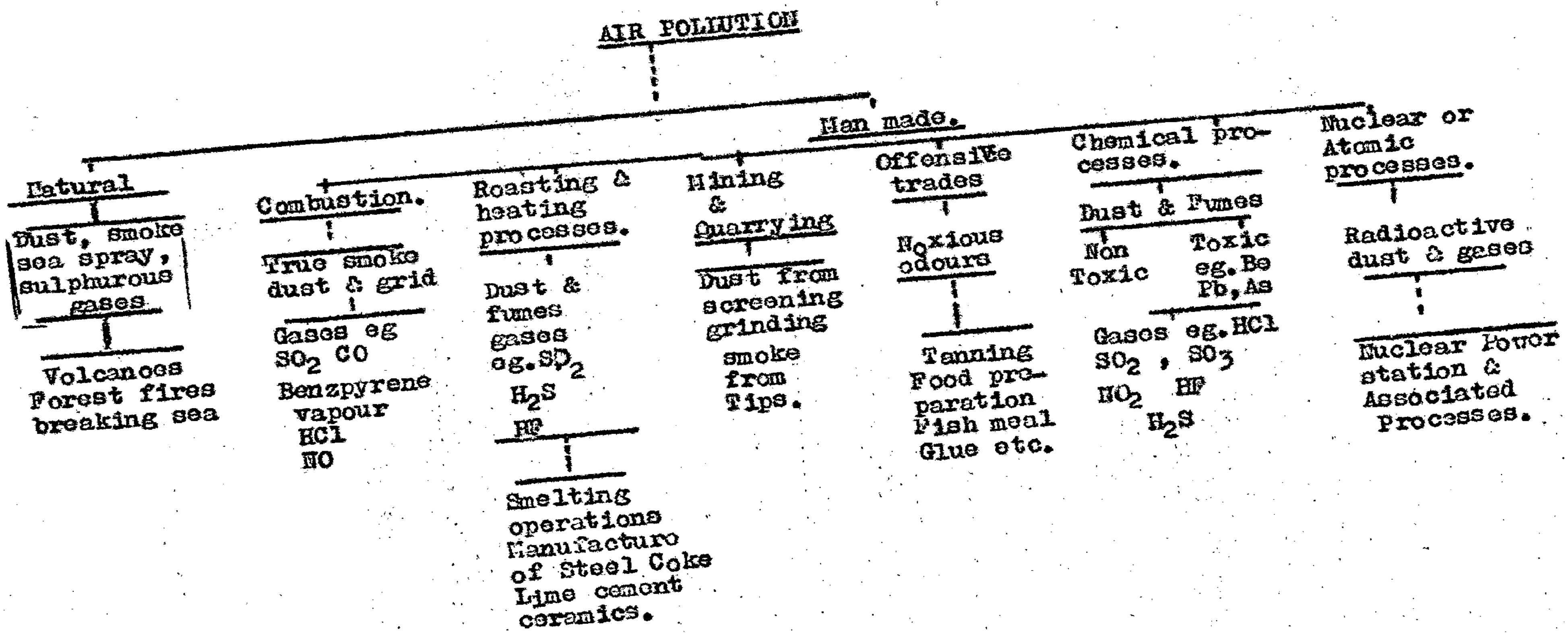
AIR POLLUTION
Natural
Dust, smoke sea spray, sulphurous gases
Volcanoes Forest fires breaking sea
Man made.
Combustion.
True smoke dust & grid
Gases eg SO_2 CO Benzpyrene vapour HCl NO
Roasting & heating processes.
Dust & fumes gases eg. SO_2 H_2S HF
Smelting operations Manufacture of Steel Coke Lime cement ceramics.
Mining & Quarrying
Dust from screening grinding smoke from Tips.
Offensive trades
Noxious odours
Tanning Food preparation Fish meal Glue etc.
Chemical processes.
Dust & Fumes
Non Toxic
Toxic eg. Be Pb, As
Gases eg. HCl SO_2 , SO_3 NO_2 HF H_2S
Nuclear or Atomic processes.
Radioactive dust & gases
Nuclear Power station & Associated Processes.

Fig. 1.1.

includes those materials added to the air deliberately for purposes of disinfection, including Ozone and various chemical sanitizers in addition to the incidental contamination of the ~~far~~ air by such processes as combustion, manufacturing, transporation and agriculture. The atmosphere is used as a disposal medium for man-made waste products. These waste products when subjected to sunlight and other natural phenomenon, cause complicated reactions, this producing a multiplicity of secondary effects. The increase in industrial activity and in the concentration of all population has resulted in an increase in both the quantity and concentration of such waste products which are responsible for serious air contamination.

1.3. OTHER CLASSIFICATIONS:

Air contaminants may also be classified on the basis of the origin or method of formation as follows :

1.3.1. Particulate Matter:

A. Liquid Particulate Matter

When the particles are large and consist mostly of water, it is common to speak of the system as a fog, mist or cloud.

i. Mists : Mists are very small airborne droplets of materials which exist in liquid state at normal temperature and pressure. They may be formed by condensation of water vapour upon suitable nuclei, atomizing of liquids, mixing violent chemical reactions, electrolytic evolution of gases from liquids or escape of a dissolved gas when pressure is released.

ii. Fogs: Forgs are airborne droplets formed by condensation of vapour. The distinction between mist and fog is of minor importance since both terms are used to indicate the particulate state of air borne liquids.

iii. Smog : It is an air mixture of smoke particles, mists and fog droplets of such small size as to impair visibility in addition to being irritating or harmful.

B. Solid Particulate Matter

i. Dusts : Generally, solid particles larger than 10 microns and smaller than about 100 microns in size are called dusts. Dusts are solid particles projected into the air by natural forces such as wind, volcanic eruption or earthquakes or by mechanical processes including crushing, grinding, demolition, drilling, shoveling, screening and sweeping or disintegration and dispersion. Dusts may be of various types viz., mineral type such as rock, metal or sand; Vegetable such as grain, flour wood cotton or pollen; or Animal including wool,hair, silk, feather and leather.

The largest sources of industrial dusts are combustion processes. About 75 percent of the industrial dust comes from fuel combustion. Both liquid and solid fuels contain some non-combustible ash, some of which is dispersed into the air during combustion. The combustion of coal in pulverized form in a power plant is considered to be one of the chief sources of fine dust in the air. The quantity of dust dispersed into the atmosphere in a large city amounts to hundreds of tons each day. Iron and Steel mills, foundries, nonferrous smelters of copper, zinc and lead; Flour and cement mills, oil refiniries, and the multitude of large and small dust producers are faced with dust problem. Foundry dusts are particularly difficult to handle because of extremely fine particles size.

ii. Fumes: Solid particles smaller than one micron in size are called fumes. Fumes are solid particles commonly formed by processes such as combustion, sublimation and condensation of vapours from normally solid materials. Metallic fumes are generated from molten metals and usually occur as oxides. Typical examples are the fumes from burning lead , or the zinc oxide produced from zinc vapour. Fumes may also be formed by distillation, galvanization or chemical reaction.

iii. <u>Smokes</u> : Smokes are extremely small solid particles ranging in size from 0.1 micron to 0.3 micron. These are produced by incomplete combustion of organic substances such as tobacco, wood, coal , oil and other carbonaceous materials. Thus smoke is a prodominantly a combustible material and consists of a mixture of solid particles such as sowt, ash, grit and gritty particles.

The souces of smoke are varied . The domestic fire is the main producer of smoke and it is emitted at a low level. The next largest producer is general industry. Many smokes such as those from wood fires or from motor exhaust contain a very high concentration of small particles while others, such as black smoke from chimneys from the combustion of coal may contain fewer particles. The steam locomotive although being smaller, is a serious contributor of smoke especially in congested areas.

Particulate matter may be further divided into two classifications viz. suspended particulate matter and settleable particulate matter.

a. <u>Suspended Particulate Matter:</u> The suspended particulate matter includes both solid particles and liquid droplets. Chemical analysis of samples collected reveals the following pollutents :

1. <u>Organic:</u> These are end products of an incomplete combustion of hydrocarbon fuels. Organic particulates

may also arise from natural causes, such as wind erosion of vegetation.

ii. <u>Chlorides:</u> Most of these compounds are waste or by-products of synthetic chemical production. Also they are formed by natural sources such as sodium chloride found in coastal areas.

iii. <u>Fluorides:</u> These may be introduced into the atmosphere by fertilizer, aluminium, steel and ceramic industries.

iv. <u>Sulphates:</u> These are formed from industrial processes Also Sulpher dioxide formed as the combustion end products is converted into Sulphuric acid by atmospheric reaction and then reacts with other substances forming sulphates.

v. <u>Nitrates:</u> These are produced by similar sources and formed in the same manner as that of sulphates.

vi. <u>Metals:</u> Metals and their oxides are contributed by industrial processes and urban activities. Measurable or trace quantities of such metals as zinc, copper, lead, chrome, iron, nickel etc., have been collected.

vii. <u>Radioactive Materials:</u> Radioactive contaminants are physically similar to ordinary industrial contaminants except that they are highly toxic by nature and may present a direct radioactive hazard both internally and externally. Therefore more stress is paid to this pollutent than others in much larger and perhaps more harmful quantities.

There are three types of hazardous radiations viz. Alpha radiation, Beta radiation and Gama radiation. Some materials may omit all three types as they are subject to radiactive decay cycle, others may be predominantly of one type or another.

Radioactive materials may originate from atomic power plants and manufacture of radio active chemicals. The air borne radioactive particles may also be dispersed in the atmosphere by atomic bomb explosion.

b. Settleable Particulate:

Large particulates are also of importance as they settle on the ground and create nuisance

1.3.2. Vapours and Gases:

Vapours are gaseous phase of substances that are liquid or solid in their commonly known state. These can be removed from air by condensation. Examples include gasoline, kerosine, benzene, carbon tetrachloride, mercury, iodine, and camphor.

The gases and vapours are usually omitted by combustion processes (internal and external), chemical and industrial processes and other similar ~~processes~~ sources. The composition of the gases and vapours varies with the nature of process. Some of the gases and vapours which are significant in community air contamination include carbon monoxide and carbondioxide; Sulphur dioxide and

Sulpher trioxide, nitrogen dioxide and nitrogen oxide, organic acids and partially oxidized organic compounds-gasoline vapours, solvents, thinners, bake oven exhaust and the like; hydrogen chloride, chlorine and fluorine. Gases with noxious odours can also be included in the list of gaseous contaminants. Vapours and gaseous contaminants will be considered in order of their prevalence and importance in air contamination:

A. Sulphur Gases and Vapours:

i. Sulphur Dioxide. Among all the compounds which contribute to atmospheric pollution, those of sulphur are the prominant ones. The effect of increase in the number of present day industries is to add to the emission of all types of sulphur compounds to the atmosphere. The largest mass emission consists of sulphur dioxide, generated by the oxidation of raw sulphur compounds in all types of fuel consumption and in ore refining. The chief sources of Sulphur dioxide in the industrial areas are the combustion of fuels, smelting & roasting of sulphide ores, refining of metals, combustion of hydrogen sulphide, in natural gas oil refinery operations and various chemical processes. Domestic sources and small apartment houses also contribute their share but to a little extent due to burning of better grade of fuel.

ii. Hydrogen Sulphide : As hydrogen sulphide gets readily burnt to sulphur dioxide, it is not often released into the atmosphere. It is one of the constituents of waste gases from pulp mills and is prevalent around sewage disposal plants, gas plants and mine seepages. It is frequently discharged into the air along with natural gas in flares from gas fields.

iii. Sulphur Trioxide (Sulphuric Acid Mist): Sulphuric Acid mist is formed during the combustion of sulphur dioxide by spontaneous oxidation in the air. It is sometimes discharged into the air from contact acid plants at concentrations as high as two grains / cu.ft. The characteristic white plume may be seen from a distance. In combustion and roasting processes, sulphates and sulphuric acids get converted into sulphur dioxide either by thermal decomposition or by the reducing action of carboneous compounds.

iv. Other Sulphur Compounds : There are several other sulphur compounds that may exist in the atmosphere as obnoxious contaminants. The persulphides of hydrogen which are formed by combination of hydrogen sulphide and free sulphur are found in the atmopshere. The other compounds being thiophene and mercaptans which are readily detected because of their extreme odour. These are generated from pulp mills and refineries.

B. Nitrogen Compounds:

Nitrogen compounds are generally not presen t in an appreciable quantity in the air so as to create any physiological effect. However, those may contribute their share in air pollution by indirect reactions. They catalyze the oxidation of sulphur dioxide particularly in aqueous solutions. They are partly responsible for the acidity in rain and fog, causing atmospheric corrosion.

The oxides of nitrogen are formed in the combustion of some fuels, particularly by oxidation of ammonia. They are also found in certain waste gases from refineries, especially those from the regeneration of cracking catalysts. These are also released but in small concentrations from certain chemical processes such as manufacture of sulphuric acid.

Amonia: Amonia is frequently present in the air. It is discharged from certain refinery operations and from chemical plants.

C. Halogen Compounds:

i. Fluorine: Fluorine is a widely distributed element. It is found almost in all coals. Most of the fluorine gets evolved on burning coal. Certain clays and iron stones contain fluorides which decompose on heating. Hence brick making from such clays and smelting of ironstone result in evolution of fluorine but in small quantity.

ii. Hydrogen Fluoride: The most important halogen compound is hydrogen fluoride. It is formed from the volatile silican tetra fluoride which yields hydrogen fluoride after being hydrolyzed by the moisture in air. Any material that contains calcium floride or the mineral fluorapatite along with sand, on treatment with acid will yield silicon tetra fluoride. Consequently, aluminium plants and phosphate fertilizer plants are sources of hydrogen fluoride. Recently, there has been a considerable use of the gas itself in the chemical industry as well as in refinery processes.

iii. Hydrogen Chloride: Some times the traces of hydrogen chloride are found in the atmopshere. It is discharged from certain chemical operations and in small quantities from refineries specially in the regeneration of cracking catalysts. The gas may also be formed by absorption and subsequent oxidation of sulphur dioxide by minute droplets of water condensed on salt nuceli.

iv. Organic Chlorides: These compounds are the most irritant of all substances, especially in the case of chlorinated aldehydes, ketones and nitriles. Cyanogen chloride (a toxic irritant gas) which is formed by the action of chlorine on hydrogen cyanide two industrial gases which are known to be discharged from certain operations.

D. Other Gases and Vapours:

i. Carbon dioxide and Monoxide: Millions of pounds of carbondioxide and carbonmonoxide are injected each day into the air by the combustion of coal, oil and gasoline.

These are also found in mine atmosphere by oxidation of coal.

ii. Methane: Amongst the gases, methane is the most important in coal mines, where it is released by the coal in large quantities. In coal mine atmosphere, methane does not occur in air above ground level. Although this gas is not toxic yet it may create explosion when 5 to 15 percent of methane forms a mixture with the air.

iii. Exhaust Gases: The incomplete combustion by hydrocarbon obtained in a deficiency of air or by sudden cooling of a flame, will produce formaldehyde, acrolein and other substances which have the physiological effects at very low concentrations. The aldehyde concentration in the air varies not only with the nature of the activity of an area but also with the density of motar traffic. Aldehydes are formed by incomplete oxidation of motor fuel and lubricating oils. The products of combustion of natural gas may also contain aldehydes. It is probable that atmospheric contamination by aldehyde is more due to exhaust and blow by gases of motor vehicles than to the waste product of industrial and heating plant sources.

iv. Organic Peroxides: Organic peroxides are found in the air but at concentrations much below 0.1 ppm. These are formed by the action of oxygen on hydrocarbon and other organic vapours especially in the presence of sunlight.

v. <u>Ozone</u>: It is present in the air to the extent of 0.01ppm but in some cities the concentration may exceed this by five-fold. Ozone is added to the air for purposes of disinfection.

vi. <u>Benzphyrene</u>: It is generally found in coal smoke, Cigarette smoke and motor exhaust.

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CHAPTER II

EFFECTS OF AIR CONTAMINANTS

The deleterious effects of air contaminants on human beings, livestock plants and structures have been discussed.

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2.1. ON HUMAN BEINGS:

2.1.1. General:

Air pollution is one of the foremost problems in public health to-day. The deleterious effects of air contamination upon human beings are such that they are not recognised. The damage to tissues of the respiratory tract or to other parts of the body may be so gradual that it is not recognised by the individual affected at an early stage. Any excess morbidity to this damage, may be attributed to a wide variety of diseases. The amount of ill health among persons subjected to air pollution for long periods of time may very well be significantly greater than the amount of ill-health among persons living in areas which are relatively free from atmospheric contamination without attracting any particular attention. It is only when the more sudden outbreak of morbidity accurs that attention is drawn to the possible connection of illhealth and air pollution.

Contaminants may find their way into man's body through mouth, by ingestion; through the long, by inhalation; and through the skin by absorption. Disease of the skin itself can be be caused by a wide variety of pollutants. In addition to these categories, contaminants may enter the body in other ways and produce harmful effects. Out of these, the effect due to inhalation will be particularly dealt as the skin absorption is of secondary importance to inhalation.

2.1.2. <u>Classification:</u>

In order to study the effects of aircontaminants on human beings, they may be classified according to their physical state, their chemical composition, or their physiological action, From physiological point of view the division can be made as follows :

A. <u>Particulate Matter:</u>

It may be subdivided into the following groups:

i. <u>Irritants:</u> Irritating dusts are those which usually produce only local reactions. Here the concentration factor is of far greater significance than the duration of exposure. Some of irritant dusts are caustics, lime, picric acid, ammonium picrate, soap powder and cereals.

ii. <u>Toxic dusts:</u> Unlike irritating dusts, toxic dusts produce remote effects which are usually systemic poisoning. They are commonly absorbed into the blood stream through the lungs, digestive tract, or skin and harm particularly organs. A dust may be both irritating and toxic.

Among the toxic dusts, lead occupies the first place in poisoning effect. The effect of lead poisoning depends upon the chemical form of the lead and on the amount absorbed. Some lead compounds are more toxic than others.

Manganese dust also creates poisoning which results in a slow chronic disease.

Arsenic dust is equally poisonous and in some cases it has caused lung cancer. The other toxic dusts are mercury, zinc, cadmium, phosphorous and certain dyestuff intermediates.

In addition to the above toxic dusts, the present day atomic energy has introduced a new potential hazard to public health. The hazard is quite large and is due to air borne radioactive dusts; The danger to human's health due to radioactive dust is thousands of times as great as the danger from non-radioactive elements with of course a few exceptions. In some cases, radioactive dust has caused lung cancer.

iii. <u>Fibrosis -producing Dusts</u> : Free silica and abestos dusts are known as fibrosis-producing dusts. They affect the lung and result in the production of fibrous tissue or scar tissue. These diseases are called silicosis and asbestosis respectively. They are not very severe but further progress of the disease may develop tuberculosis which may finally result in death.

But silica in its combined form (silicates) is harmless except in few cases.

Asbestosis affects the lung similar to silicosis but it differs in character and distribution. The further development of the disease to tuberculosis is less in the case of asbestosis than silicosis. A number of cases have indicated that asbestos acts as a contributory factor in lung cancer.

iv. Inert Dust: The word 'inert' indicates that this type of dust neither produces fibroustissue in the lungs nor causes systemic poisoning. The inert dust may consist of materials like coal, marble , emery and other foreign matters. Although the dust is inert, yet it may have an adverse effect on well being of the individual. The inert dust has a capacity to interefere with sunlight, thus minimizing the bacteriostatic and bacteriocidal effect of the sun's rays and further increasing the chance of air borne respiratory infection. Moreover, when inhaled along with fibrousis producing dusts, it creates a disease known as 'mixed dust fibrosis'.

v. Allergy - producing Dusts : This type of dust only affects those people who are particularly susceptible. They may result in diseases such as hay fever or asthma. Allergy producing dusts include pollen, certain kinds of wood dust and cotton dust, feather dust, and wool.

vi. <u>Fever -producing Substances:</u> These are usually fumes of magnesium and zinc oxide which produce metal fume fever on inhalation. The metal-fume may also occur due to exposure to other metals such as copper, cadmium, manganese, iron and antimony.

B. <u>Gaseous Substances</u> (Gases and Vapours):

They may be subdivided into four general groups:

a. <u>Asphyxiants:</u> The asphyxiants do not affect the lungs directly but creates interference with the oxidation of the tissues. This group can be subdivided into simple and chemical asphyxiants.

Simple asphyxiants are physiologically inert gases and affect only when present in high concentrations by producing an atmosphere deficient in oxygen. They may cause the dilution of the atmospheric oxygen, to certain extent that it may result in the death of the person exposed. Examples of simple asphyxiants are nitrogen carbondioxide, hydrogen, helium methane, ethane, propane, and butane. They cause asphyxia in ecnlosed spaces.

The chemical asphyxiants even in low concentrations creates interference with normal oxygenation of the tissues through their chemical action. Examples are carbonmonoxide, cyanide and its compounds. Acute cyanide poisoning is quick and death occurs in a very short period.

b. **Irritants:** Irritants are those gases and vapours which are corrosive in their action. They are responsible for the inflamation of the skin, eyes or respriratory tract. In causing inflammation, concentration of the irritant plays a more important part than duration of exposure.

Irritants affecting chiefly the upper respiratory tract are ammonia, sulphur dioxide, aldehydes, hydrogen chloride, hydrogen fluoride, ethylene oxide and sulphur trioxide.

Irritants affecting both the upper respiratory tract and lung tissues are bromine, chlorine, chlorine oxides, fluorine, iodine, ozone, sulphur chlorides, phosphorous trichloride, and phosphorous pentachloride.

Irritants affecting mainly the terminal respiratory passages and air sacs are arsenic trichloride, nitrogen dioxide and nitrogen tetraoxide, and phosgene. In confined spaces, these gases may build upto a lethal concentration which may finally result in death.

c. **Inorganic and Organometallic Gases:** The inorganic and organometallic gases are those which contain mercury phosphorous, lead, arsenic, etc., such as diethylarsine, tetraethyl lead, nickel carbonyl, hydrogen arsenide, mercury and phosphorous. These gases give rise to poisoning.

d. Volatile drugs: This group acts as simple anesthesia and does not create any serious systemic effect. [illegible]

2.1.3. Maximum allowable Concentration.

An average man can stand a certain amount of contamination. Laboratory research, field studies and industrial experience have helped in the establishment of maximum safe concentration limits. These limits are known as maximum allowable concentration (mac) and represent the amount of the contaminant to which the average worker may be exposed for 8 hours daily without significant harmful effects. It is to be borne in mind that these safe limits are not fixed values but may vary from individual to individual.

In general, the concentration of gaseous contaminants is expressed as parts of contaminant per million parts of air by volume (ppm). But when the contaminan-t is dispersed in the atmosphere in solid or liquid form such as mist, dust, or fume, its concentration is expressed in milligrams of the contaminant per cubic meter of the air (mg/m^3) or in millions of particles per cubic foot of air (mppcf). Appendix I gives a list of maximum allowable concentrations for some of the contaminants.

2.2. ON LIVESTOCK

Like human beings, air contaminants also create deleterious effects on livestock. But the mechanism by which an animal gets affected is different from that of human beings. In case of livestock, the poisoning results from eating forage which has become contaminated with airborne toxic substances. Thus the hazard is due to ingestion of contaminated forage rather than inhaling the polluted air.

Air contaminants may be harmful to the livestock in two ways. They may either directly contaminate the forages or vegetation in their toxic form or may be first absorbed and then react to form toxic materials. The former is a usual case while there is no example for the truth of the latter.

The air contaminants which are generally responsible for poisoning in livestock, are arsenic, fluorine, and lead. Among these pollutants, fluorine is the most hazardous one.

a. <u>Arsenic Poisoning:</u> It was found to be very common in areas around copper melters and resulted in considerable livestock losses. An acute arsenic poisoning also occurs when arsenic in the form of arsenic trioxide or lead arsenate is used in some insecticides. But this is of much smaller degree as compared to that resulting fro-m industrial processes. The arsenic poisoning may create uneasiness and the animal may become exhausted and finally collapse.

b. Fluorine Poisoning: Fluorine is never present in its elemental state but is always in the form of impurities, the dispersion of which may result in fluorine poisoning in live stock commonly known as 'fluorosis'. The extent of the injury caused by fluorisis to the livestock depends on the fluoride level maintained in forage over an extended period of time. Fluorine toxicosis in livestock may result in dental fluorosis. It also attacks the bones of the body, retards the growth and finally results in general ill health of the animal.

c. Lead Poisoning: Lead is a cumulative poison and may finally result in death.

2.3. ON PLANTS:

Air contamination also causes injury to vegetation. Infact a contaminated atmosphere may injure plant life more than animal life, The damage may be caused by a small number of contaminants present in relatively low concentration. The main contaminants responsible for plant contamination are sulphur dioxide, hydrogen halides, and halogens (particularly hydrogen fluoride) , smog gases and organic compounds (aldehydes, ketones, organic acids and chlorinated compounds). In enclosed places like greenhouses, ethylene, hydrogen cyanide and mercury vapour have caused injury to vegetation. There are other contaminant such as hydrogen sulphide, nitrogen oxides, ammonia and carbon monoxide which are usually not present in high concentrations so as to be harmful to plant life. Plant species are identified by patterns of leaves and flowers and by their growth habits. Under normal conditions, they develop certain known characteristics but when they get contaminated due to air pollutants, they develop certain symptoms on the leaves or flowers which reflects towards tho contaminants responsible for it. Effects of some of the contaminants on plants are dealt seperately as bollow :

a. Sulphur dioxide: Acute sulphur dioxide injury to vegetation results in the killing of sharply defined marginal or intervoinal areas of the leaf, which subsequently dries up and usually bleach to an ivory colour. This, however, does not lead to the collapse of the leaf. The long continued exposure of the sulphur dioxide leads to the build up of the sulphate content and at length the leaf is shed. Different species of plants and the same plant grown in different environments vary in their susceptibility to sulphur dioxide.

b. Hydrogen Fluoride: Short exposure of low concentration hydrogen fluoride to vegetation usually results in interveinal and marginal acute markings. The various plants affected by hydrogen fluoride are those of pines, conifers, rye, oats, barley, wheat prume, peach, etc. In some cases such as fruit trees, there results an extensive shedding of the injured leaves. In addition to hydrogen fluoride, there are other fluoride compounds such as silican tetrafluoride which is in no way less than hydrogen fluoride as an injurious contaminant to vegetation.

c. Miscellaneous Fumigants:

i. Chlorine: Damage to vegetation by chlorine is generally rare. Infact, chlorine is more toxic to vegetation and results in marginal and intervenial injury. It damages vegetation like peach, buckwheat, beans etc.

ii. Hydrogen Chloride: Hydrogen Chloride is sufficiently less toxic to vegetation than sulphur dioxide. The gas is absorbed by the vegetation and results in the build-up of chloride on the leaves. The threshold concentration is about 100 ppm for a few hours fumigation.

iii. Nitric Oxides: Nitric oxides injury creates brown margins and black spots on the leaves. It affects grain plants and conifer. The damaging effect accurs at about 25 ppm concentration.

iv. Ammonia. Ammonia is a gas of intermediate toxicity. But the characteristic injury due to ammonia differs from the previously described gases. Practically all parts of the leaf are affected rather than any particular region. After a long exposure the leaf loses its colour become brown upon drying.

v. Hydrogen Sulphide: Hydrogen Sulphide is less toxic to leaf tissue than other gases. Plant damage due to hydrogen sulphide occurs generally due to accidents which increases its concentration in the atmosphere. The main difference between injury caused by hydrogen sulphide and sulphur dioxide is that hydrogen sulphide injures the yongest leaves rather than the middle aged or older leaves. The plants most sensitive to hydrogen sulphide injury are cosmos, radish, poppy, etc.

vi. Ethylene: It causes injury to the leaves even in small amounts. It may retard the growth of the plant and may result in the shedding of the leaves. The most sensitive vegetation are sweet peas, tomatoes and buckwheat.

vii. Smog: Smog also causes injury to leaves of certain vegetation. The degree of plant injury depends not only upon the quantity of contaminants which contribute to smog formation but also upon meteorological factors. The smog injury may be either due to gases (smog gas) or due to deposition of fog droplets on the leaves. The leaf lesions due to smog gas appear as a so-called 'silver leaf' on the under surface of the leaves of many plants such as beets, spinach, alfalfa, and many other plants. If the smog is severe, the injury may result in the total collapse of certain areas. The other type of injury on plant leaves enough acids along with some toxicants. This results in spot-type of lesions. This leaf spot injury occurs in alfalfa, spinach and other plants.

2.4. ON STRUCTURES:

The effects of air contaminants on buildings are apparent in residential as well as in industrial areas. It results in the discolouration and disfigurement of the buildings. Sulphur dioxide leads to the development of decay in limestone and other building materials containing carbonates. It also induces decay in the neighbouring materials which are not directly exposed to sulphur dioxide. The damaging effects are seen in the form of blistering and scaling of the surfaces. It also contributes in the corrosion of some of the metals (iron, steel and zinc) used in buildings.

The damage to building due to emissions of smoke and fume is easily recognized by their poor appearance. It leads to the disfiguration of building by sooty deposits.

In case of paints, sunlight plays the most important part in deterioration. Air contamination makes it to lose its appearance but does not affect its durability. This is seen by the blackening of white lead-base paint when it comes in contact with hydrogen sulphide.

The effects of air pollution on buildings varies with the circumstances. Some materials may be more resistant than others. The damage to buildings takes place in a short time but it seldom leads to any great depth.

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CHAPTER III

AIR SAMPLING AND CONTAMINANT EVALUATION

Depending upon the type of contaminant, air sampling devices have been classified into two groups; Particulate matter sampling devices and Gaseous substances sampling devices. The former type group has been subdivided according to the principle of collection while the latter group according to the methods adopted for contaminant evaluation in the field and laboratory.

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3.1. GENERAL:

The solution of an air pollution problem requires sampling and analysis of the contaminated atmosphere. The aim of sampling is primarily to determine types and properties of impurities, degree of contamination and presence or absence of toxic or harmful substances. The collected samples also provided quantitative information. The analysis of the contaminants present in the samples helps in the development of remedial measures and establishment of base level concentrations for legislative proposes. It also gives an idea regarding the performance of the air cleaning equipments and serves as a basis for future reference.

The determination of the atmospheric contaminant size and concentration requires a suitable equipment which may extract a representative sample from a major volume of air and concentrate the contaminants in such a manner as to permit subsequent measurement. The complete assembly consists of a source of vaccum, a metering device for the measurement of the quantity of gas sampled and one or more of the collection devices. The analysis of the collected material is usually done in a laboratory. By proper combination of collection technique and analytical procedure the units can be devised very specific for a number of contaminants.

3.2. TYPES OF SAMPLING DEVICES:

Sampling devices are classified into two groups:

3.2.1. Sampling Devices for Particulate Matter.

3.2.2. Sampling devices for Gases and Vapours.

3.2.1. Particulate Matter Sampling and its Evaluation:

The sampling instruments for particulate matter may be classified according to the physical basis of operation, under the following groups :

a. Gravity Settling Devices: The principle of settling technique is adopted in the following equipments:

i. Deposit Gauge: It is the earliest form of apparatus and is meant for open air sampling. It consist of a glass work in the form of a bowl about 12" in diameter and this is supported on a metal tripod . A wire screen is provided at the top for some protection to the bowl. The collected material along with the rain water goes into a bottle of approximately 10 litres capacity. 1.

During sampling work the deposit gauge should be so located that it is away from any nearby object which may otherwise affect the collection of particulate matter. After a month, the gauge is examined. About 500 ml of water is poured into the bowl to wash the deposited matter adhered to the inside surfaces ~~t~~of the collecting bottle. The collected material is analysed for dissolved impurities and undissolved matter. The result of the analysis of deposited matter are usually expressed in Tons per sq. mile per month for a particular area. It is noted that the amount of material collected by the deposit gauge does not represent the weight discharged by the chimneys in the area concerned. However, it is a useful instrument and provides with the measurements of varied types of contaminants present in the atmosphere.

ii. <u>Petri Dishes:</u> Petri dishes are employed for quick determination of the distribution of deposited matter in a given locality. They are exposed for a period of 24 to 48 hours in a calm and dry weather. The dishes are placed usually at intervals of quartermile to half a mile.

To determine the amount of collected matter, it is brushed on to a watch glass and weighed to an accuracy of 0.1 mg. A microscopic or chemical examination of the collected material may be carried out to identify a particular source of pollution. The results are generally expressed as the deposits in tons per square mile per month, with the help of petri dish surveys, contour lines of equal pollution may be drawn on maps.

iii. <u>Settling Chamber:</u> It is one of the simplest method of sampling particulate matter and is adopted for particles as small as about 1 μm in size. In this a volume of air is entrapped in a wooden chamber and the particulate matter is allowed to settle on microscope slides.

Settling chambers are available in different sizes and shapes. A convenient size consists of a wooden box about 1.5 ft. square and provided with a door on one side. Microscope slides are provided on floor, ceiling and walls of the box. The Chamber is placed in the path of the contaminanted air at a suitable location. If the air to be sampled occupies a large volume, it can be gently fanned into the box. After collecting a representative amount of dust laden air the chamber is closed and is kept in the same position for about 16 hours. This results in the removal of the particulate matter from the static volume of air and finally in its settlement on microscope slides. The slides are studied under a microscope and the size as well as concentration are determined.

Settling cahmbers can also be used for collecting droplets on especially prepared slides which are usually coated with petroleum jelly for droplot preservations.

b. Filteration Devices: The removal of the particulate matter from the contaminated air stream by filteration provides an easy means for sampling. The most important factor in filteration is the particle size. The different mechanisms involved during filteration and the size range over which each is most effective is as shown in the Table 3.1.

TABLE 3.1.

Mechanisms invol-ved in Collections of Particulate matter By Filteration

Mechanism	Particle diameter µ
Diffusion	0.3
Interception	1(depends on fiber size)
Inertial (impingement)	0.5
Electrostatic attraction	0.01 to 01.0
Sieving	0.1 (depends on pore size)

From Table 3.1. it is evident that electrostatic attraction is very affective in the removal of very small aerosol particles. Filters made of certain plastics and resins possess the property of developing sufficient electric charge, during sampling.

A number of materials are used as filter bodies such as porous paper, porous ceramics, cotton, wool, glass-cloths, packed asbestos mats, etc. The choice of the filter media depends upon the size as well as the type of the contaminant. The following are the types of filters commonly used in air sampling.

1. <u>Thimble filter:</u> It is widely used for sampling explosive dusts. The paper thimble apparatus makes use of a whatman extraction thimble filled with fluffed - out cotton to reduce clogging and is operated at a sampling rate of 2 cfm

From the change in weight of the dried. thimble, the dust concentration in the air is determined .

ii. Sugar crystal filters. Filters consisting of soluble sugar crystels can also be used for sampling due to its high affinity for dust particles. After sampling, the filter is dissolved in some suitable solvent and the resulting suspension of the collected particles is studied microscopically or by sedimentation techniques. This method of sampling finds much application in mines. But it suffers from a draw back that most of the sugar crystals carry enough contaminants or dusts in the original form.

iii. Molecular or Membrane filters: The molecular or membrane filters (also known by the trade names of Millipore and Isopore filters) are found to be quite suitable for air sampling. They are made of a mixture of cellulose nitrate and acetate and remove particulate matter by screening action. These filters are nearly 100 percent efficient for particles greater than 0.1 micron in size. They are commercially available as three types : HA (Hydrosol assay), AA (aerosol assay), AP (aerosol protective) . The pore sizes of these filters are as shown in the Table 3.2.

TABLE 3.2.

Pore sizes of Membrane Filters.

Filter type	App. Pore size /u
HA	0.1 - 0.5
AP	1·2 ~~1.2~~ - 1.6
AA	0·5 - 0·7

Particle counting and its size distribution are determined by a light field microscopic method. The particle counts divided by the volume of air sampled gives the dust concentration. If the dust concentration is high or sufficient volume of air is sampled, the filter can be weighed in a balance and the concentration is calculated in terms of the weight per unit volume of air sampled. Care should be taken to avoid the moisture adsorption.

Dust concentration can also be determined by photometric measurements of dust spots on the filter paper. The darkening of the filter paper gives an idea regarding the concen ration of the contaminant. It is measured by the light reflacted from the deposit.

c. Impingement Devices: A better developed form of sampling device is an impinger working on the principle of impingement. In this instrument a dust laden air stream moving at high velocity is allowed to strike a stationary surface placed perpendicular to the axis of the air stream. The sudden change in the direction of flow with the consequent loss of kinetic energy of the contaminant separates the particles from the air stream. A number of instruments operating on this principle have been devised. The important ones are the Konimetor, Owen's jet, Sonkin cascade impector, Greenburg-smith apparatus and midget impinger.

1. The Konimeter: This instrument was originally devised by R.M. Kotze and later modified. In its modified form it consists of a nozzle 0.6 mm. in diameter through which the dust laden air is drawn and allowed to impinge upon a circular collecting plate placed at a distance of 0.5 mm. from the end of the nozzle. The air stream is induced by a small valveless spring-operated piston pump. The collecting plate is covered with a thin adhesive (glycerine jelly) film which traps and retains the dust.

On passing the air through the konimetor, the sample obtained on the collecting plate is in form of a spot. Several samples can be taken on the same spot so as to estimate the average concentration. Provision is also made to study thirty such samples on a single plate.

Konimeter samples can be evaluated by using a microscope with light field illumination and provided with a holder so as to facilitate the rotation of the collecting plate for counting different samples. The dust concentration is expressed in terms of million particles per cu.ft. of air.

The Konimeter has a low dust collecting efficiency and is unsatisfactory for high dust concentrations. But it is the single sampling device and is the most compact one. Ease and speed of sampling and counting are the main advantages of this method. Although the counts are considerably below those obtained with other types of impingers, yet it is quite useful in estimating the effectiveness of dust-control methods.

ii. Owen's Jet Dust Counter : This impingement device was introduced by Owens and is somewhat similar to the Konimeter. In this instrument, the air sample (50 ml. or more) is ~~qu~~ first drawn through a moistening chamber and then through a stream lined rectangular nozzle of 0.1 cm x 1.0 cm. in dimension. The air finally impinges on a glass cover placed in an air tight chamber which is provided with a hand pump. The high velocity air coming out of the nozzles undergoes a pressure drop which subsequently lowers the temperature resulting in the condensation of moisture on the dust particles. This helps in the collection of the particles on the cover glass which is not given any adhesive coating as in the case of Konimeter. Later on the moisture goes away leaving the dust on the cover glass.

The ribbon of dust obtained on the glass cover is not uniform and as such creates difficulty in counting. It possesses all the disadvantages as that of Konimeter in addition to varying efficiencies depending upon the pull on the pump plunger. Hatch and Thompson have modified this instrument which enables to obtain sixteen samples on a single cover slip.

The cover slip with dust deposit is mounted with its side down on a microscope slide and examined under a microscope with dark field illumination. The dust c concentration is expressed as in case of Konimeter.

iii. Sonkind Cascade Impactor: This is a better form of impingement device. In this instrument(Fig. 3.1) the dust laden air passes through a number of jets of decreasing apertures and as such the speed of air through the jets becomes progressively greater. This results in the simultaneous collection of particles by impingement on glass plates as well as their classification according to size ranges. The largest particles collected on the slide opposite the first jet and the smallest ones on the slide opposite the last jet.

The collected material on the slide is examined under on electron microscope. The separation of the particles according to varied size ranges affords facility in counting. Cascade impactor is more efficient that single jet-type instrument and can be used effectively for sampling of particles over a wide size range.

iv. A continuous Sampling Impinger: In this device dusty air is drawn through a jet and impinged against a rotating drum. This leaves black or grey marks on the white paper rapped round the drum. Provision is made for the automatic recording of the dust concentration from the shaded intensity of the dust spot.

v. Greenburg - Smith Apparatus: It is a standard impinger (Fig. 3.2) and is widely used for dust sampling. The air is drawn through an orifice 2.3 mm. in diameter at the rate of 1 cubic foot per minute and impinged against a glass plate located perpendicularly at a distance of 5 mm. from the orifice. The bottom of the sample flask may also serve as the plate. The plate is covered with distilled water (at least 1" in deepth) or some other liquid to collect dust particles on impingement. The air is usually drawn with the help of an electrically driven air pump.

The device is an efficient one for sampling all air borne dust above 0.7 μ in diameter. However, by arranging two impinger flasks in series, the particles which are generally below 0.5 μ in size, can also be sampled.

The sample collected in the impinger flask is diluted with sampling medium (distilled water or some other liquid) depending upon the size of the sample, the dust concentration and the method of counting. After proper agitation of the impinger flask, sufficient sample is transferred into a clean sedgwick-Rafter cell for counting the particles under a microscope with light field illumination. A microprojector can also be used for both counts and particle size determinations.

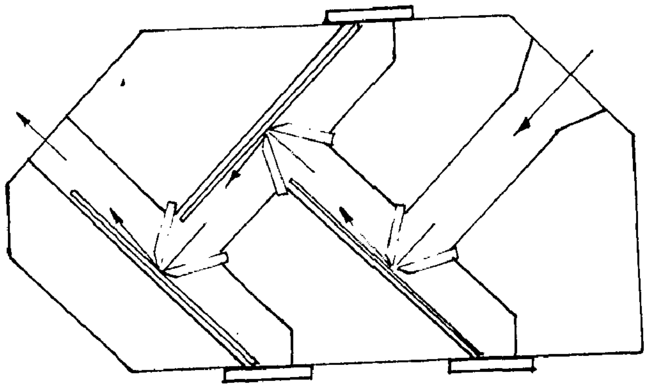

FIG. 3.1

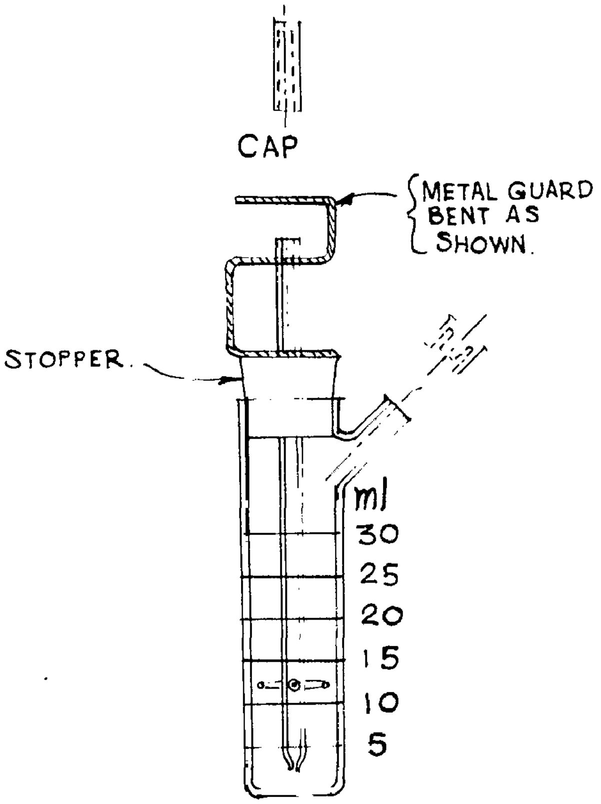

FIG. 3.2

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vi. The Midget Impinger: It is similar to the Greenburg-Smith standard impinger. In place of electrically driven pump, it is provided with a hand operated pump. By hand cranking the air is drawn through an orifice of 1 mm. in diameter at the rate of 2.8 litres per minute. The sampling and the counting are done in the same manner as the standard impinger. Midget impinger is quite efficient in sampling the dust particles ranging in size from 0.7 to 10 μ. It can also be used for sampling flammable dust for which standard impinger cannot be used.

d. Thermal Precipitation Devices: Thermal precipitaters are more efficient than the impactors, especially in the collection of particles less than 1 μ in size. The operating principle of this instrument was first pointed out by Aitken in 1870. The particulate sampling is done by taking advantage of the presence of particle-free atmosphere around a hot surface. When the dust laden air is passed between a heated wire and adjacent coated glass plates, the fine particles that are repelled from the hot wire , collect on the glass plates according to size in the direction of air travel. The thermal precipitator appears to precipitate all the fine particles, but it should be operated at low air ~~flows~~ rates. These flow rates can be increased by replacing the wire by a flat ribbon.

Green and Watson devised a thermal precipitator (Fig. 3.3.) for the collection of industrial dust samples. In this the dusty air is drawn by water displacement through a slot 0.051 x 0.95 cm. in cross section at about 0.7ml./minute. A michrome wire of 0.025 cm. in diameter is located centrally in the slot. This wire is heated electrically to a temperature of 100°C. The walls of the slot are formed by"3/4" cover slips backed by brass blocks for cooling. On passing the air between the hot wire and the cool surface of the cover glass, the suspended dust particles are deposited upon the cover slips. The particle counting of the deposited matter is done under a microscope. To facilitate particle counting, Laskin provided the plates with an oscillating mechanism so that the particles are spread over a larger area with more uniform distribution. A further improvement is attained by rotating the collection plate. Thermal precipitators are almost 100% efficient for all dust particles ranging in size from0.2 -20.0μ.

e. <u>Electrostatic Precipitation Devices</u>: Electrostatic precipitation is a very efficient method for collecting all types of small particulate matter. Both alternating (AC) and direct current (DC) precipitators have been used as air sampling devices. They are more advantageous over the other sampling devices in that the air flow rates are high enough which result in the rapid collection of the weighable material. To facilitate accurate weighing, the weight of the collecting electrode is usually kept low.

The particulate collection unit of the precipitator consists of electrically grounded collecting surfaces or electrodes in the shape of pipes or plates and the charged electrode in the form of wire or rod is located at the centre of the pipe or midway between the grounded plates. The charged electrode is kept insulated from the collecting electrode as well as the shell of the insulator is connected to the source of high voltage current. The voltage used ranges from 8000 to 30,000 volts. On passing the dust laden air through the collection unit, the particles get charged and under the influence of the existing electrostatic field, they are driven in a direction perpendicular to the air motion. and are precipitated on the collecting surfaces. A microbalance may be used to weigh the collecting electrode before and after sampling so as to determine directly the weight of the dust collected. The weight of the deposit can also be determined by weighing a small beaker (10 ml) into which the collected material has been transferred by rapping or some other device.

Electrostatic sampler usually handles contaminated air or gas stream upto 1200 deg. F. The presence of moisture does not affect the collection efficiency. The precipitater should be operated such that the relationship of tube diameter, airflow and voltage must be within certain limits in order to approach the maximum efficiency of 100 percent. This device is suitable for sampling fumes, smokes, or other suspended matter with a particle size below 3/4" /u in diameter. It is, however, not suitable for sampling in

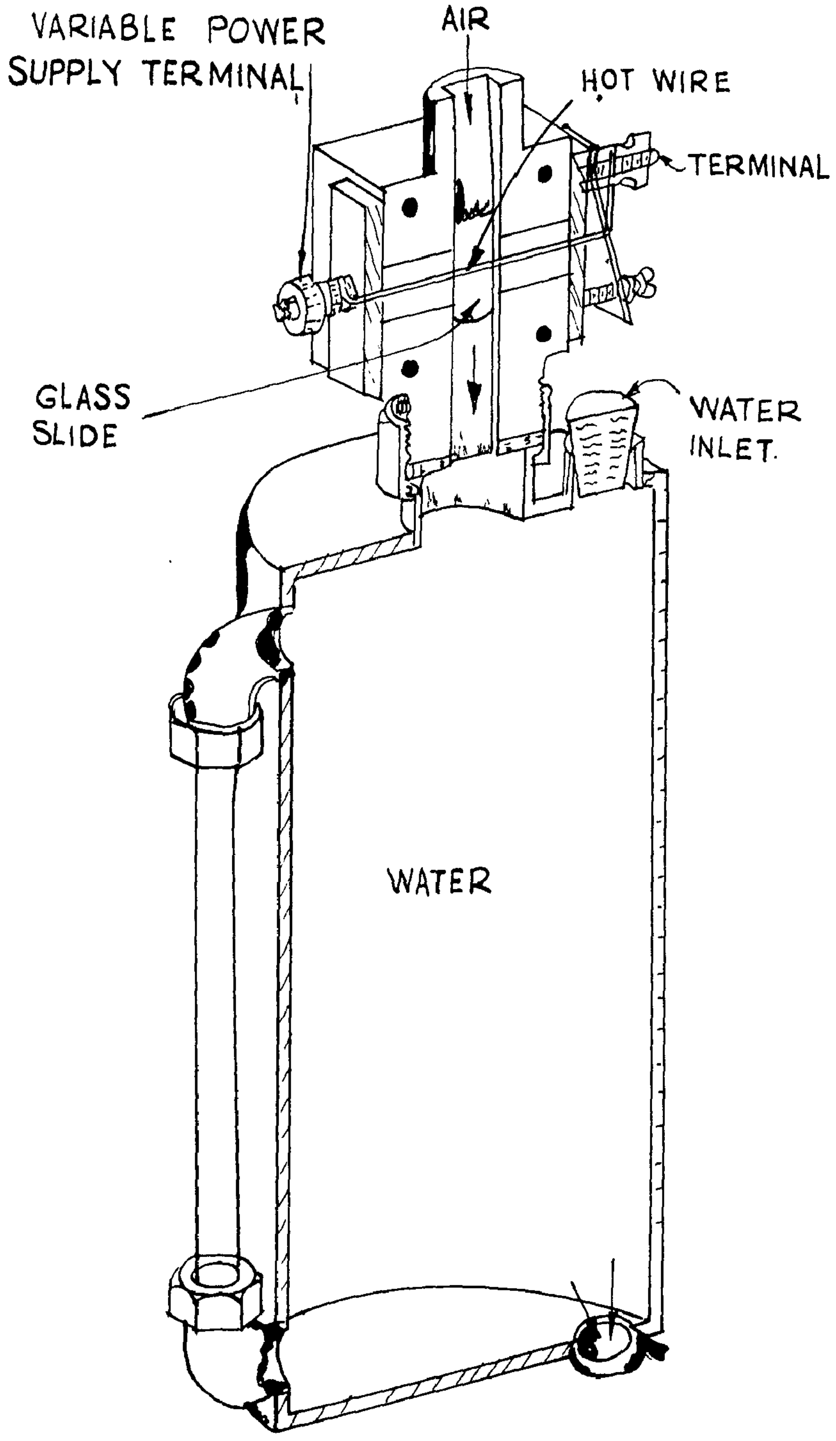
VARIABLE POWER SUPPLY TERMINAL
AIR
HOT WIRE
TERMINAL
GLASS SLIDE
WATER INLET.
WATER

FIG. 3.3

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3.2.2. Sampling and Evaluation of Gases and Vapours:

A. Methods Giving Quantitative Results in the Field:

a. Evaluating the Intensity of Odour and Irritation: Most of the gases and vapours in the air may be detected and estimated by their characteristic odours and irritant effects. The odours can be classified into six classes as follows: spicy, flowery, fruity, resinous (turpentine) foul and scorched. Odours are best determined by the first and second inhalations. Katz and Allison devised the odour and irritation scales as shown in Table 3.3 and 3.4.

Table 3.3.

Scale of Odour Intensities.

Degree	Intensity.	Description.
0	No odour	No detectable odour.
1	Very faint	~~Min.~~ Minimum but positively perceptible odour.
2	Faint	Weak odour, readily perceptible.
3.	Easily noticeable	Moderate intensity.
4	Strong	Cogent, forcible odour
5	Very strong	Intense effect, may irritate.

Table 3.4.

Irritant Scale (Nasal Irritation and Eye Irritation)

Degree	Intensity	Description.
0.	No irritation	Not detectable.
1.	Faint	Just perceptible,not painful.
2.	Moderate	Moderate irritation, midway between 1 and 3.
3.	Strong	Discomforting, painful, but may be endured.
4.	Intolerable	Exceedingly painful, cannot be endured voluntarily.

Although the odour and irritation method of evaluating exposures is very useful, yet it suffers from some limitations. It does not offer any record. Moreover the sensitivity of the sense of smell varies from individual to individual, and the sense fatigues rapidly. So this method gives only a rough estimation regarding the concentration of gaseous contaminants.

b. Portable Rapidly Indicating Devices: These devices are not specific. But they are quite advantageous due to their portability and immediate availability of results.

1. Interferometer: The most widely used physical instrument is the 50 cm. portable gas interferometer. This instrument accurately measures minute changes in refractivity due to the presence of gaseous contaminants in the air stream. The comparison is usually made with dry air from which carbon-

dioxide is removed and the dry air is maintained at the same temperature and pressure as that of the contaminated air. The instrument may be calibrated against known concentration of gaseous contaminant in the air within the range for which it is to be employed. It may also be calibrated for absolute refractivity changes (refractivity factor). Now the instrument scale reading can be directly converted to concentration value by using unit refractivity change due to the presence of gaseous contaminant.

$$\%\ \text{vapour in air} = \frac{\text{interferometer reading x refractivity factor (of instrument)}}{\text{Unit refractivity change (of vapour).}}$$

It is to be noted that the refractivity of a mixture of vapour is the sum of the refractivities of the components. As such interferometry method is more specific if the sampling air contains a single gaseous contaminant.

ii. <u>Portable Orsat Apparatus</u>: For the determination of Carbond-dioxide, Oxygen, nitrogen, methane and some other combustibles, including carbon mondxide in high concentrations, Orsat gas absorption device is a convenient means of estimation. It consists of a 100 ml gas buret and four pipets. The first three pipets contain sodium hydroxide, alkaline pyrogallate, and acid cuprous chloride solution for the absorption of carbond dioxide, oxygen and carbond monoxide respectively. The fourth pipet is a slow combustion pipet for burning combustible gases. The volume of the absorbed gas is read directly by noting the increase in the water level of measuring tube. The limit of accuracy is 0.2 to 0.3 percent. The chief application of this device is in the analysis of the atmopshere in mines.

iii. Combustion Devices: These devices are meant for flammable gases and vapours. The contaminated air is drawn across a platinum filament which is heated by a dry cell. This filament forms one arm of a wheatstone bridge and is balanced against another heated filament in an inert atmosphere before it is used for contaminant evaluation. On drawing the sample air across the hot filament, any combustible gas present is burned catalytically. This increases the tepperature of the filament and consequently results in an increase in resistance to the flow of electricity. The increase in resistance is proportional to the amount of flammable gases or vapours in the sample air and the concentration is directly measured by a meter. These instruments are very useful in evaluating fire and explosion hazards. 'Benzene indicator' and 'Carbon monoxide indicator' are the examples of combustion devices. All the combustion devices should be checked periodically against known mixtures of the vapour to be analyzed.

iv. Ultraviolet Absorption Devices: In these devices, ultraviolet absorption is used for the evaluation of mercury vapours, trichloroethylene and some other vapours. In the device for measuring trichloroethylene, light of a fixed wavelength in the ultraviolet range is passed through an absorption cell onto a cell sensitive to ultraviolet light.

When an air sample free of dust and containing vapours having an opacity to light of this wave length is passed through the cell, the depletion of transmission is measured and this is proportional to the concentration of the vapour present.

c. **Collection in Indicator Medium:** Some of the gaseous contaminants may be collected in a liquid medium contained in scrubbers or impingers. The volume of the ~~gas~~ sampled air which brings a change in the colour of the liquid medium, is measured. The colour change is used to estimate the concentration of the gaseous contaminant. Ammonia, hydrogen sulphide, sulphur dioxide, hydrogen cyanide, acid gases, etc., can be determined by this method. This method of concentration determination is quite accurate. The accuracy usually depends upon gas sampled and the efficiency of the scrubber.

d. **Hard Piston Pump and Rubber-Bulb Collection Devices:** These devices such as MSA hydrogen sulphide detector, aromatic hydrocarbon detector and P.S. (Pallado-sulphite) Carbon monoxide detector are used for quick and approximate determination of gaseous contaminants. Sample air is drawn through the granular gels by hand pump or rubber aspirating bulb. The gels impregnated in different compounds are used depending upon the type of contaminant to be determined. The presence of the gaseous contaminant in the sample air changes the colour of the gel. The change in the colour of the gel is used for quantitative estimation. by matching with standard colour cards. The length of the coloured column or the volume of sample air necessary to produce a desired colour may be used for the determination of gaseous contaminant. The volume of air sampled is measured by the number of piston strokes. The gels impregnated in different compounds are used depending upon the type of contaminant to be determined.

B. Methods Requiring Laboratory Analysis:

a. Halogenated Hydrocarbons Combustion Apparatus: Several devices have been used for the combustion of halogenated hydrocarbon vapours in the atmosphere. In the combustion tube method, the contaminated air is passed through a heated tube containing a platinum foil. The product of combustion are collected in a suitable flask and the concentration is determined by titration in the laboratory. In the modified combustion method known as the sulphur lamp method, some suitable medium is used for scrubbing the vapour from the air and this may be then burried in the lamps. The combustion methods are generally used for the determination of chloride, bromides, iodides, organic halogens and acid halogens. As organic halogens cannot be differentiated from acid halogens, their concentrations can be determined by filtering out the acid halogens.

b. Adsorption for Evaluation by Weight: This method is applicable to gases and vapours of high molecular weight and moderate toxicity. The usual adsorbent is an activated charcoal or silica gel placed in a weighing tube which is provided with a filter on either side of the adsorbent. The filter proceding the adsorbent is meant for the removal of carbondioxide and water vapour from the air sampled. The filter following the adsorbant is used to collect carbon - dioxide and water which may be lost by the adsorbent as the air is passed over it. The contaminated air is drawn through the adsorbent at a constant rate and after a suitable sample is collected the tube with its contents is weighed. The difference in the weight of the tube before and after sampling gives the concentration of the gaseous contaminant. This adsorption method collects an integrated sample and is more applicable to gases of high concentration which reduces the sampling period.

c. <u>Condensation at Low Temperature</u>: Most of the vapours may be concentrated by condensation on passing the air through a chamber immersed in a low temperature bath. The air is passed at a slow rate so as to result in effective condensation and eliminate any loss of the condensed material. The common refrigeratnts used for maintaining low temperature are ice, solid carbon dioxide, liquid nitrogen or liquid oxygen. The equipment employed for sampling depends upon material being collected, the quantity, and the precision required. Moreover the equipment should be so designed that choking of the passage with ice or solid contaminant condensed from the air is avoided. The concentration of the vapour may be determined either by weighing or measuring the volume of the condensed material.

d. Collection By Absorption or Adsorption for Laboratory Analysis : The collecting device may be a scrubber or impinger and the collecting medium may be granulated silica gel or a liquid of low volatility. The contaminant is either adsorbed or absorbed. In some cases, it may be retained by chemical reaction. The collected sample is brought to the laboratory where it is evaluated by various means such as colorimetric, volumetric, polarographic, or spectrographic analyses.

e. Spectrometry:

1. Infrared: The infrared spectrometer is a relatively new tool and is used for the evaluation of organic matter in the air . It is quite accurate and is adopted for control purposes or for standardization. In this method absorption of energy by almost all aromatic substances in the infrared region is used for both qualitative and quantitative analysis.

The apparatus consists of a heat source, a prism to isolate the desired energy region, a cell for placing a suitable thickness of material for analysis in the path of the radiation, and a detector for measuring the radiation. The gaseous contaminant is collected either by freezing or by absorption technique. A combination of these two techniques may also be used to provide sufficient matter for infrared analysis. It is to be borne in mind that the absorption liquid used should have no interfering absorption bands in the significant range of the contaminant to be analysed. The absorption of energy in the infrared region is proportional to the concentration of absorbent in the solution.

2. <u>Ultraviolet:</u> Several organic solvents, especially in the aromatic series, have characterisitc absorption patterns in the ultraviolet region of the spectrum. The pattern is used to recognize the solvent while its capacity at specific wave length is used to estimate the concentration. The sample is collected as in the case of infrared analysis.

3. <u>Light Absorption:</u> Visible light spectrometry is similar to infrared and ultraviolet spectrometry. But there are very few compounds which give distinctive abs-sorption patterns in light spectrometry.

f. <u>Gas Chromatography:</u> This method is particularly suited to a complex mixture where the components may be separated without any chemical change. Instruments are used to fractionate vapours and measure their thermal conductivities. The measurement of the thermal conductivity of the vapour is related to its concentration. The paints, thinners and other volatile solvents are determined by this method.

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CHAPTER IV

CONSIDERATIONS IN AIR CONTAMINATION

Before adopting air contamination control methods a number of factors such as plant location, topography, meteorology, characteristics of contaminants, legal requirements , neighbourhood requirements and economy have been considered.

-:0:-

The decision to apply available methods of air cleaning to control air contamination depends upon a number of factors some of them are :-

4.1. INDUSTRIAL-PLANT LOCATION AND ZONING:

In determining the location of an industrial plant, the factor of air contamination due to its operation should be taken into account along with the other factors which may be necessary for the running of the plant. If it is to be located near an agricultural area, proper consideration should be given to possible damage to the vegetation due to the released contaminants. This will help in determining the level to which the contaminant evolution should be controlled. The negligence of this important factor has proved to be an expensive error for many large past undertakings. It is usually easier and less expensive to avail of the control methods at the initial(design)stage than at a later stage when the plant is constructed and put to operation.

When a new plant is to be located in an already industrialized area, a preliminary survey of the existing levels of contaminants is essential. This provides with an idea regarding the extent to which the contaminants can be added from the new sources without producing harmful affects. Even in cases where the area under consideration gets polluted due to contaminants from outside sources, the air pollution survey is helpful in relation to the contamination level.

4.2. TOPOGRAPHY :

It is an important factor from plant location as well as air contamination point of view. The ability of the atmosphere to disperse contaminants depends markedly upon local topographical features. Emission from plants located at land water boundries, in undulating or hilly terrain, in valleys and in locations of various other types present different problem in air contamination control. ~~The idea~~

The ideal topography is a comparatively level terrain in a region where the average wind velocity is of the order of 10 mph or more and where deep temperature inversions are a rare occurring. But even in cases of level land, some microfeatures as the character of the surface affect the local vertical distribution of temperature as well as the wind.

In case of plants situated in coastal areas, air circulation between the sea and land is an important feature in dispersion of the contaminants. In day time, there is on-shore breeze which is reversed during night, and becomes the land breeze. The land breeze blows towards water and thus helps in dispersal of the contaminants which may otherwise get accumulated and result in higher contentration level.

Valley sites require serious considerations than level or undulating terrain, specially when the average wind velocity is less than 10 mph. In fact, valley is a poor site for large industrial plants. The contaminants discharged from industrial operations get trapped below the level of the surrounding hills. The condition becomes much worse if the plant is surrounded by a relatively narrow valley with mountains rising fairly steep on either side. During the day time, the~~y~~ solar heat results in an upward breeze along the slopes while at night , a mountain breeze slopes down resulting in the accumulation of pollutants above the valley floor.

Recent wind-tunnel tests have indicated that the height and ~~slopes~~ shapes of the surrounding buildings causes a change in the wind pattern which may subsequently affect the contaminant dispersion. Hence this factor should also be taken in account.

4.3. METEOROLOGY:

The dispersal of a contaminant in the atmosphere may occur either near ~~the~~ a source or at distances away from the source. The meterological variables governing the behaviour of a contaminant near the source are wind direction, wind speed and wind turbulence. Wind direction indicates the general area into which the contaminant will move. The contaminant concentration down wind from a source varies inversely as the wind speed. The rate of diffusion depends upon the degree of turbulence which depends upon three main factors, viz. the speed of the wind, the nature of the surface over which the air stream moves and the rate at which the temperature of an air mass falls with increasing altitude. An uneven surface or any obstruction will increase the turbulence in the ground layers of the air.

Air stability is also a meterological factor contributing to air pollution. The concentration of air contaminant is directly related to the stability of the atmosphere. Differences in air stability depends mainly on the rate at which the temperature falls with increasing altitude. When a stable air mass is forced to rise, it tends to sink back towards its original level in due course. However, if the unstable air is lifted up it bounces up higher and higher with much turbulent motion. The stacks A, B, C, and D(Fig. 4.1) illustrate the discharge of smoke plumes, in relation to air stability and turbulence. Chimney "A" shows smoke emitted in stable air. Under such existing condition, the smoke finds difficulty in rising up and spreads out more nearly horizontal in a consolidated plume which diffuses slowly as it moves downwind with little turbulent motion. Chimney B indicates the emission in a markedly stable air in which case the plume fails to rise much above the stack and begins to sink towards ground level. Chimney C shows rapid smoke diffusion in an unstable air mass.

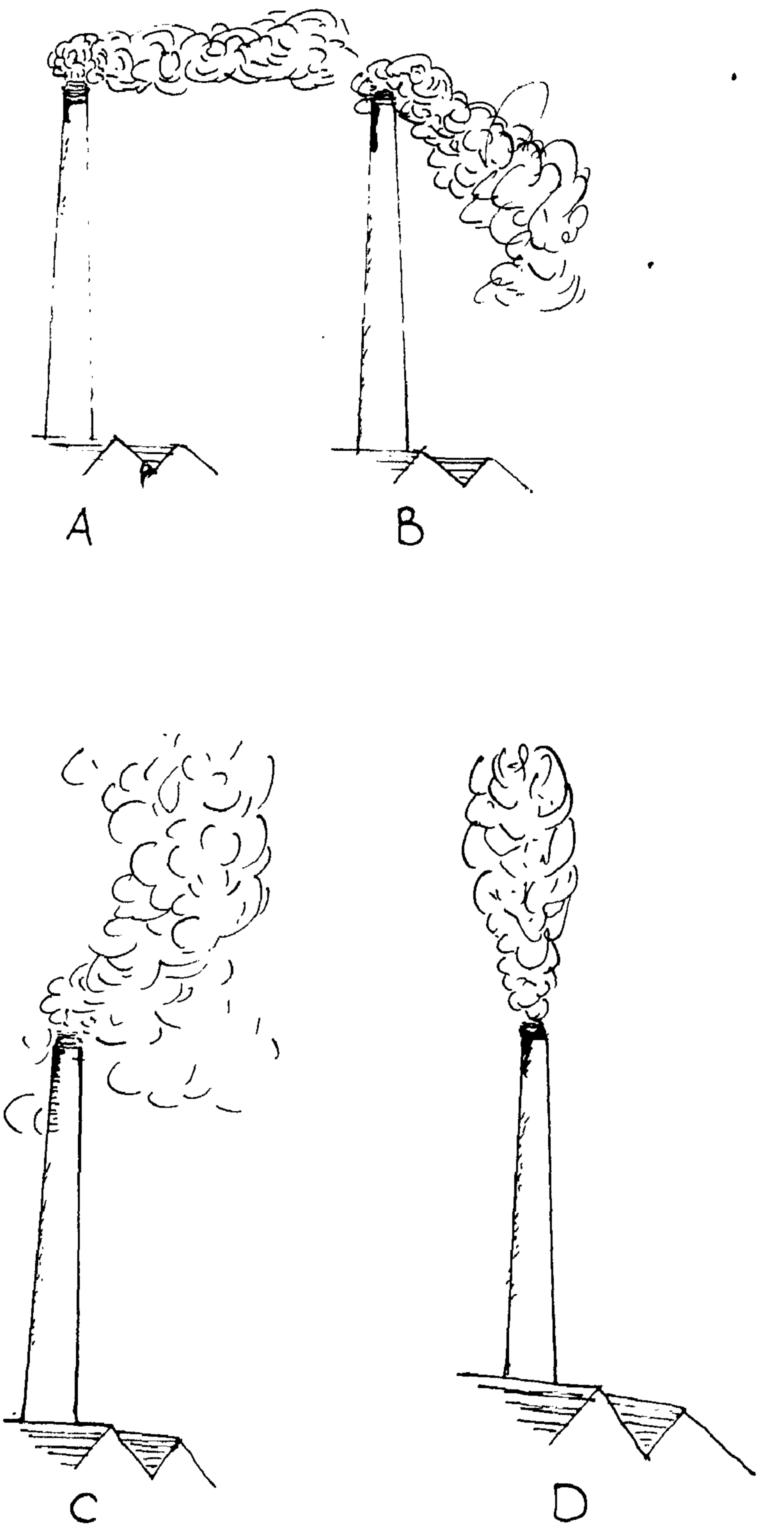

FIG. 4.1

Under the condition, the smoke is billowing in all directions especially upwards, in confused turbulent eddies. Chimney D shows smoke emitted under calm conditions, but with light turbulent diffusion.

Temperature inversion is another factor which adds to air contamination. When the air temperature increase with increase of altitude, the normal lapse rate is inverted, and an inversion of temperature occurs. Such a condition usually exists just above the ground surface but may also occur much above it. Emissions within inversions get trapped within the air layers and result in high concentrations of impurities. This may intercept with the day light.

4.4. CHARACTERISTICS OF CONTAMINANTS TO BE EMITTED:

A perfect knowledge regarding the type and amounts of contaminants to be emitted from a new installation is essential. It is necessary to know the particle size andthe physical properties of the contaminants. Particulate contaminants are to be treated differently than gaseous emissions causing nuisances. It is also necessary to know whether the contaminants, after being released agglomerate, flocculate or react with other pollutants to form substances which may have entirely different characteristics. The toxicity of each contaminant to be emitted should be known so that it may be controlled to a level which may not create any deleterious effect on people, animals or vegetation in the surrounding areas. Sampling techniques may be used to determine the contaminant characteristics.

4.5. LEGAL REQUIREMENTS:

Local codes may impose restrictions on stack dust loading and emission concentrations that make stack gas cleaning mandatory.

4.6. NEIGHBOURHOOD REQUIREMENTS:

These establish the degree of cleaning necessary beyond specific legal requirements. In the neighbourhoods not previously subjected to industrial emissions, a relatively higher degree of cleaning will be required for maintaining good community relations than would be required in an area adjacent to an industrial complex. Future growth in industry and population should also be taken into account.

4.7. ECONOMIC CONSIDERATIONS:

Economy in air contamination control is a basic one because industry can be penalized for its operations. An economic evaluation of an air pollution problem is to obtain a solution which can be pursued without excessive cost and under conditions without any interference with existing operations.

The most important approach is the recovery of a by-product which has some market value or may be consumed in the process itself. But in cases where the bye product is insignificant in offsetting the cost of the control equipment, it is still used simply on the basis of promoting good community relations. Also if the cost of the control equipment is higher in relation to the operation cost that it cannot be economically operated for a longer period, a less expensive but still effective method is to be devised.

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CHAPTER V

AIR CONTAMINATION CONTROL METHODS:

Air contamination near a source can be best controlled by its abolition and substitution of nontoxic materials. The control can also be exercised by segregation of the process, wetting the contaminants or exhaust ventilation systems. Among these the last type is dealt in details.

-:0:-

Methods for the control of contaminant exposure are divided into the following groups:

5.1. ABOLITION OF THE SOURCE OF CONTAMINATION :

Evidently, the simplest and the most effective approach to control an industrial toxic hazard is to substitute non-toxic materials for toxic materials. If this is not possible, the basic process may be modified to eliminate the production of contaminants. Sometimes it may be impossible to attain the treatment at the source without eliminating the entire process. Although this is the perfect control method, yet its application is often restricted due to the cost involved and impracticability. But where this type of control is practical, it should be preferred to other methods. Examples of substitution of less toxic materials are the substitution of steel shots for sand in abrasive blasting; artificial abrasive grinding and polishing wheels for sand stone wheels; and nonsilica parting compounds for siliceous compounds in foundaries; Examples of the process change include controlling the temperature and speed of chemical reactions so as to decrease the rate of mist, gas or vapour formation;and changing from manual batch charging to machine and hopper charging.

5.2. SEGREGATION OF HAZARDOUS PROCESSES:

In this method of control the dangerous operation may be isolated from other operations. In such cases, only few workers engaged, will be exposed to the hazard and they may be protected by respirators. This type of control method finds application especially in explosive industries.

5.3. WET METHODS :

The use of water or other liquids to prevent the escape of dust into the atmosphere is a very old method of controlling dust hazard. The dust control is done by directing the liquid spray at the dusty operation or by handling material in a wetted state. When properly applied, it yields good results. The effectiveness of wet methods depends upon wetting the dust as well as proper disposal of dust-laden liquid.

Because of the advantages of simplicity and cheapness wet method of control has become quite attractive. It is used as an effective dust control in rock drilling, blasting crushing, screening, materials transfer, foundry shake out, core knockout, and abrasive blasting. It is also used as an ancillary to other preventive methods.

5.4. GENERAL VENTILATION:

5.4.1. General

General ventilation implies that the air is supplied or removed from a general area, space, room or building. It is of two types: natural ventilation and artificial ventilation. When the air exchange is caused by natural phenomenon, it is called natural ventilation and if it is produced by some mechanical means, it is known as artificial or mechanical ventilation. In general ventilation, ~~that~~ the atmospheric contamination is controlled not by eliminating or reducing the amount of contaminant produced but by diluting the concentration of the contaminant in the air by mixing with relatively clean air. Hence it is also called dilution ventilation. It is used as an auxiliary line of defense to other control methods.

Dilution ventilation is well suited to the control of relatively non-toxic materials especially when they are liberated in small amounts in close proximity to any worker. It is the only practical method of controlling solvent vapours which are less toxic than many dust and fumes and are usually released at low rates.

5.4.2. General Ventilation Specifications.

General ventilation rates can be specified in terms of air changes/ hr;, minutes/air change; air flow/sq.ft. of floor; air volume on a per capita basis; or air volume required to dilute known or predictable concentrations of contaminants to safe or acceptable level. The first two ways of expressing general ventilation rates are in usual practice. They are based on the assumption of uniform air distribution throughout the room. But such an ideal distribution is rarely accomplished. Table 5.1. gives air changes rates for some of the operations.

TABLE 5.1.

AIR CHANGES RATES FOR GENERAL VENTILATION

Type of room or buildings Public and Industrial.	Air changes/hr.	
	Low	High
Auditoriums; assembly halls	4	30
Bakeries	10	60
Boiler rooms, engine rooms	4	60
Foundries, ferrous	4	30
Foundries , non-ferrous	6	60
Hospitals, ordinary	2	15
Laboratories, chemical	6	30
Machine shops	3	20

In case of lack of knowledge regarding specific equipment or per capita requirements, it is easier to estimate ventilation rates on the basis of the amount of floor area devoted to known kinds of activity. Table 5.2. gives a few examples.

TABLE 5.2.

GENERAL OR SPACE VENTILATION RATES BASED ON FLOOR AREA

Ventilation/sq.ft. of floor C.f.m.	Type of room, Building, or process.
1	General industrial buildings having no localized sources of irritating or explosive air contaminants.
2	Battery charging rooms.
50	Enclosure or booths for arc Welding.
100	Rooms for abrasive blasting or metal spraying (supplied-air helmets required for workers.)

5.4.3. Volume of Air Needed.

Knowing the rate of solvent consumption and its maximum allowable concentration in the atmosphere , the minimum quantity of air which may dilute the contaminated air between the source and the breathing zone of the worker, may be computed as follows :

$$Q = \frac{0.81 \times 10^6 \times S}{WC} \qquad (1)$$

Where

Q = Ventilation rate in cubic foot/minute.

S = Rate of solvent consumption in lbs/hr.

W = Gram molecular weight of the solvent.

C = Maximum allowable concentration of the solvent (ppm)

To ensure complete dilution of the solvent vapour before reaching the breathing zone of the worker, it is usual practice to provide higher ventilation rate than the standard depending upon the factors such as circulation rate, distance of worker from source from source of vapour, importance of heat loss and the number of workers affected.

In case of dusts or fumes, the required minimum ventilation may similarly be computed as follows :

$$Q = \frac{0.033 \times 10^6 \times S}{C} \qquad (2)$$

Where Q and S are as given in equation 1 .

and C = Max. of the contaminant in milligrams per cubic meter (mg/m^3).

But general ventilation is rarely satisfactory in case of dust or fume control, owing to their high rate of production and relatively high toxicity. It is largely limited to gaseous contaminants (gases and vapours) , except mercury.

5.4.4. <u>Make-up Air.</u>

The quantity of air needed to replace that which has been exhausted, is known as 'make-up air." In case of very small systems handling only a small volume of air per min. it is usual practice to ignore make-up air which may otherwise find its way in by simple leakages. But in some cases it creates a problem by interfering with the general ventilation of a room and bringing a marked temperature drop, especially in cold days. In order to supply a certain volume of make-up air for a room, the following factors should be given consideration :

i. Make-up air should be warmed to the room temperature before it is supplied.

ii. Draughts should be avoided by providing air inlets of adequate size . Baffles may be used to prevent air streams directly striking the workers.

iii. To avoid undue load on exhaust fans, adequate air inlets should be provided.

In case of handling non toxic materials some of the exhausted air may be recirculated through proper filtering arrangements.

5.4.5. Advantages and Disadvantages of General Ventilation:

The general ventilation system has following disadvantages :

1. The ventilation plant may not be able to scavenge all parts of the rooms, resulting in the build up of high local concentration.

2. The maximum allowable concentration figures are correct only on the basis of uniform air distribution and in the light of existing knowledge which is imperfect.

3. The workers near to a source of contamination may be exposed to appreciably higher concentrations than the average for the whole room.

4. General ventilation system makes the room a large settling chamber for any dusts, fumes, or mists suspended in the air, the concentrations of which may be within safe limits. This is true in case of plants manufacturing or

using highly flammable metal dusts which are seen deposited on inaccessible machinery surfaces.

5. It is impossible to recover all the contaminants that has escaped into the room atmosphere.

Inspite of the above disadvantages, general ventilation is still used in many industries due to following reasons; (i) Simplicity and economy of natural general ventilation; (ii) relatively low first cost of mechanical general ventilation; (iii) absence of interference with manufacturing operations; (iv) flexibility in plants with constantly changing layouts; (v) existence of contaminating processes throughout the entire plant; (vi) Desire for large volumes of air circulation in hot weather; (vii) Discovery that local exhaust systems do not eliminate the necessity of supplying large volumes of heated air in the cold days to that escaping from the loosely constructed buildings by exfilteration. This volume of air change may be more than sufficient to control process air contaminants by the method of dilution, if means are provided to disperse contaminants from the immediate vicinity of the workers.

5.5. LOCAL EXHAUST VENTILATION:

5.5.1. General:

This method of contaminantion control is employed in cases where the contamination sources are more or less specific or local. It is especially suitable when the types and concentrations of air contaminants from a single process vary from time to time. It is probably the most important single method of preventing industrial atmospheric pollution.

In fact, there is no line of distinction between general and local ventilation when applied to industrial processes. Local exhaust ventilation results in some degree of general ventilation in the boundry zone between the room and the process. The air inlet may be so located that the air traversing towards the exhaust hood, passes over the largest possible surrounding area, thereby contributing its full share of general ventilation.

The basic purpose of local exhaust ventilation is to collect the contaminated air in a concentrated form and convey it preventically through the ducts to an air cleaning plant. Thus it prevents the dispersion of contaminants into the surrounding atmosphere in harmful proportions. The exhaust air after being freed from its contaminants may either be discharged to the outside atmosphere or subjected to recirculation within the workplace. A local exhaust system is made up of four major parts; exhaust hood, piping system, air cleaning plant and source of suction.

5.5.2. Contaminant Dispersion:

Particulate matter released due to certain operations may be dispersed in the air by virtue of its own kinetic energy. Most of the large size particles settle rapidly in relatively still air and are of minor importance in connection with any serious hazard. But ~~macroscopic~~ microscopic particles are dispersed only very little distance by their own kinetic energy and are dispersed by means of aircurrents. In case of gases and vapours, the dispersion is due to diffusion, density difference and air movement. Among these factors air movement is of prime importance. The following are the common sources of air motion responsible for dust dispersion around the machines :

i. Forces resulting from the operation or process itself such as fan action of a rotating wheel.

ii; Forces incidental to the operation of the machine or process, such as vibration of machinery and air blast from a badly placed exhaust port on a pneumatic tool;

iii. Drag of air by large particles thrown off at considerable velocity from their sources, such as particles thrown off during grinding operation creates an air current which carries the fine particles.

iv. Miscellaneous external forces, such as open doors and windows, inlet supply ports, convection currents, movement of nearby workers and machinery.

In order to control the dispersion of contaminants due to air motion, the forces responsible should either be destroyed or controlled such that the contaminants are brought under the influence of the local exhaust hood from where they can be carried away from the work place.

5.5.3. Basic Considerations of Hood Design

Hood is the most critical part of an exhaust ventilation system. Its function is to enclose the source of contamination as completely as possible and to create an air flow pattern in the zone of dust-laden air of such magnitude and direction so as to be able to capture the contaminated air and direct it into the local exhaust system. The effectiveness of a hood depends upon its shape, location, the connecting duct and the exhauster. Hood design requires the consideration of following points.

1. <u>Study of the Process or Operation:</u> Most of the operations or processes differ greatly from each other . This necessitates individual study so as to provide satisfactory control system. While some operations result in dispersion of dust at high velocity either in some particular direction or in all directions, there are other operations which release dust with negligible velocity. In some cases, the air disturbance may be due to presence of nearby windows or rapidly moving machinery while in other operations, there may be no such air disturbance. In some operations, the specific gravity of the released contaminant is to be given consideration while in other cases, temperature difference may be of prime importance in air motion.

2. <u>Selection of Minimum Capture Velocity:</u> The minimum capture velocity is the air velocity which must be created by the local exhaust hood at the point of release of the contaminants

or within the contaminated zone so as to capture a large percentage of the contaminants to prevent their concentration exceeding the maximum allowable limit in the surrounding atmosphere. Actual velocity in any specific case is to be estimated with consideration of local conditions such as drafts, traffic disturbances, convection currents, mechanical motions, etc., around the ventilated process. In such estimates, experience and judgement of the designer are of great value. Further research to reveal rational ways are still awaited.

In case of small hoods dealing with low quantities of air flow, the capture velocity remains effective only for a short distance or depth. Hence proper selection of control velocity is very important for successful operation of small hoods. But in case of large hoods handling large quantities of air flow, such as used in foundries shakeout operations, pickling, spray painting, etc., the effective depth of capture velocity is quite large and as such capture velocity is of minor consideration. In such cases general ventilation plays a more important role than local exhaust effect, Therefore, large exhaust hoods work satisfactorily even with less amount of air than estimated theoretically (dealt later) Table 5.3 serves as a guide of minimum control velocities for different conditions of generation of the contaminants.

TABLE 5.3.

Minimum control Velocities.

(Minimum air velocities recommended for the capture of ducts, fumes, smokes, mists, gases, and vapours released at various types of operations).

Conditions of Generation, Dispersion, or Release of contaminant.	Minimum control velocity in f.p.m.	Examples of processes and operations.
1. Released with no significant velocity into relatively quiot air	100	Evaporation or escape of vapours, gases, or fumes from open vessels, degreasing, pickling, plating.
2. Released with low initial velocity into moderately quiet air.	100-200	Paint spraying in booths intermittant dumping of dust into hopper, welding.
3. Released with considerable velocity or into zone of rapid air movements	200-500	Domo spray painting in small booths and with high prossure, rotating mixers, active barrel or container filling, loading conveyors.
4. Released with high velocity or into zone of very rapid air movement.	500 or above.	Grinding, abrasive blasting, heavy crushing.

For actual determination of minimum capture velocity it is advisable to conduct experiments with full-scale model hoods, This operation is carried out in a place which is isolated from other sources of contamination and the volume of air is determined on the basis of allowable contaminant concentration in the atmosphere.

3. Study of Equipment and Structure surrounding the Operation: The designer should have full knowledge regarding the location of various sources of contamination other than that for which the exhaust ventilation is in question. He should collect data regarding the area of the contaminant release, the movements of the workers, and other interferences. He may then design hood of required capture velocity with minimum possible air flow and with least interference in normal execution of work.

4. Selection of the best Type of Hood: After studying the process or operation and that of the equipment or structure surrounding the operation, the type of hood required can be determined. The velocity pattern in front of the hood (dealt later) should also be considered during hood selection.

After selecting the type of hood, it is located so as to enclose the process. If this is not possible, it should be placed as close as possible to the source of contamination such that it does not interfere with the normal execution of work. In cases where contaminants are thrown off at high velocity, the hood should be located in that particular direction. Baffles and Flanges can be used to reduce the air flow from ineffective areas and direct the contaminants towards the hood.

5. Determination of Air volume to be Exhausted: With the help of Table 5.3. and equations dealt under "Air Flow versus hood shape", the required quantity of exhaust air

to capture the contaminants may be determined.

6. Development of Hood Shape and Size: From the information gathered from previous steps, it is possible to develop approximate hood shape and size. It is better if the hoods are made streamlined without abrupt velocity and direction changes as this results in considerable savings of power consumption.

5.5.4. Air Flow Versus Hood Shape:

Hoods may be divided into four major groups:
a. Enclosing Hoods, b. Rectangular or Round Hoods c. Slot hoods, d Canopy Hoods.

a. Enclosing Hoods: The original conception of enclosing hood comes from the laboratory where it is recognised as a standard device to prevent air contamination due to the process going inside it. Enclosure of the process offers a high degree of protection. It cuts out the ineffectiveareas and results in minimum air disturbance due to outside air currents. To prevent any leakage to outside atmosphere, the enclosure is usually held under slight negative pressure.

Because of the simple design, high efficiency and positive action, enclosing hood finds wide applications to industrial processes. It is used in cases where the process results in the evolution of very highly toxic materials such as radioactive substances, Beryllium, Methyl bromide etc. In such cases as slight air contamination is unacceptable.

Special arrangements should be used to ensure 100 percent enclosure. There are other processes which require their manipulation from outside. In such cases, the degree of manipulation determines the extent of the enclosure which is maintained around the process. Glove boxes are one example of this type of enclosures. They are provided with permanent attachment of rubber gloves for convenient insertion of hands. Other examples of enclosing hoods are spray-paint booths, abrasive blasting cabinets, grinder hoods and shake out hoods.

The quantity of air to be exhausted through the opening in the enclosing hood may be determined by the following equation:

$$Q \quad AV \qquad (3)$$

Where Q = Quantity of air in cu. ft. /min.
A - The total area in sq.ft. of the openings into the hood.
V - The minimum Capture velocity in feet per minute (Table 5.3. used as a guide).

If V and A are known , Q can be obtained directly from Figure 5.1.

b. <u>Rectangular or Round Hoods</u>: These are the most inefficient type of hoods as in most of their applications a good percentage of air moving towards the hoods does not pass through the zone of contamination. They are used for operations, such as welding; stone surfacing, downdraft in table tops

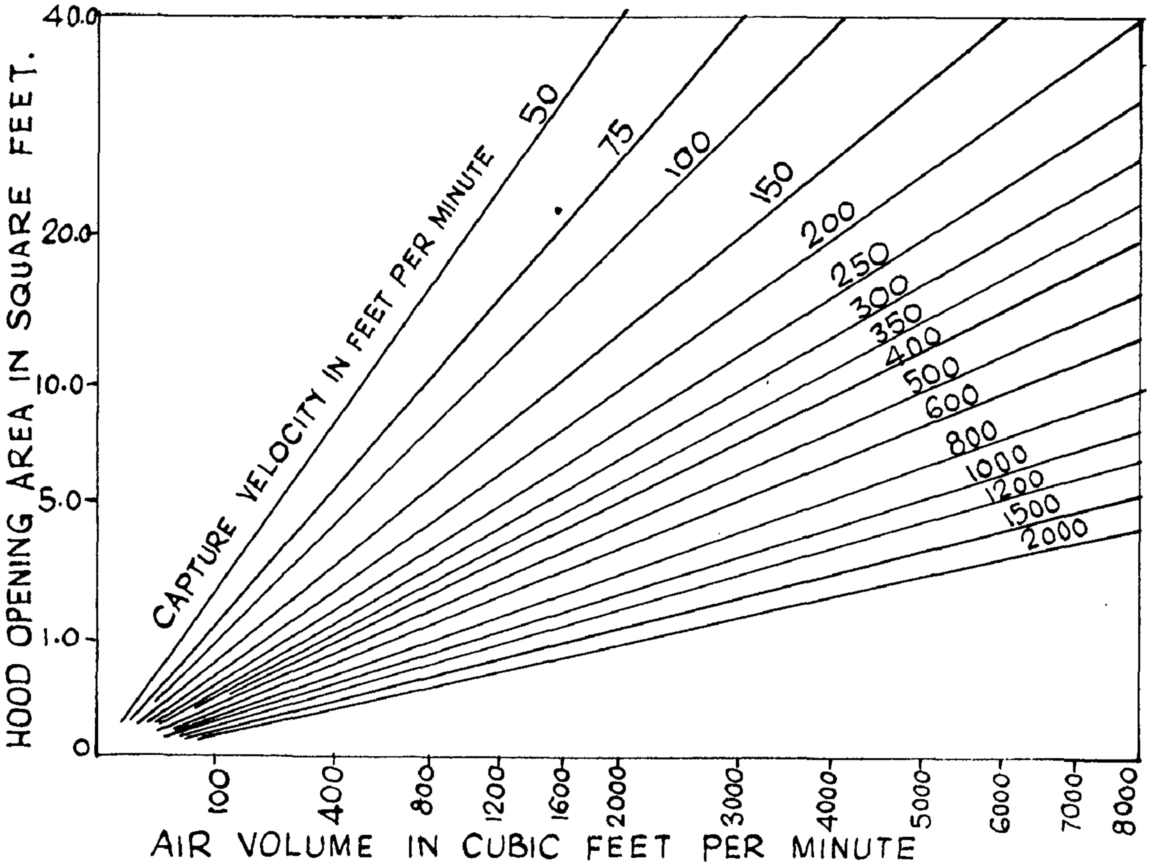
HOOD OPENING AREA IN SQUARE FEET.
40.0
20.0
10.0
5.0
1.0
0
CAPTURE VELOCITY IN FEET PER MINUTE
50
75
100
150
200
250
300
350
400
500
600
800
1000
1200
1500
2000
100
400
800
1200
1600
2000
3000
4000
5000
6000
7000
8000
AIR VOLUME IN CUBIC FEET PER MINUTE

FIG. 5.1

for degreasing, cleaning and cementing; drilling; and material transfer.

To have the conception of flow characteristics (velocity contours) infront of rectangular or round exhaust hoods, consider air-flow towards a point source of suction. In such a case, the velocity contours are spherical surfaces (Fig. 5.2) each having its centre at the suction point. Knowing air velocity of distance x from the suction point, the total quantity of air is given by the equation:

$$Q = A V \qquad (4)$$

Where Q - Air entering the point source of suction in cu.ft./min.

A = Surface area in Sq. ft. of a sphere of radius x ft.

V - Air velocity in feet /min. at x distance from the suction point.

Since A is a spherical surface, equation ~~#~~ 4 becomes

$Q = V (12.57 x^2)$ But this air flow pattern does not match with those of freely suspended rectangular or ~~reund~~ round exhaust hoods which are found to flatten directly infront of the hood (figures 5.3 to 5.6).

Dalla Valle determined the following equation for both round and rectangular hood openings :

$$Q = V (x^2/b + A) \qquad (5)$$

Where Q Air exhausted in Cu.ft./min.

V - Centre line air velocity in ft./min at a distance x ft. from the hood

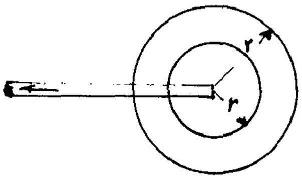

FIG. 5.2

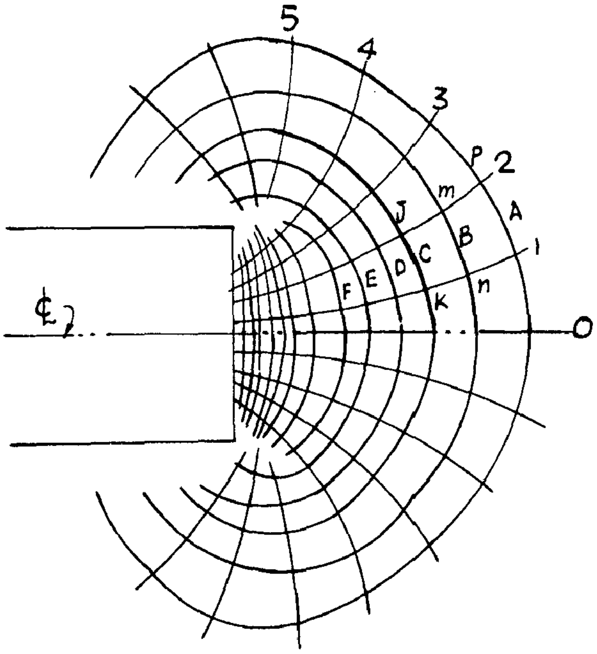

FIG. 5.3

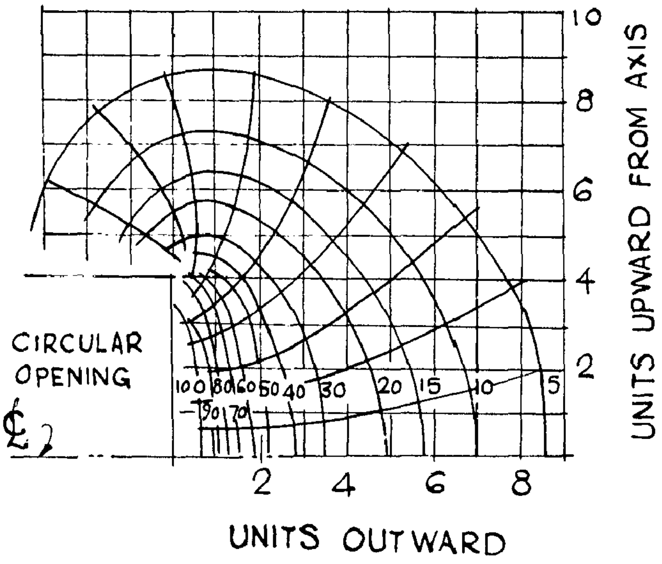

FIG. 5.4

x = Distance in feet along the hood centre line from the face of the hood to the point where air velocity is V ft./min.

b = A constant depending upon hood shape.

A = Area of hood opening in sq.ft.

Taking b = 0.1, the equation for round or essentially square hood becomes:

$$Q = V\ (10\ x^2 + A) \qquad (6)$$

On taking different values for constant b, a number of equation can be obtained (See Table 5.4).

TABLE 5.4.

DALLA VALLE'S EQUATION FOR VARIOUS FORMS OF EXHAUST HOODS.

Shape of hood opening.	Constant b.	Equation.
Circular	0.083	$Q = V\ (12\ x^2 + a)$
Square	0.083	$Q = V\ (12\ x^2 + a)$
Rectangular, sides in following proportions:		
10 x 9	0.081	$Q = V(12\ x^2 + a)$
10 x 8	0.078	$Q = V(13\ x^2 + a)$
10 x 7	0.075	$Q = V(13\ x^2 + a)$
10 x 6	0.071	$Q = V(14\ x^2 + a)$
10 x 5	0.065	$Q = V(15\ x^2 + a)$
10 x 4	0.059	$Q = V(17\ x^2 + a)$
10 x 3	0.049	$Q = V(20\ x^2 + a)$
10 x 2	0.037	$Q = V(27\ x^2 + a)$
10 x 1	0.020	$Q = V(50\ x^2 + a)$

Dalla Valle also discovered the principle of "Similarity of contours" which may be stated as follows:

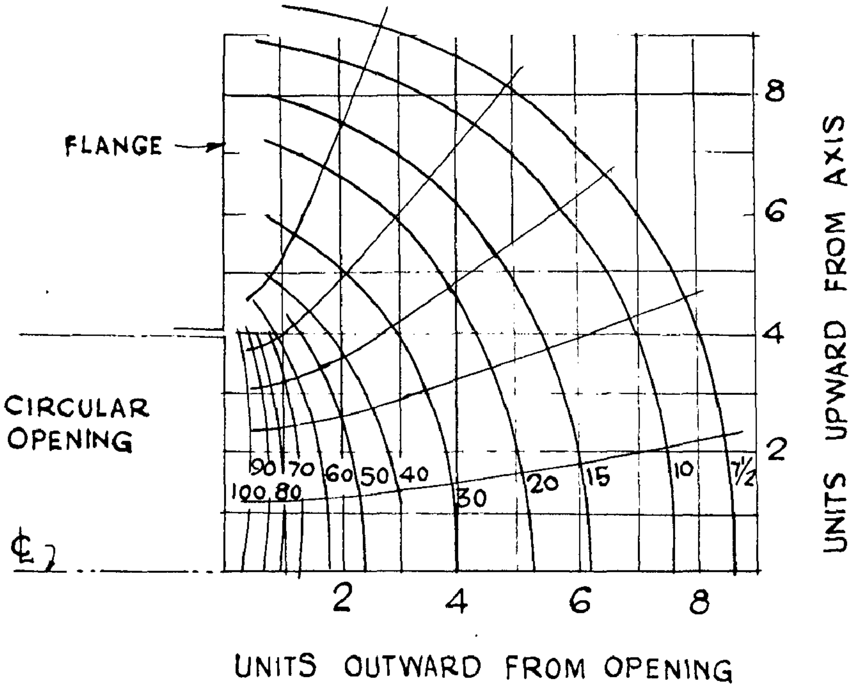
FLANGE
CIRCULAR OPENING
℄
90
70
60
50
40
100
80
30
20
15
10
7½
2
4
6
8
UNITS UPWARD FROM AXIS
2
4
6
8
UNITS OUTWARD FROM OPENING

FIG. 5.5

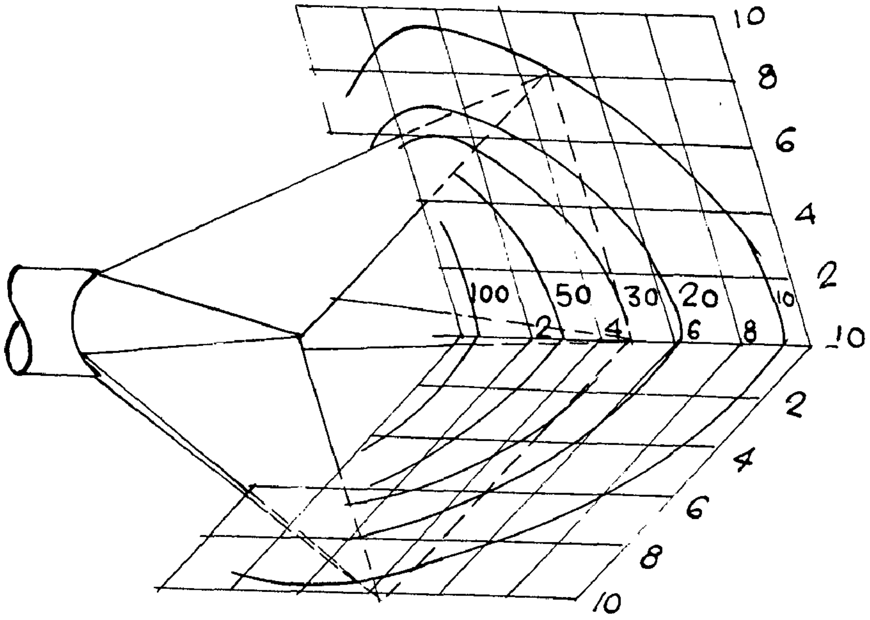
10
8
6
4
2
100
50
30
20
10
2
4
6
8
10
2
4
6
8
10

FIG. 5.6

x = Distance in feet along the hood centre line from the face of the hood to the point where air velocity is V ft./min.

b = A constant depending upon hood shape.

A = Area of hood opening in sq.ft.

Taking b = 0.1, the equation for round or essentially square hood becomes:

$$Q = V(10x^2 + A) \qquad (6)$$

On taking different values for constant b, a number of equation can be obtained (See Table 5.4).

TABLE 5.4.

DALLA VALLE'S EQUATION FOR VARIOUS FORMS OF EXHAUST HOODS.

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10 x 5	0.065	$Q = V(15x^2 + a)$
10 x 4	0.059	$Q = V(17x^2 + a)$
10 x 3	0.049	$Q = V(20x^2 + a)$
10 x 2	0.037	$Q = V(27x^2 + a)$
10 x 1	0.020	$Q = V(50x^2 + a)$

Dalla Valle also discovered the principle of "Similarity of contours" which may be stated as follows:

" The positions of the velocity contours for any hood when the contours are expressed in terms of the average velocity at the hood opening, are purely functions of the shape of the hood; the contours are identical for similar hood shapes when such hoods are reduced to the same base of comparision." This principle is of great help in hood design. Knowing the air flow pattern in front of small hoods, the designer can develop large similarly shaped hoods which may be tested in model form.

Although the equation 6 is true for axial velocity, yet it is quite accurate for air velocity at any point in front of the hood. In case of points at relatively large distance from relatively small hoods, the distance x should be measured from the centre of the plane of the hood opening. But if the source is at a relatively short distance from a relatively large hood, the distance x should be measured perpendicular to the plane of hood opening from a point situated at a distance greater than 2 x from hood edge.

On knowing, V, x and A, Q can be determined graphically. 'A' and 'x' can be used to obtain a dimensionless value known as "hood-location function (Fig. 5.7). In case of circular hoods, the diameter 'd' in inches is used in place of area 'A' from "hood location function" and V, Q is obtained directly from Fig. 5.8. This value of Q is in agreement with that obtained from Dalla Valle's equation for freely suspended hoods.

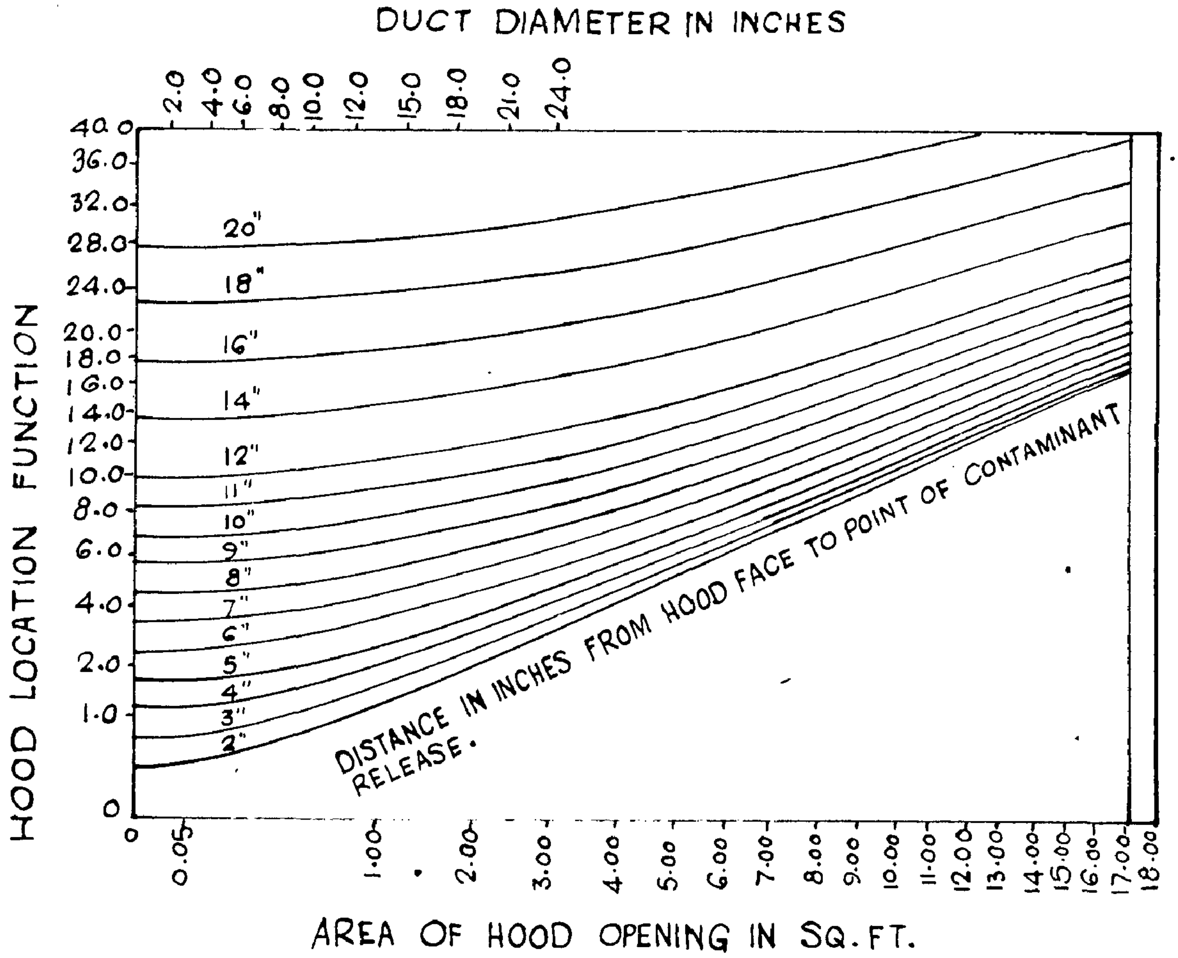

DUCT DIAMETER IN INCHES
2.0
4.0
6.0
8.0
10.0
12.0
15.0
18.0
21.0
24.0
HOOD LOCATION FUNCTION
40.0
36.0
32.0
28.0
24.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
1.0
0
20"
18"
16"
14"
12"
11"
10"
9"
8"
7"
6"
5"
4"
3"
2"
DISTANCE IN INCHES FROM HOOD FACE TO POINT OF CONTAMINANT RELEASE.
0
0.05
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
AREA OF HOOD OPENING IN SQ.FT.

FIG. 5.7

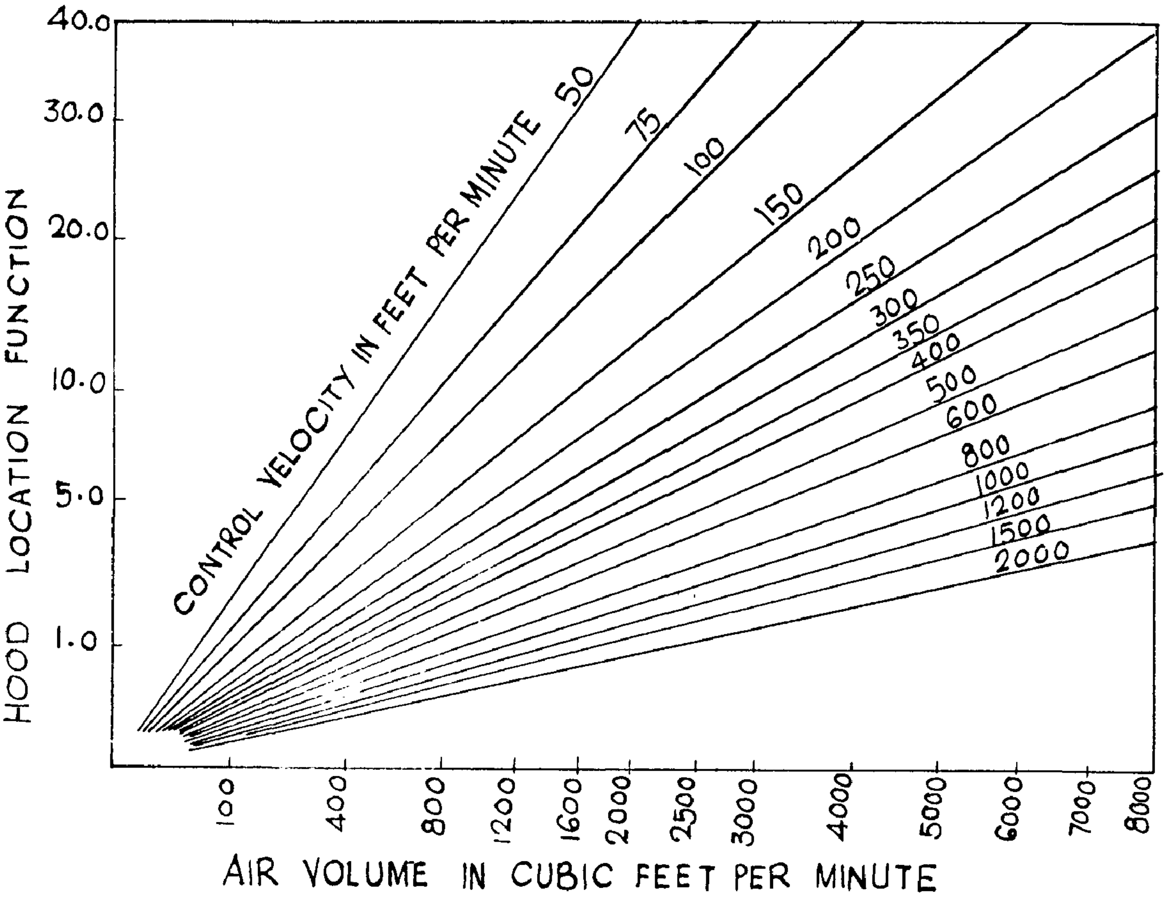

HOOD LOCATION FUNCTION
40.0
30.0
20.0
10.0
5.0
1.0
CONTROL VELOCITY IN FEET PER MINUTE
50
75
100
150
200
250
300
350
400
500
600
800
1000
1200
1500
2000
100
400
800
1200
1600
2000
2500
3000
4000
5000
6000
7000
8000
AIR VOLUME IN CUBIC FEET PER MINUTE

FIG. 5.8

Efficiency of round or rectangular hoods can be improved by using flanges which reduce the airflow Q by about 25 percent. So dalla Valle's equation for flanged hoods becomes $Q = 0.75 V (10 x^2 + a)$.

From Dalla Valle's equation, it is evident that Q increases almost as the square of the distance x and V varies directly with Q irrespective of hood face velocity. This necessitates placement of the hood close to source of contamination. The equation further shows that for a constant Q, V varies inversely as the hood-location factor. Also from Figures 5.7 and 5.8 it is found that a small hood opening is better than a larger one. But this is not true in practice due to increased entrance hood loss. To keep down entrance hood loss, a tapered hood may be used but the velocity pattern in front of the flanged duct end is better than that of the tapered hood (Figure 5.9). Hence on overall basis of design, flanged hood is better.

c. <u>Slot Hoods:</u> Slot hoods are usually employed for lateral exhaust ventilation at tanks or vessels. They are infact an extreme form of rectangular hoods. The hood opening is relatively very long and relatively very narrow. They differ widely from rectangular hoods in air flow characteristics.

To have a conception of air flow pattern in front of a slot hood, a line source of suction of infinite length is considered. This gives cylindrical velocity contours having their axes on the live source of suction (Fig. 5.10)

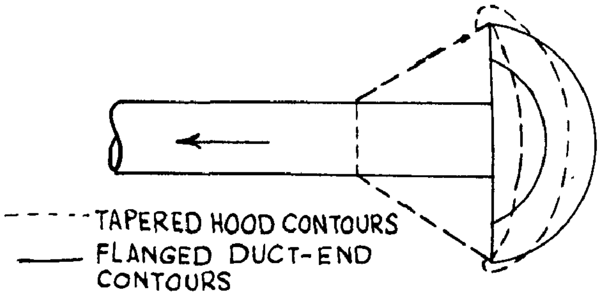


FIG. 5·9

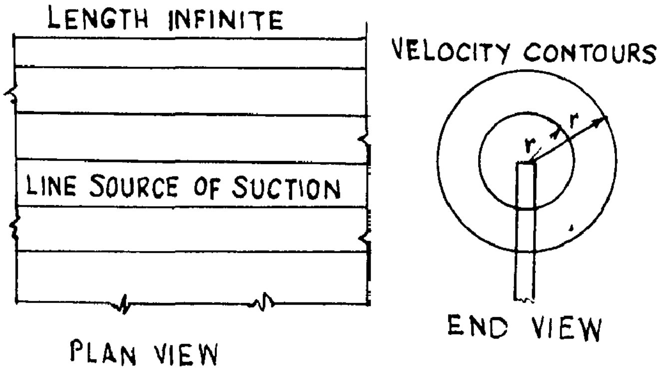


FIG. 5.10

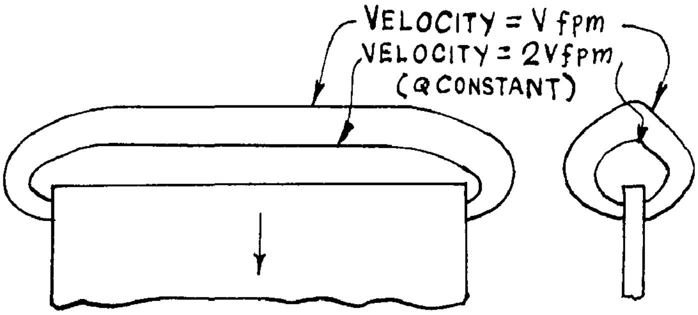


FIG. 5. 11

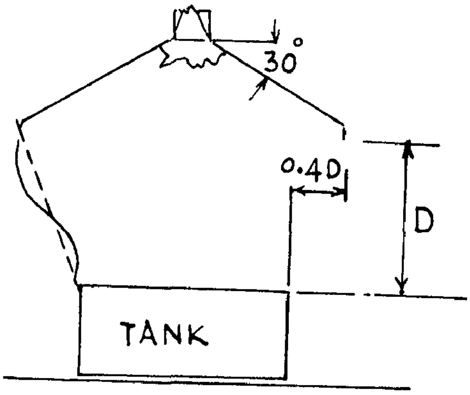


FIG. 5. 13

The quantity of air flow is given by the equation :

$$Q \quad 6.28\ r\ L\ V \qquad (7)$$

Where Q = Rate of air-flow in cu.ft/min.

r = Distance from source of suction to a point where air velocity is V (or radius of cylinder in ft.).

L = Length of cylinder in feet.

V = Air velocity in ft/min. at a distance r feet from source of suction.

But as slot hoods are of finite length, the velocity contours are found to be almost flat in the axial plane of the hood, except of the ends (Fig. 5.11). So the general equation for slot hoods becomes:

$$Q = K\ L\ W\ V \qquad (8)$$

where Q - as in equation 7.

K = constant varying between 1.5 to 5.0

L = Length of hood in feet.

W = Table or tank width (same as r in eq. 7)

V - Capture velocity in ft/min.

The value of K for freely suspended hoods, at table tanks or table tops, and hoods provided with flanges at right angles to each other is about 6.28, 2.8 and 1.5 respectively.

Knowing table or tank dimensions, Q can be obtained from Figure 5.12. which is plotted on the basis of 100 fpm capture velocity. The curve 1 and 2 are used for slot hoods ~~with and without flanges at right angles~~

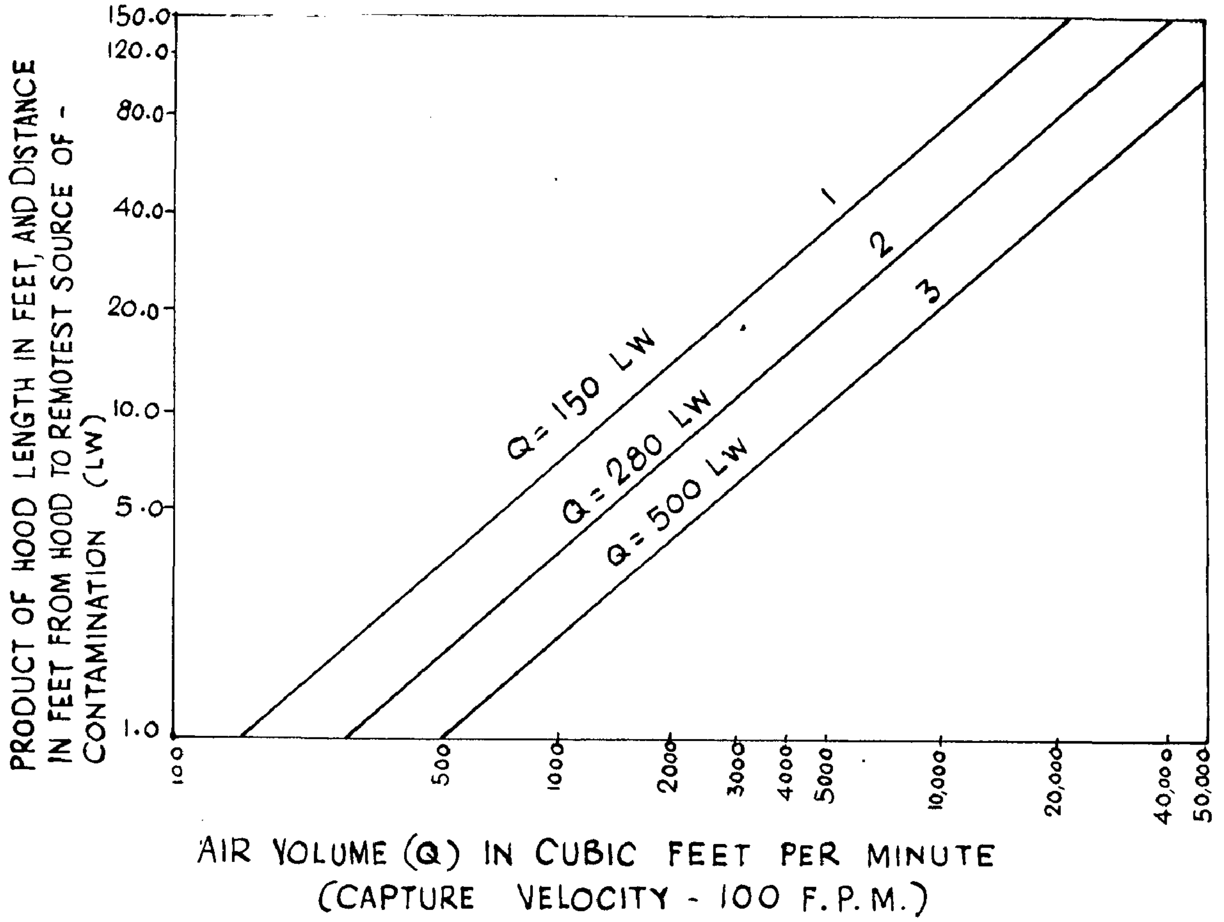


FIG. 5.12.

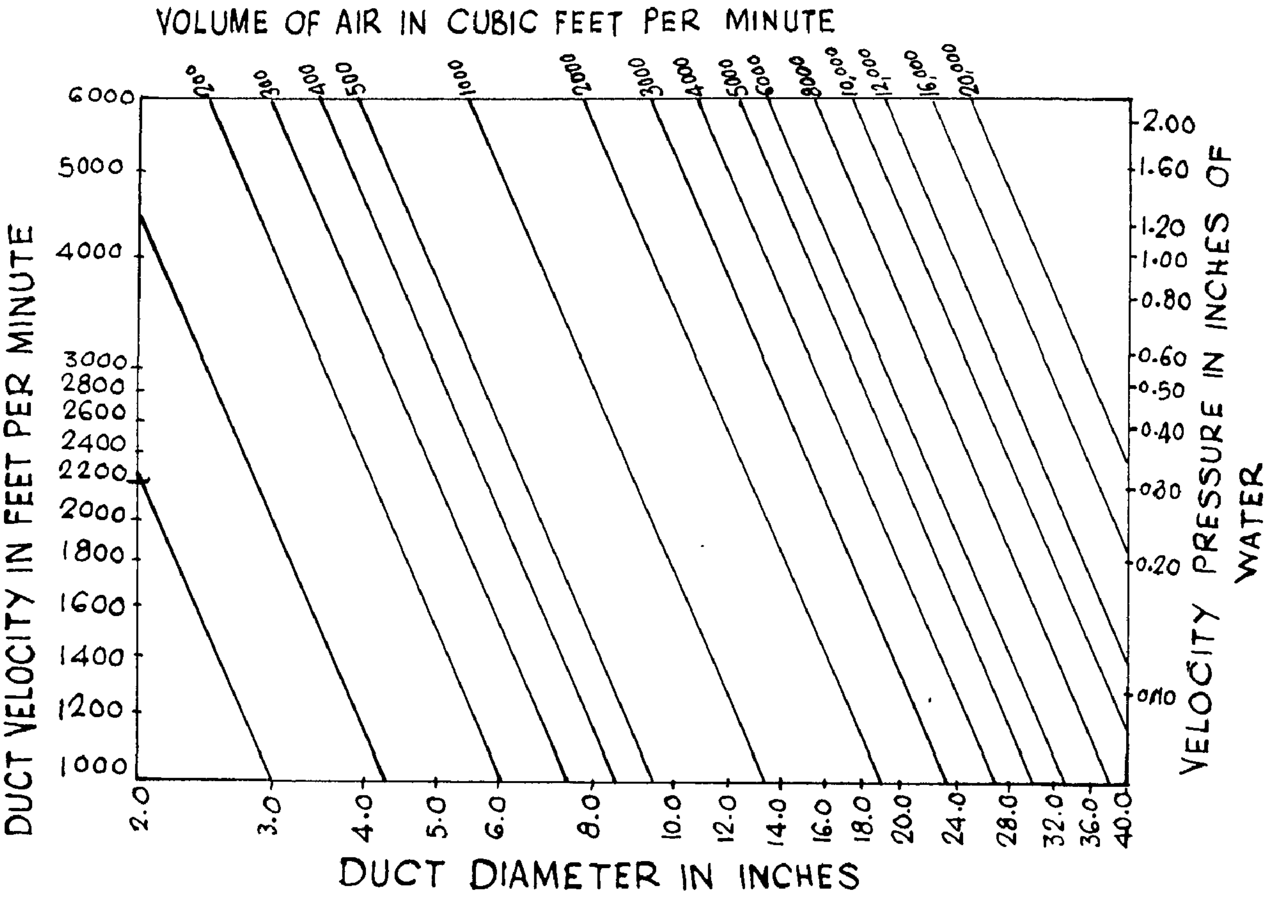


FIG. 5.14

with or without flanges at right angles to the flat surface. The curve 3 is meant for freely suspended slot hoods without flanges. For capture velocity other than 100fpm , the value of Q so obtained is changed proportionately.

Slot hoods usually present difficulty in obtaining uniform air flow over the entire length . This problem, can, however, be got over by making the rear part of slot hood of larger crosssectional area or using an adjustable slot hood or by dividing a large slot hood into number of sections . Guide vanes may also be used to equalise airflow rates.

d. Canopy Hoods: Canopy hood is also known as updraft hood. It is suited in cases where the contaminated air is substantially above room temperature and the workers seldom have their faces over the source or in line with the rising contaminated air. It is usually placed over tanks, tables and furnaces. It should not be employed to control highly toxic materials.

Canopy hood is , in fact, a type of rectangular or round hood but it differs widely in the velocity pattern. Fig. 5.13 gives the shape of a velocity contour in front of a typical canopy hood. The equation of air flow is given by the equation :

$$Q = P\,D\,V' \qquad (9)$$

Where Q Quantity of air in cu. ft. /min.

P = Perimeter of Hood face in ft.

D = Perpendicular distance in feet from hood face to top of tank or table.

V' = Average velocity through opening between hood edge and table or tank top.

For the hood shown in Fig. 5.13 , Dalla Valle found that the minimum capture velocity was about 0.7 times, the average velocity when D was about 3½ or 4 ft, so the equation 9 becomes:

$$Q = 1.4 P D V \qquad (10)$$

Where V Minimum capture velocity in ft./min.

Q , P and D = same as in equation 9.

Canopy hoods do not give a sound performance in usual practice. Slight air disturbance changes the direction of contaminated air and it crosses the effective depth and of the hood. Moreover, the convaction currents create much larger volume of air than that for which the hood is designed to handle.

5.5.5. Design of Local Exhaust Systems:

The principle on which the local exhaust systems are designed , is to acquire suitable capture velocities for various hoods in the system and maintain the conveying velocities to carry the contaminants through each duct. The two common design procedures are :

A. Sizing the ducts on the basis of transport velotity and system balance.

B. Sizing the ducts on the basis of transport velocity only and obtaining balance by means of dampers and blast gates.

A. Balanced System Design: This method of local exhaust design is preferred to control the operations handling very highly toxic materials. The design calculation begins at the branch having greatest resistance and proceeds, branch to main, and section of main to section of main, on up to the source of suction. To obtain the balances system, it is necessary that the pressure drop in any branch must equal the drop incurred in that part of the system which lies upstream of the branch under consideration. This is achieved by suitable choice of duct sizes, elbow radii, etc. in the upstream from each junction.

In the original design, an allowance for future expansion should be given due consideration so that on inclusion of additional machines, the efficiency may not suffer due to overloading. If the future expansion is not a major one, an independent line may be provided from the air - cleaning plant or self-contained systems may be used for the additional machines.

Considering the total pressure (T P) of a single branch duct, it is the sum of the velocity pressure (V P) and the resistance pressure (R P). The R P gives the energy loss involved in moving the air through the hood, duct and accessories. It is the sum of the resistances suffered by air in the hood main duct, different branch ducts, bends, enlargements or contraction, air cleaning plant and at the entrance to the main duct.

The various steps involved in the calculation of the T P of a branch duct are the determination of the following:

i. Transport velocity.
ii. The V P
iii. Hood-entrance loss in terms of the V P.
iv. Straight-duct equivalent of the bends.
v. Total equivalent length of straight ducts and the resistance in terms of the V P.
vi. Other energy losses in terms of the V P.
vii. Main-duct entrance loss in terms of the V P.
viii. Summation of values obtained in the step 2, 3, 5, 6 and 7 to determine T P in terms of the V P.

i. Transport~~t~~ Velocity : The air velocity required to transport the contaminants mainly varies with the size , and specific gravity of the material and partly with the shape of the materials. Dalla Valle obtained the following equation for horizontal transportation:

$$V = 6000 \left(\frac{\sigma}{\sigma+1}\right) d^{0.4} \qquad (11)$$

where V - Duct velocity in ft/min.
σ - Specific gravity of the contaminant.
d particle diameter in inches.

From the point of view of power economy, it is recommended to keep the transport velocity at its minimum value for satisfactory conveyance of the contaminant. Table 5.5 lists the duct velocities for a variety of contaminants.

Table 5.5.

RECOMMENDED MINIMUM TRANSPORT VELOCITIES.

Name of contaminant	Examples	Duct velocity.
Vapours, Gases, Smokes, fumes, and very light dust.	All vapours, gases, and smokes; zinc and Aluminium oxide fumes; wood flour and cotton lint .	2000 fpm
Medium-density dry dusts.	Cotton , wood chips, rubber and bakelite dust.	3000 fpm
Average industrial dust.	Fine coal, brass turnings, grinding sand blast.	4000fpm.
Heavy dusts.	Lead and foundry shake out dust, metal turnings.	5000 fpm.
Large particles of heavy moist particles	Moist lead or foundry dust	5000 fpm or over.

Table 5.5. indicates that dissimilar contaminants should not be exhausted by a single system owing to the widely different velocity suitable for each of the contaminant transportation. Although a single exhaust ventilation system handling different types of contaminants is quite economical in installation, yet it consumes too much power and hence not adopted.

11. <u>Velocity Pressure:</u> The duct area is given by the equation

$$A = Q / V \qquad (12)$$

Where A = Duct (rectangular or round) area in sq.ft.

Q = Quantity of air in cu. ft. / min.

V = Minimum transport velocity in ft/min.

From A, the duct dimensions are calculated. In case of round pipe, the duct diameter is directly given by the equation :

$$d = 13.5\,(Q/V)^{0.5} \qquad (13)$$

Where Q & V = same as in Equation 12 d = duct diameter in". inches

If the duct size obtained falls below a standard one, the next smaller size is selected, and the actual velocity for rectangular ducts is determined by the equation 12 and for round ducts by the following equation.

$$V = \frac{183\ Q}{d^2} \qquad (14)$$

Q and d same as in equation (13).

V = Average duct velocity in ft/min.

Knowing the Av. duct velocity, velocity pressure is given by

$$V\,P = \left(\frac{V}{4005}\right)^2 \qquad (15)$$

Where VP Velocity Pressure in inches of water.

V Same as in equation 14.

On knowing quantity of exhaust air and minimum transport velocity, VP can be directly obtained from Fig.5.14

iii. <u>Hood Loss</u> : It depends upon the shape of the hood and is due to the contraction of the air stream at the throat of the hood. The greater is the contraction, the lower is the coefficient of entrance (C_e) and consequently the greater is the energy loss at the entrance. Figures 5.15 to 5.26 show some of the typical hood shapes with the correspondin-g coefficients of entry and energy loss in terms of the VP at the throat of the hood. In case of tapered hoods, Ce depends upon the proportions of the hoods. Table 5.6 lists Ce for tapered hoods of different proportions with the included angle (θ) or the ratio L/D-d (Fig. 5.27).

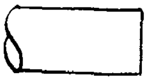
TABLE 5.6.

COEFFICIENTS OF ENTRY FOR TAPERED OR BELL SHAPED HOODS OF DIFFERENT PROPORTIONS.

(D more than 1.4 d in fig. 5.27, flanged or unflanged).

Included angle θ in deg. (Fig. 5.27	Ratio. L/D-d (Fig. 5.27)	Round. Throat dia. 8" & larger.	Throat dia. less than 8"	Sq. or Rectangular. Throat dia. 8" & larger	Throat dia. less than 8".
0 -360 *	-	0.72	0.70	0.70	0.68
20	2.8	0.96	0.91	0.94	0.89
40	1.4	0.99	0.93	0.95	0.90
60	0.87	0.88	0.92	0.94	0.88
90	0.50	0.95	0.90	0-91	0.85
180 †	[illegible]	0.87	0.79	0.80	0.77
270 *	-	0.75	0.74	0.74	0.72
360 or 0	-	0.72	0.70	0.70	0.68

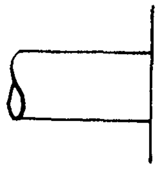
* Unflanged duct ends.
† flanged duct ends.



PLAIN DUCT END

$Ce = 0.72$
$he = 0.93$ VP

FIG. 5.15



FLANGED DUCT END

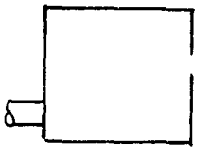
$Ce = 0.82$
$he = 0.49$ VP

FIG. 5.16

SHARP EDGED ORIFICE

$Ce = 0.60$
$he = 1.78$ VP

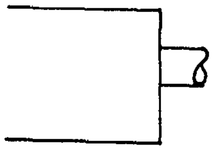
FIG. 5.17



ORIFICE PLUS FLANGED DUCT

$Ce = 0.55$
$he = 2.3$ VP

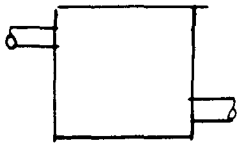
FIG. 5.18



DIRECT BRANCH-BOOTH

$Ce = 0.82$
$he = 0.49$ VP

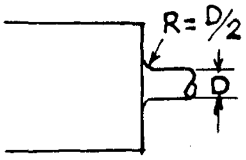
FIG. 5.19



TRAP OR SETTLING CHAMBER

$Ce = 0.63$ (APPROX.)
$he = 1.5$ VP

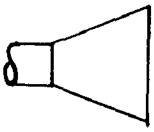
FIG. 5.20



BOOTH PLUS ROUNDED ENTRANCE

$Ce = 0.97$
$he = 0.06$ VP

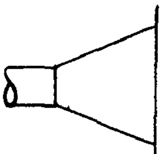
FIG. 5.21



TAPERED HOOD

$Ce = 0.82$ TO 0.98
(SEE TABLE)

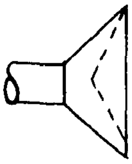
FIG. 5.22.



FLANGED TAPERED HOOD

$Ce = 0.82$ TO 0.98
(SEE TABLE)

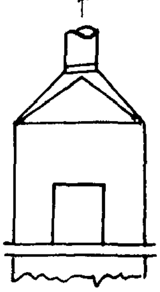
FIG. 5.23



DOUBLE TAPERED HOOD (INNER CONE)

$Ce = 0.70$ (APPROX.)
$he = 1.04$ VP

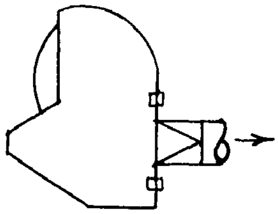
FIG. 5.24



HOOD, AS OVER LEAD POT LOW FACE VELOCITY

$Ce = 0.82$ TO 0.98
(SEE TABLE)

FIG. 5.25



STANDARD GRINDER HOOD

$Ce = 0.78$
$he = 0.65$ VP.

FIG. 5.26

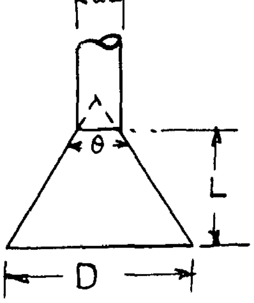


FIG. 5.27.

Knowing Ce, the hood entrance loss at the throat the hood may be calculated by the following equation:

$$he = 100 \left(\frac{1 - Ce^2}{Ce^2} \right) \qquad (16)$$

Where he - Hood entrance loss in percentage of VP
Ce = Coefficient of hood entry.

In case of hoods of complicated shape, Ce is determined by guess work. However, in certain cases, the complicated hood may be divided into simple hoods and from the Ce of individual hood the hood loss can be determined for each of them from the Table 5.7. The sum of these individual hood losses gives the hood loss for the complex hood from which the over-all coefficient Ce can be determined from the same Table. 5.7.

TABLE 5.7.

PRESSURE LOSS AT HOOD ENTRANCE IN PERCENTAGE OF VELOCITY PRESSURE AT THROAT FOR DIFFERENT COEFFICIENTS OF ENTRY.

$$he \quad 100 \left(\frac{1 - Ce^2}{Ce^2} \right)$$

Coefficient of Entry.	Hood entrance loss in % of VP at throat.	Coefficient of Entry.	Hood entrnce loss in % of VP at throat.
1.00	0	0.75	78
0.95	11	0.70	104
0.90	23	0.65	137
0.85	38	0.60	178
0.80	56	0.55	230

iv. Bends, Straight Duct Equivalent : The energy loss for bends can be expressed in terms of the length in feet of straight duct which has the same RP. The RP for bends varies with the degree of curvature and with the amount of bend. The equivalent length of straight duct is given by the following equation.

$$EDL = K \theta d^{1.2} \qquad (17)$$

Where EDL = Equivalent Length of Straight duct in feet.

K = Constant which varies with the degree of curvature (Table 5.8)

θ = The angle of bend in degrees.

d = The duct diameter in inches.

TABLE 5.8.

VALUES OF K IN EQUATION 17 FOR BENDS OF DIFFERENT RADII

Centre line radius of bend in terms of duct diameter.	Value of K in eq.17.
1	0.0273
1½	0.0140
2	0.0094
2½	0.0078
3	0.0094

v. Resistance Pressure of Straight ducts: The RP in a pipe line varies with air flow, length of pipe, pipe diameter, and coefficient of roughness. In order to calculate the RP of a duct work including bends, the total duct length is obtained by adding the straight duct length of a branch pipe determined upto a junction point with another duct to the equivalent length of straight ducts for the bends. The following equation gives the RP of straight ducts :

$$RP = \frac{0.058\ L\ Q^{1.91}}{cd^{5}} \qquad (18)$$

Where RP = The duct resistance pressure in inches of water.

L = The total length in feet of ducts including the straight duct equivalent of the bends.

Q = Quantity of air in cu. ft/min.

C = Coefficient of roughness (Table 5.9)

d = duct diameter in inches.

As RP is usually expressed in terms of the VP, the equation 18 is converted to the following form :

$$L = 0.0365\ cd\ Q^{0.09} \qquad (19)$$

Where L = Length in feet of duct which has an energy loss (RP) of 1 VP.

c,d and Q = same as in eq. 18.

Knowing the duct length having an energy loss of 1 VP, the RP of the total duct length can be determined in terms of VP.

TABLE 5.9.

COEFFICIENT OF ROUGHNESS FOR DIFFERENT TYPES OF DUCT WORK

Type of Duct work	Coef. of Roughness
Excellent, Smooth pipes	60
Average exhaust system of good design	55
Not-too-well-designed system with rough ducts	40
Old, bent, and damaged ducts (also most flexible metal hose)	30

Although round ducts are better for exhaust systems, yet they are replaced by rectangular ducts in some cases. In order to calculate the RP of a rectangular duct, the usual practice is to determine the diameter of equivalent round duct and then the remaining procedure in calculating the RP of the duct work is the same as for round ducts. The relation between the rectangular duct ~~diversions~~ dimensions and the diameter of equivalent pipe is given by the following equation :

$$d = 1.075 \, (xy)^{\frac{1}{2}} \qquad (20)$$

where d = Diameter of equivalent round duct in inches.

x & y the Dimensions in inches of the rectangular duct.

vi. Other Energy Losses: These include the miscellaneous losses caused by entrance connections from branches into main ducts, transition pieces, chip traps, air-cleaning equipments, etc. Pressure losses through air cleaning, plants vary with the design of the, apparatus.

vii. Main-duct entrance loss:

Energy loss occurs at a point where a branch duct enters into the main duct. This loss depends upon the angle at which the branch duct enters the main. The RP for the main duct entrance loss can be obtained from the Table 5.10 in terms of VP.

TABLE 5.10.

Angle in degrees at which branch duct enters main in deg.	Entrance loss (RP) in percentage of VP in the branch.
10	6
20	12
30	18
40	25
50	32
60	45.

viii. The Total Pressure: The Total pressure of the branch duct is the sum of the individual RP's determined under items 3, 5, 6 and 7 in terms of the VP plus 1.0 VP as found under item 2. Since the TP of the branch should be the same as that of the main at the point of junction, the TP for the branch calculated can be used to determine actual V. If this is not in close approximation with that determined under item 2, the duct size is recalculated to maintain balance in the system.

B. Transport-Velocity Design:

It is probably the most popular design procedure and is relatively a simple one. Like the previous design procedure, the calculation also begins at the branch of greatest resistance and pressure drops are calculated through the branch and through the various section of the main on upto the source of suction. At every junction where a branch pipe meets the main, the volume of air-flow in the branch duct is added to that of the main. The duct work is then sized to give the desired minimum transport velocity at the desired CFM by using equation 12 or 13. Air balance is obtained by varying the resistance in any particular branch with artificial means such as dambers or blast gates located in the branches close to the main duct. This method of design is relatively advantageous in allowing reasonable extensions. But in course of time, the dampers may be damaged or worn out, and may be choked with the particulate matter. Hence this method is not adopted to control operations dealing with highly toxic materials.

5.5.6. Corrections for Temperatures and Elevations:

The data in the foregoing tables and figures are based on an air density of 0.075 lb/ cu.ft (70°F dry air at 29.92 in. of mercury barometric pressure). The corrections are applied only when the temperature exceeds 100°F and the elevation is more than 1500 ft. To correct for high temperatures or elevations, the exhaust air volume may be increased by the reciprocal of the density to keep the same weight of air flowing into the hoods.

-:0:-

CHAPTER VI

AIR CLEANING DEVICES.

Before discharging the exhaust air into the atmosphere, it is cleaned of its contaminants. Air cleaning devices for particulate matter and gaseous substances have been discussed separately. Later respirators meant for personal protection of workers have been dealt.

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6.1. GENERAL

Air cleaning devices remove contaminants from an air or gas stream before it is discharged into the atmosphere. This approach to the contaminant hazard is a supplement to the dilution method and can make the dilution method work to advantage. These devices are available in different designs and are used depending upon the air-cleaning requirements. The choice depends upon a number of factors such as degree of removal required, quantity and characteristics of the contaminant to be removed, particle size and size distribution, temperature of the gas or air stream, corrosive components in the gas or air stream to be cleaned, method of disposal of collected material, safety hazards and economy.

6.2. TYPES OF AIR CLEANING DEVICES:

Air cleaning devices are divided into two basic groups :

6.2.1. Particulate Emissions Cleaning Devices.
6.2.2. Gaseous Emissions Cleaning Devices.

6.2.1. Particulate Emissions Cleaning Devices:

Various particulate cleaning devices used are settling chambers, centrifugal collectors, scrubbers, fabric collectors, air filters, electrostatic precipitators, and thermal precipitators. In these equipments, the separation of the particles in the gas stream is obtained by exerting a force on the particles. The force exerted causes the particles to settle on a collecting surface. These forces are varied such as gravitational, inertial, physical, electrostatic, thermal, etc. The particles can also be got rid of the gas stream by modifying their properties so that more effective collection may take place. This includes increasing the size of the particles by condensing water vapour on them or by agglomeration of fine particles. The common types of particulate cleaning devices are the following.

A. Settling Chamber: Basically, a settling Chamber is an enlargement of a flue or duct carying the contaminated gas stream. The velocity of the gas stream is reduced significantly in the chamber and consequently it results in the settling out of the particles by gravity within the limits of the chamber. This device is used to collect coarse particles above 40 microms in size.

The most common form of a settling chamber is a box like structure (Fig. 6.1.) which is set horizontally. In order to minimize turbulence and ensure uniform velocity in the chamber, a deflector may be suspended in the chamber. This also helps in the early settlement of particles. The efficiency increases with the length of the chamber and particle size and falls with increased gas velocity.

Settling chamber does not find much applications in practice as an air cleaning device. However, in case where other types of devices cannot stand up the high temperature

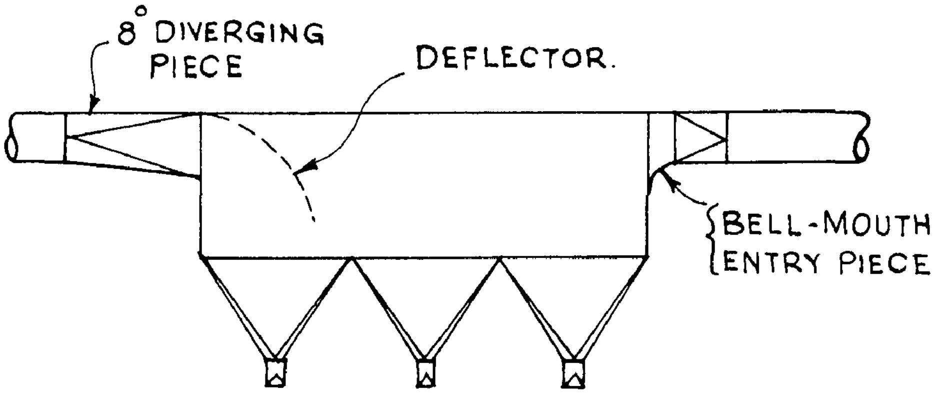


FIG. 6.1

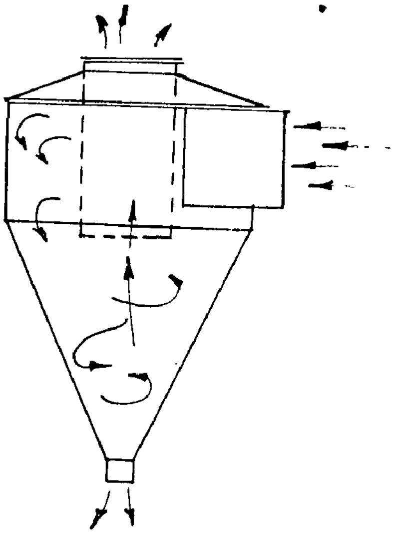


FIG. 6.2

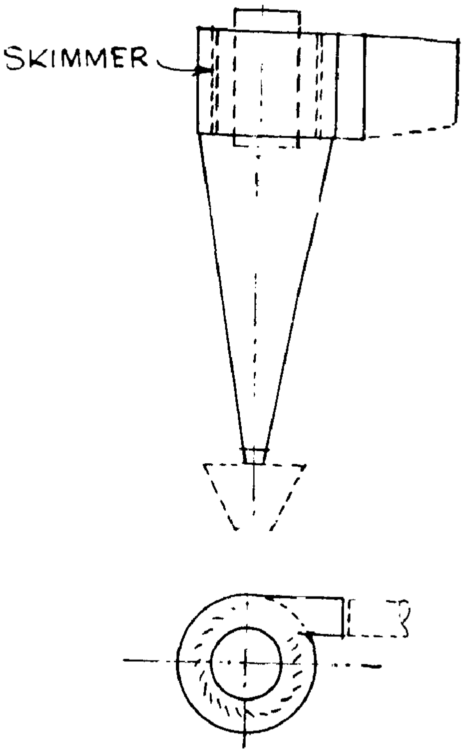


FIG. 6.3

in handling the hot dusty air, a settling chamber may be used and is often followed by water sprays which aid to better cleaning and cool the air to reasonable discharge temperature. This type of cleaning is used in metallurgical processes. It finds place in the manufacture of some food stuffs and powders as a first step in product recovery. It is sometimes used along with higher efficiency collection units and relieve them from overloading or excessive wear.

B. <u>Inertial or Cyclone Collectors</u> : The cyclone separator is the most widely used gas cleaning device and is usually considered to be effective for particles larger than 10 to 20 microns in size. The separation of the solid particles from an air or gas stream is effected by centrifugal and gravity forces. The centrifugal effect is obtained by directing the contaminated air in a path which is tangent to the chamber at the point lying on the periphery of the upper portion (circular) of the collector. The velocity of the air at inlet is sufficient to force itself downwards in a helical path called the outer vortex. The accelerated air stream forces the moving stream in its front. At the bottom of the outer vortex, the gas stream takes a turn and the clean gas is directed upwards in a helical path around the axis of the collector known as inner vortex. The centrifugal force on the particulates make them to move to the cyclone walls, from where they slide down by gravity into the conical shaped bottom.

The cyclone separators are divided into the following groups:

i. <u>Simple Cyclone</u> : Simple cyclone (Fig. 6.2) is commonly applied as a preliminary collector for the separation of a large percentage of coarse particles. It is used as a separator in the product conveying systems using an air stream to transport material. Principal advantages are low cost, low maintenance and low pressure drop (¾" to 1½") but it cannot be used for the collection of fine particles.

ii. <u>Skimmer Type Cyclone</u>: Skimmer Cyclone (Fig. 6.3) is also used to remove coarse particles but operates more efficiently than a simple cyclone. The cyclone is fitted with a 'skimmer device' to assist in the initial removal of a large portion of the entrained matter in the air stream.

The resistance offered by skimmer type cyclone is nearly the same as for simple cyclone. This type of cyclone is not used for those matter such as material of viscous nature which may clog up the skimmer device.

iii. <u>High Efficiency Cyclones</u>: As the name indicates this type is meant for high efficiency. It is preferred to the simple or skimmer type cyclones in collecting smaller size particles. The principle on which it operates, is the same as that of an ordinary cyclone. It makes use of an increasing angular velocity through a cyclone shaped collector (Fig. 6.4).

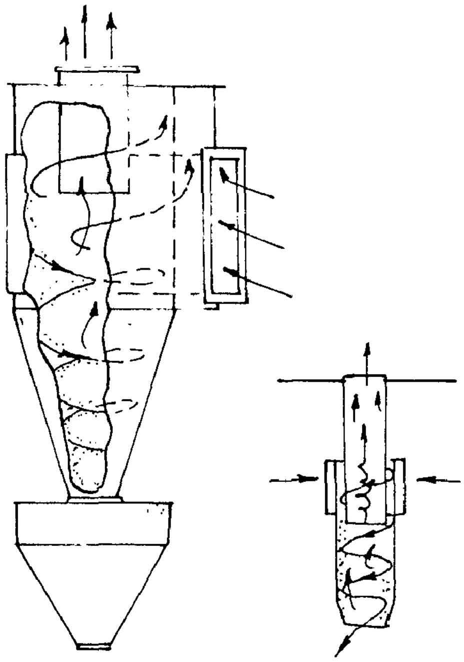


FIG. 6.4

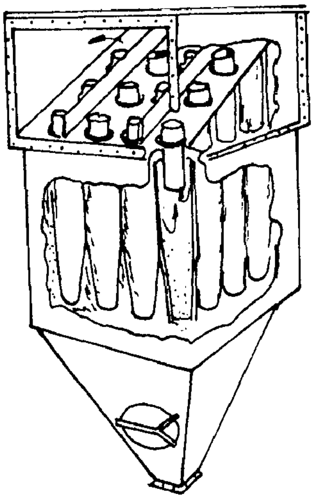


FIG. 6.5

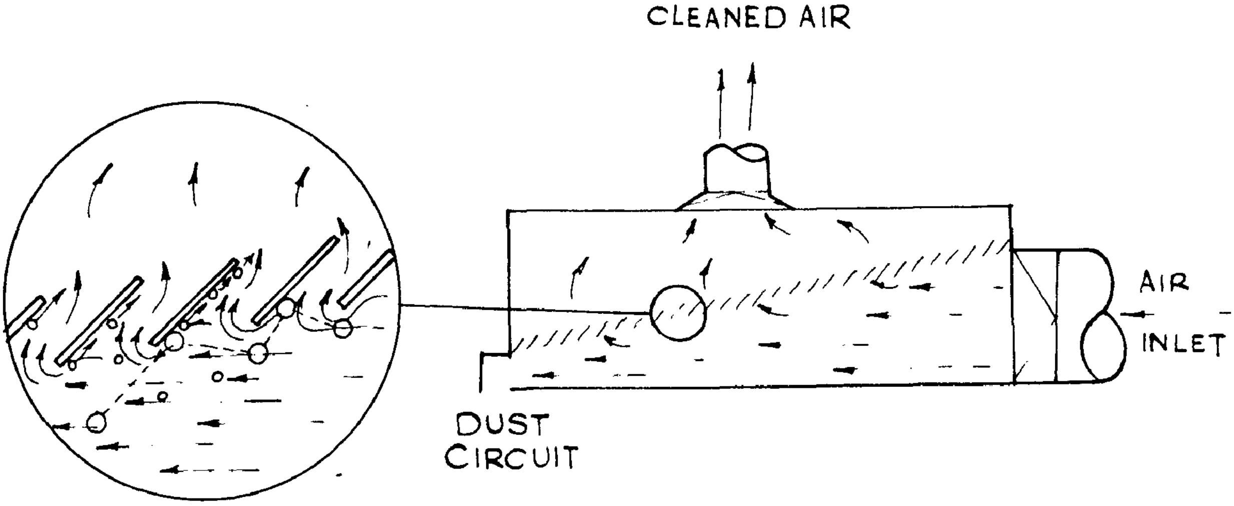


FIG. 6.6

The momentum of the suspended solid particles is sufficient so as to force the particles against the lower walls of the collector from where they slide down to cone bottom.

iv. Multiple Cyclone Collectors: These are meant for efficient collection of small size particles and preferred to the simple or skimmer type collectors in this respect. These are used for large variety of dust collection.

Multiple cyclone collector (Fig. 6.5) consists of a group of small diameter cyclones arranged in parallel with promision of a common inlet and outlet. The number of tubes depends upon volume of air to be handled. The diameter of the small cyclones is from 6" to 16" and the ratio of length to diameter is quite large. The separated dust from each small cyclone finally discharges into a common collector hopper.

v. Lower Type Cyclones: Centrifugal forces can be applied to a particle by a rapid change in direction of air flow by a number of plates set at an angle to the air stream (Fig. 6.6) . Coarser particles are held back in the dirty air side due to impaction.

Efficiency of this device depends upon louver spacing. Main advantages are simplicity, low cost of its construction and relatively low pressure drop for the degree of removal obtained. Disadvantages are dust accumulations and abrasion on the louver elements.

vi. Dry Dynamic Precipitators: It operates on the same principle as cyclones with the exception that the centrifugal force is produced by use of an integral fan. The blades of the fan are shaped so as to direct the separated dust into an annular slot leading to the collection hopper and the clean gas goes out.(Fig 6.7)

The chief advantage of this separator is that for the same capacity, it generally occupies less space than an equivalent cyclone . Thus resulting in greater compactness. Care should be taken to balance the rotating member to minimize the vibrations which may otherwise tend to keep the particles in suspension during air cleaning operation. In this unit air turbulence usually interferes with separation of fine particles and this necessitates its adaption along with other air cleaning devices. It is particularly adapted for dust control installations where equipment space is at a premium, and an unusually high dust removal efficiency is not necessary.

c. Impingement Separators (Dry Type) : These separators are used for deposition of particulates larger than 20 microns in size. In these devices the dirty air or gas is subjected to several violent changes in direction and / or velocity as it passes around an obstruction which may

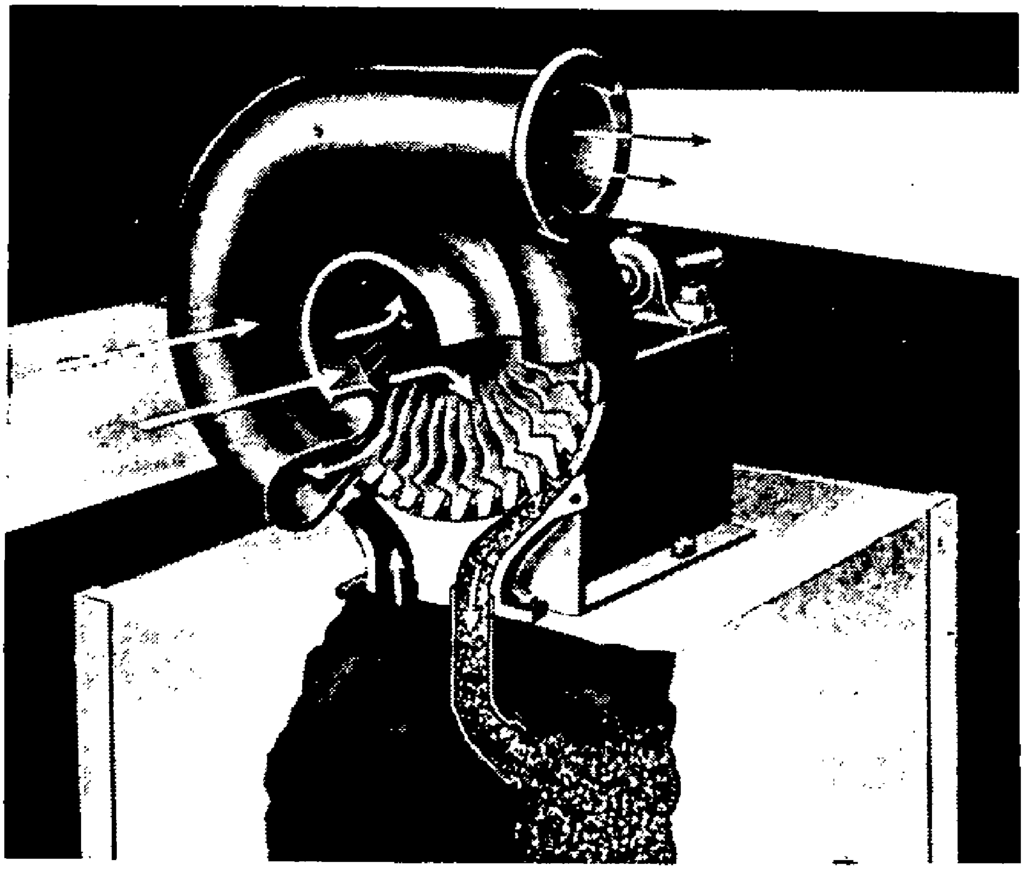


Fig. 6.7

be in the form of a simple baffle or some complicated pattern. This results in the separation of the particulates.

Impingement separaters are used as cinder traps for cleaning flue gases from stoker fired furnaces. The pressure loss across the unit is quite less and depends upon the type of baffling, the spacing, gas velocity etc.

d. Packed Beds (Dry Type) In packed beds (~~Fig. 6.8~~) the particulate laden gas stream is passed through a bed packed with granular solids and gets rid of the undesired matter by impingement. It also serves as an impingement separator. The packed bed may consist of sand, granite, quartz, coke or fibrous materials such as mineral wool and steel wool. The bed depth depends upon the type of the packing used. However, it varies from 2 to 6 feet.

Efficiency depends upon the fineness of the material particles used for the packed beds. For fine packing the gas velocity is between 1 to 15 fpm and while for coarse packing, it is of the order of 1 to 50 fpm. In case of fine packing with proper gas velocity maintained., the efficiency may touch even 100 percent. When dealing with high dust concentrations, provision should be made to have a moving bed in order to withdraw the material for cleaning, thus maintaining a reasonable pressure drop and constant gas flow.

Recent developments have indicated that packed beds using mineral fibres collect acid gases, mist fumes, along with the solid particulates. Acid gases are held through the chemical reaction with mineral fibres. After exhaustion the bed can be recharged for further use. Still considerable developments are awaited for its practical application, in large scale.

G. Wet Collectors : The principle of a wet collector is to wet the contaminants and remove them from the air stream. This is accomplished by impingement of the dirty air stream against a wetted surface or by passing the contaminated air stream through a liquid bath or spray. Wet collectors have the ability to handle high temperature and moisture laden gases. They can be adopted for the removal of mixed contaminants such as gases and solids or liquid particles. The collection of dust in a wetted form eliminates a secondary dust problem in connection with the disposal of the collected material. But the use of water may give rise to corrosive conditions and the disposal of the waste liquids may become a problem. Wet collectors located out of doors in cold climates should be protected against freezing by suitable measures such as exhausting the air at room temperature or higher.

The resistance through most of the wet collectors, with the exception of packed towers, is constant during the operation provided the moisture eliminators do not get dirty and plugged up. Space requirements are nominal. Pressure losses and the efficiency vary according to the design of the equipment. The following are the various types of wet collectors generally used for air cleaning:

a. <u>Impingement Type:</u> It is similar to the dry impingement type except that the surfaces used for collection of solid matter is wetted with water or some other liquid and the deposited matter is washed away by the continuous flow of water through the chamber.

b. <u>Packed Beds (Wet Type)</u> : These are similar to the dry type with the exception that the packings are kept wet (Fig 6.8) In this the liquid passes concurrently or counter current-ly or in cross flow with respect to airmovement. These are generally used for the abatement of highly corrosive contaminants.

Water is frequently distributed through V-notched ceramic or plastic weirs and its consumption is 5 to 10 gpm per 1000 cfm of air (70 deg. F) dealt. While dealing with furnace flues (1600 deg. F) directly, brick linings are used to avoid the possible damages due to high temperature.

c. <u>Static Washers and Scrubbers:</u> These are most widely used in the industry for cleaning of air and gases. In addition to cleaning, it simultaneously provides cooling effect also. Water is the usual wetting agent. In cases where water fails to wet the substance, some other liquid such as oil may replace water as the wetting agent. These

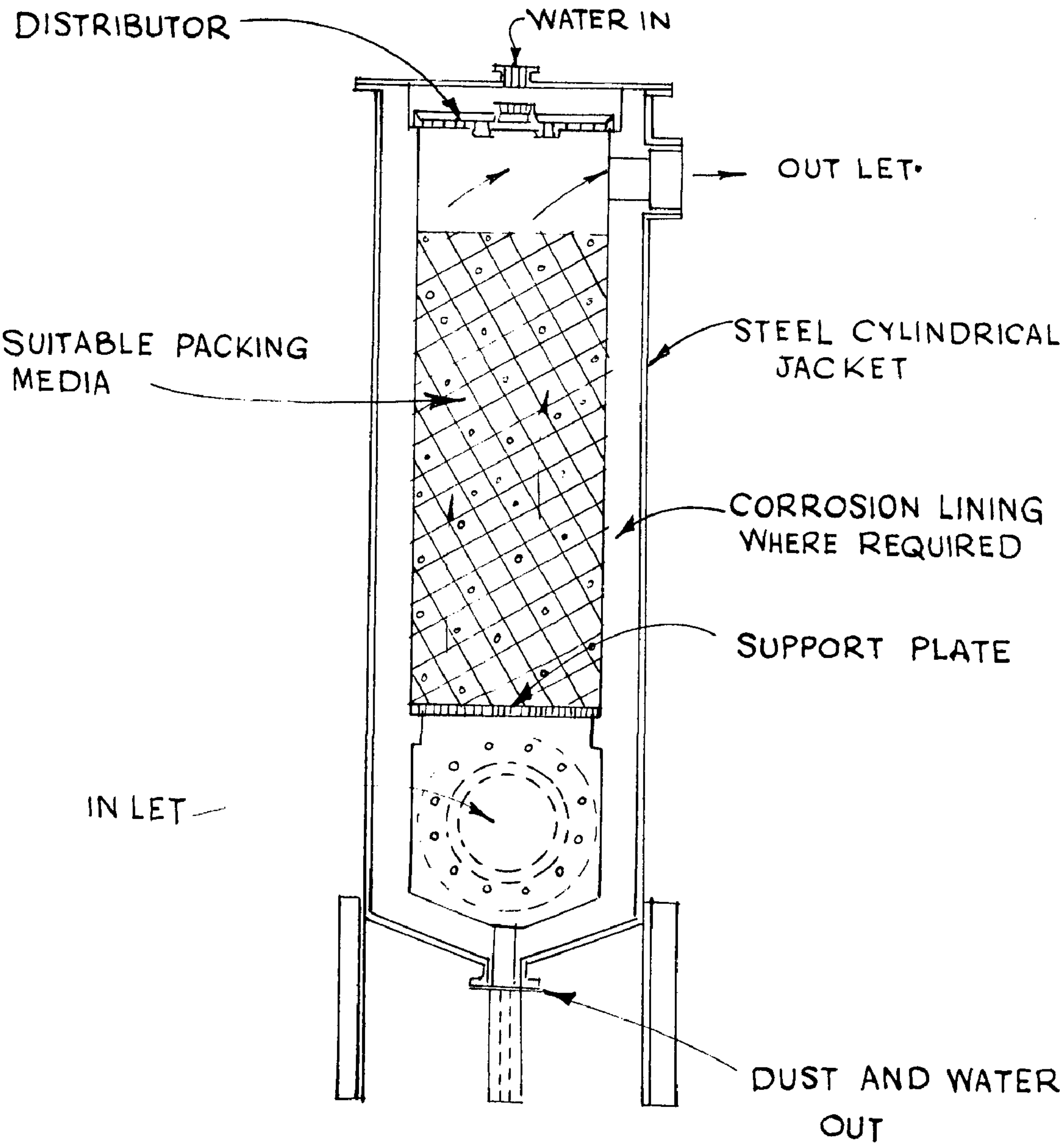

DISTRIBUTOR
WATER IN
OUT LET.
SUITABLE PACKING MEDIA
STEEL CYLINDRICAL JACKET
CORROSION LINING WHERE REQUIRED
SUPPORT PLATE
IN LET
DUST AND WATER OUT

FIG. 6.8

liquids decrease the bubble size, accentuate forthing, increase entrainment and contribute a little to the collection efficiency resulting in the particulate removal from the contaminated air or gas.

The air is usually passed through one or more sprays of water at velocities not exceeding 1000 fpm. In another spray method, the water is picked up by a high velocity air stream of about 2700 fpm and then through a sudden change in direction of air travel, the matter is dropped out with the entrained water. It should be noted that the effectiveness of this method does not ordinarily depend much on the contact of the dispersoids with the water droplets but with the wetted walls and baffles. Consequently in case of straight, empty flues or towers provided with ordinary sprays, the air cleaning is not efficient partly because of the number of spray droplets being inadequate to meet the load, and partly because of the particulate being surrounded by gas film which prevents the contacts with spray droplets. Similarly mere bubbling of the gas through a high column of liquid will not serve much of the purpose unless it is well distributed through out the liquid. The following are the main types of scrubbers :-

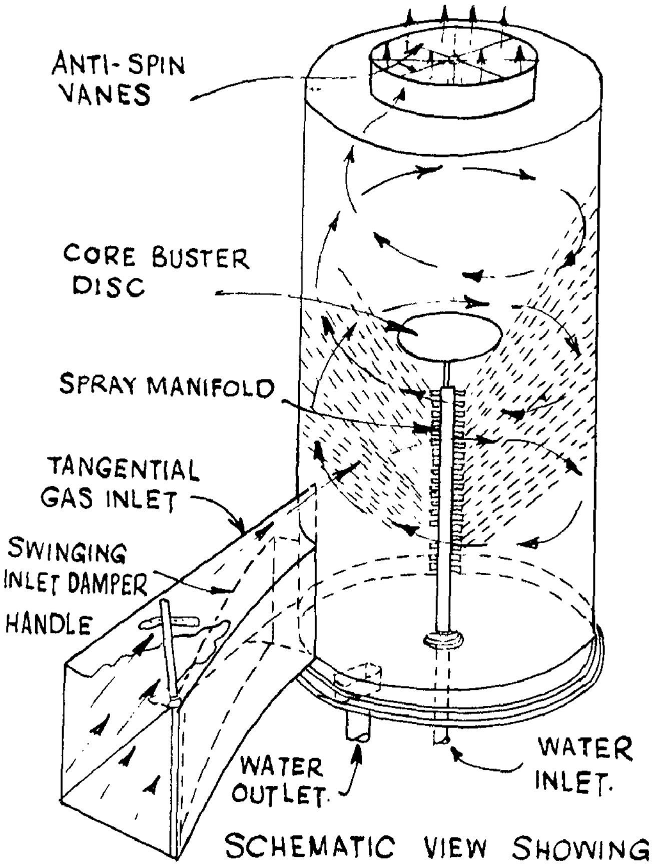
1. <u>Spray Chamber:</u> It is the simplest type of gas scrubber. It consists of an empty tower into which the water is introduced at the top through a bank of spray nozzles while the gases are led opposite to the direction of falling drops. The water droplets serve as targets on which the dust particles collect by impaction. It is employed as a primary cleaner as well as a cooler. It can satisfactorily remove the coarse dust but with less of efficiency. The gas velocity is usually of the order of 3 to 5 fps.

Another type of spray chamber commonly known as air-washer is used mainly for humidity control in air conditioning. Side by side it aids in the air cleaning. It consists of a horizontal chamber containing banks of nozzles set at different heights above the level of the sump water. The arrangement of the nozzles is such that the water may be sprayed with or against the air or in either direction using different sets of nozzles. At the exit, eliminaters consisting of zig zag plates are provided to remove mist particles. At the bottom water sump is provided with a pump for the ~~circulation~~ recirculation of water. In some cases, wetted baffles are provided across the air stream in the chamber itself. Water requirements for air washer range from about 0.5 to 20 gallons per 1000 cu.ft. of gas. The pressure drop is of the order of ½" to ¾" wg. Spray tower also falls in this catagory with the exception that it has a tower structure.

Modification of the simple spray scrubber is a cyclone spray scrubber known as the Pease Anthony cyclone spray scrubber (Fig. 6.9). In this the water is sprayed through nozzles from a manifold located at the centre. The air is introduced either at the top of bottom of the cylindrical tower. The fine droplets are thrown violently through the passing gas stream at high velocities by the centrifugal force. As shown in Fig. the unsprayed portion in the upper part above the nozzles is provided to give enough time to the droplets containing the collected matter to reach the scrubber walls before the gas emerges out . These scribbers are used in case of lime kiln dust, cleaning, Blast furnace gas and flue gases from powdered coal furnaces.

High efficiency of the order of 97% is obtained for particle size above 1 micron. Entering gas velocity is as high as 200 fps. Water consumption is 3 to 10 gallons per 1000 cub. ft. of gas. ~~Prcoure~~ Pressure drop is between 2" to 6" of water.

ii. <u>Atomizing Scrubbers</u>: This type of collector uses venturi orifice for intermixing of the dust and water particles. The intermixing is attained by rapid contraction and expansion of the air stream and a high degree of turbulence. Water is introduced at the throat of the venturi through which the particulate is passing at a high velocity, and impaction air collection takes place as the stream expands. Water consumption is 5 to 7



SCHEMATIC VIEW SHOWING ELEMENTS OF PEASE-ANTHONY SCRUBBER

FIG. 6.9

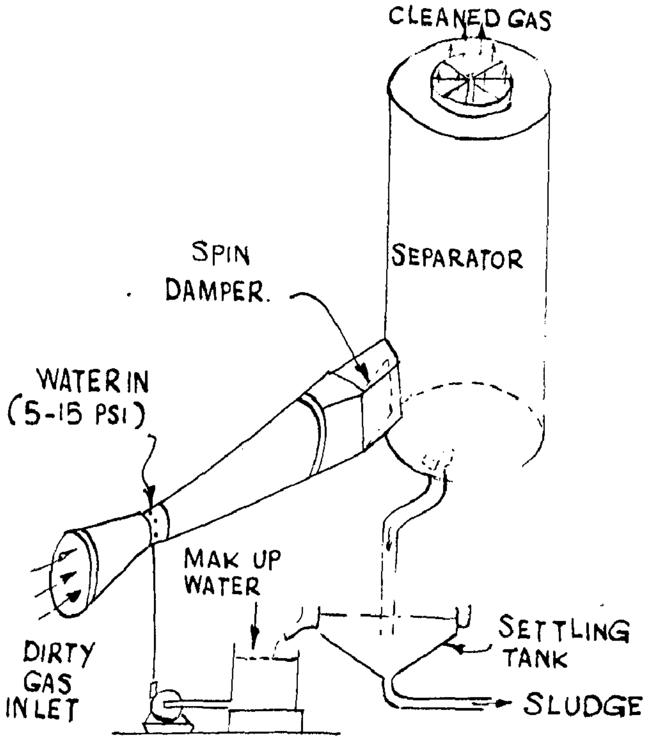


FIG. 6.10

gallons per 1000 cfm. Pressure losses vary from 10" to 30" wg.

The atomizing scrubber known as the Pease-Anthony Venturi scrubber (Fig. 6.10) is designed for the removal of submicron particles for which the water rate should be in the range of 2 to 6 gallons per 1000 cub. ft. of gas and the overall pressure loss is 13" to 20"Wg water with high efficiencies of the order of 95%. For the collection of coarser particles, the lower velocity and water rate may be used resulting in less pressure loss.

Venturi scrubbers are used for the removal of dusts and mists coming along with the gases from open hearth furnaces, blast furnaces, sulphuric acid converters and from vaporized organic ~~methods~~. materials.

d. <u>Wet Centrifugals</u> : Wett centrifugals (Fig. 6.10) utilize a combination of centrifugal force and water contact to effect collection. They are cylindrical in either the shape of a tower or with the axis horizontal. Air is introduced tangentially and usually directed counter-concurrent to flow of water by baffles or directional plates which help in capturing particulate matter and aid in the dispersal of spray droplets. Pressure losses range from 2½ to 6" of water.

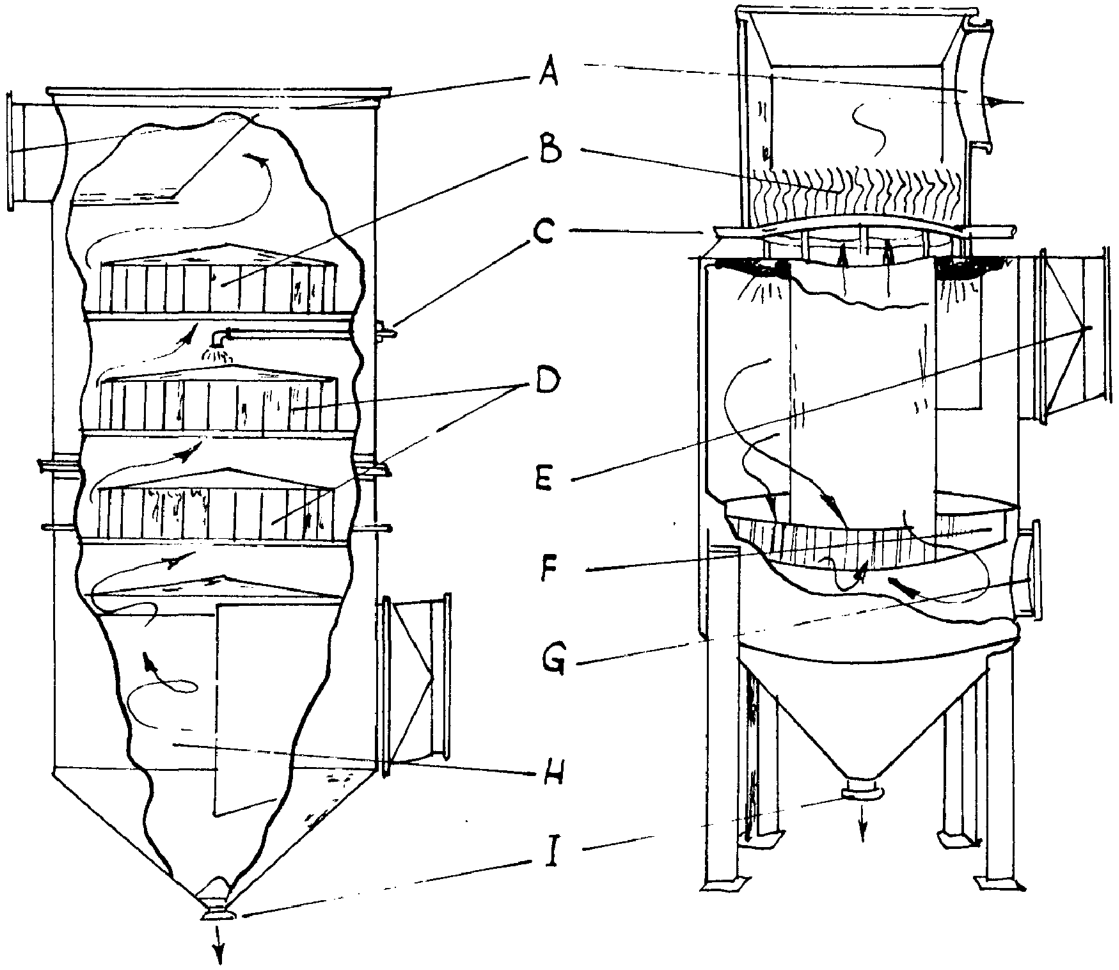


FIG. 6.11

SYMBOLS	PARTS
A	CLEAN AIR OUT LET
B	ENTRAINMENT SEPARATOR
C	WATER INLET
D	IMPINGEMENT PLATES
E	DIRTY AIR INLET
F	DISINTEQRATOR
G	INSPECTION DOOR
H	WET CYCLONE FOR COLLECTING HEAVY MATERIAL
I	WATER & SLUDGE DRAIN

e. Wet Dynamic Precipitator: The wet dynamic precipitator (Fig. 6.12) utilizes the same basic equipment as the dry type with the exception that it is supplemented by a liquid spray at the inlet. This is advantageous as it combines two air cleaning principles - dynamic precipitation and washing.

f. Orifice -Type of Wet Dust Collector: In this collector (Fig. 6.13) air flow is brought in contact with a sheet of water in a restricted passage. Water flow may be induced by the velocity of the air stream or can be maintained by pumps and weirs. Pressure losses usually vary from 3" to 6" in most of the industrially used collectors. However in some cases for the abatement of fine particles, this type of collectors are designed for high pressure losses of the order of 20".

F. Filters: The purpose of a filter is to remove as much of the contaminants as practically possible, the first choice depends upon the degree of air cleanliness required. Other factors which affect the choice include particle size, particle shape, specific gravity, temperature of the gas stream, concentration etc. For individual units, the filters can be made in such practical sizes as 50, 500, 800 and 1000 cub. ft./min. They are classified into 2 groups on the basis of the type of filter medium employed :

1. Fibrous Filters.
2. Fabric Filters.

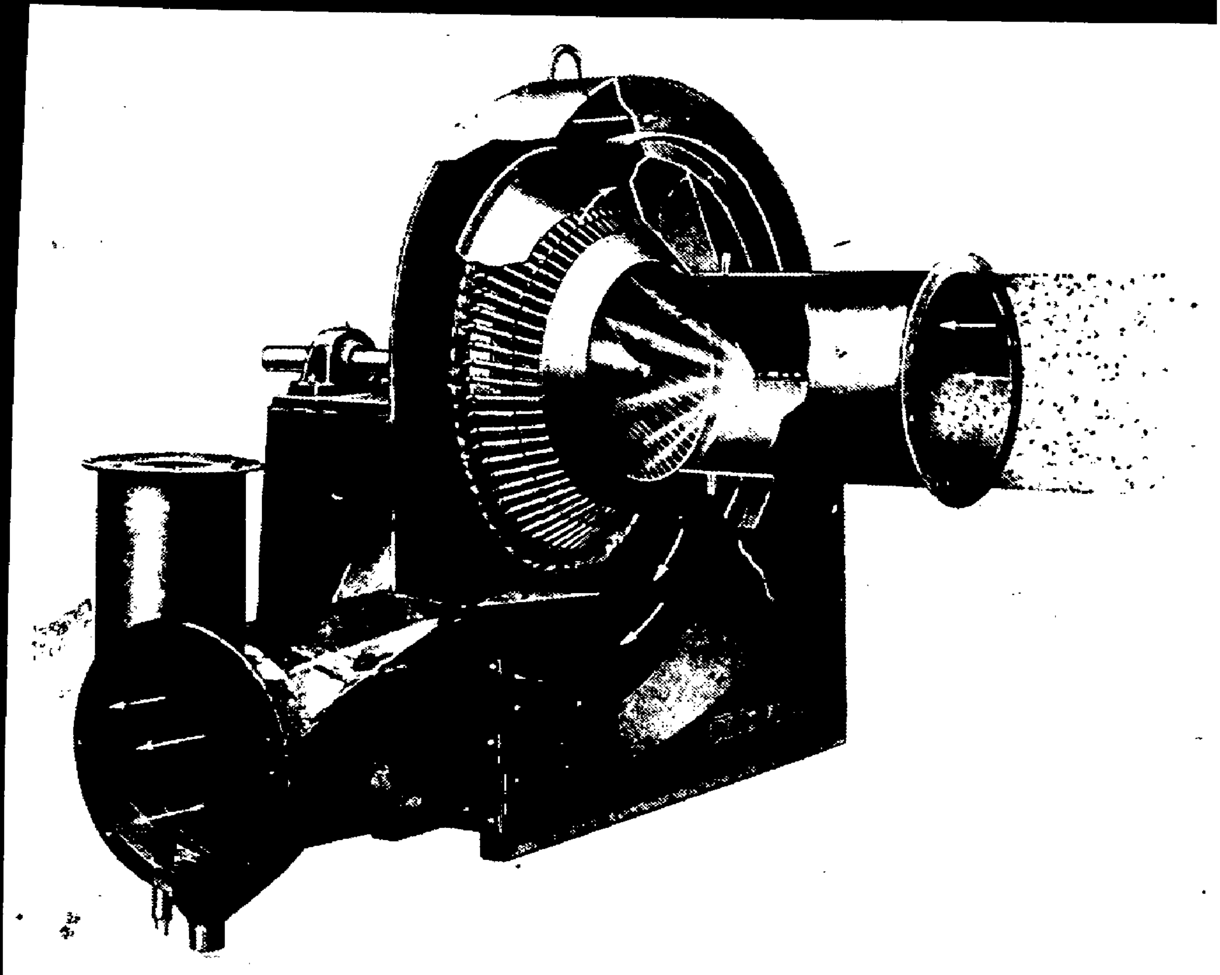


Fig. 6.12

1. **FIBROUS FILTERS:** Fibrous filters are also known as "Air filters". They are usually employed for cleaning large volumes of gas carrying very light dust concentrations. As such they find applications in the ventilation, air conditioning and heating systems where the dust concentration is generally below 5 grains per 1000 cub. ft. of air. Filter media usually consists of wool, asbestos, cellulose, glass or metal fibres which is densely packed in a metal or cardboard and wire frame. The depth of the packing is much more than the width. The efficiency of the air filter depends upon the size of the media fibres and the density with which the fibres are packed. Air filters may be subdivided into two classes:

a. **Viscous Filters:** They are so called because the filter medium employed, is coated with a viscous material to cathh the particles and retain them. Compared to the dry type the viscous filters are better suited for the removal of larger size dust particles and for handling high dust concentrations, These filters are made in units of convenient size (generally of the order of 20" by 20" in face area) to facilitate installation, maintenance, and cleaning.

The filter pad used in the viscous filter may consist of one or some times a combination of a wide variety of coarse media, including glass fibres, animal hair, wood shavings, corrugated fibreboard, split wire or metal screening. It is usually coated with oil or grease of high flash point and fire point; low volatibity no visco-

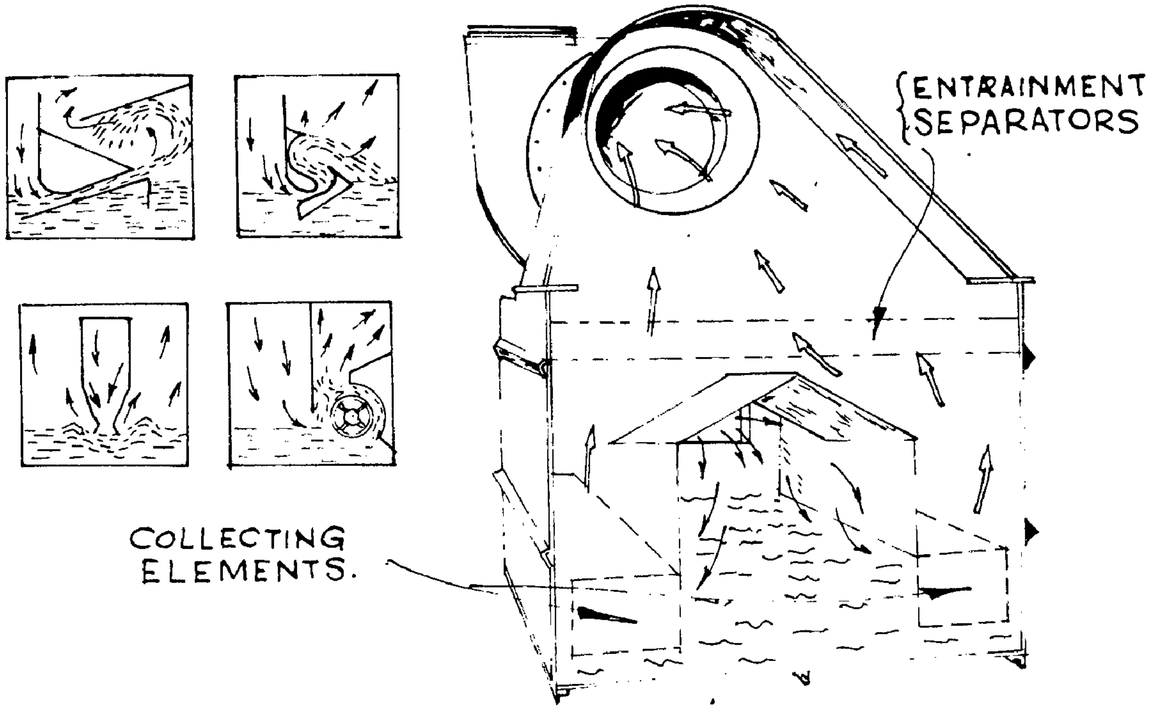


FIG. 6.13

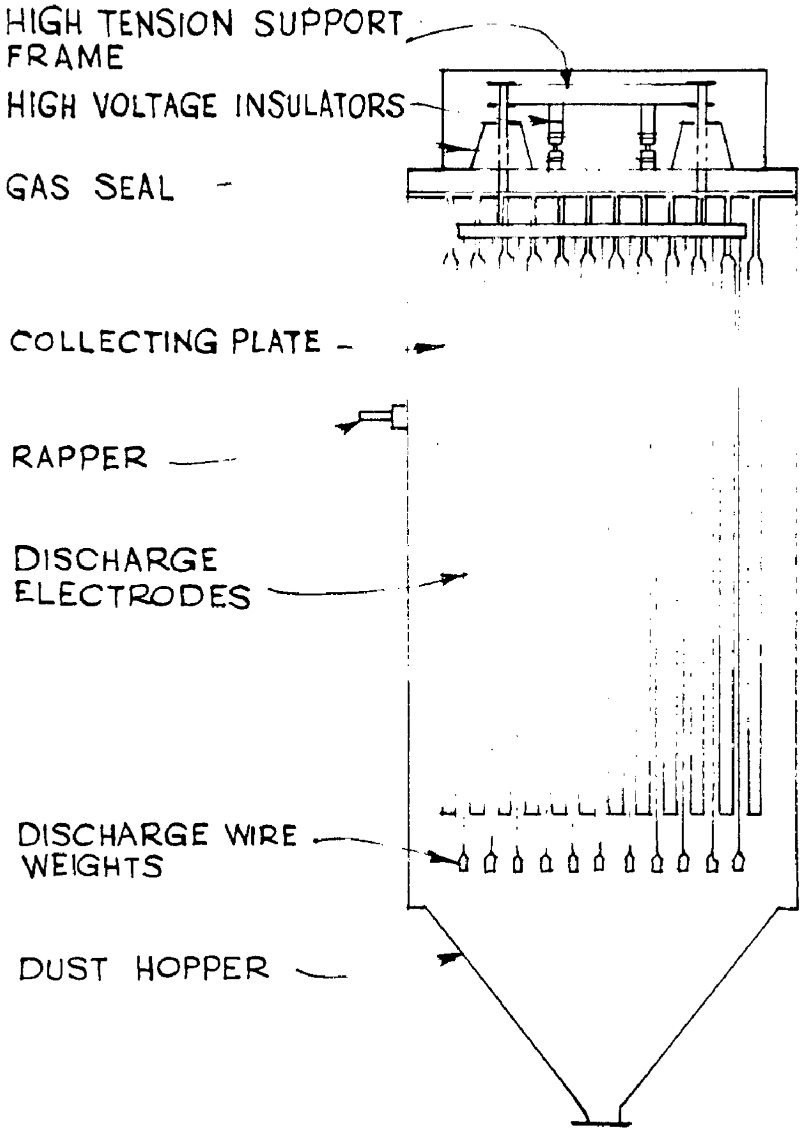


FIG. 6.14

viscosity change with variation in temperature and ability to wet and retain the particles.

Viscous filters depends upon the impingement principle in operation and as such are called viscous-impingement type filters. In the operation of this filter the air stream gets divided into many small columns of air each of which is diverted from its normal paths during its passage through the filter. At each change of direction, the larger dust particles proceed in the same straight path due to their momentum and when they impinge against the elements or fibres of the medium, they are held up by the adhesive surface. The adhesive employed should be carefully selected. However, it is the usual practice to follow the filter manufacturer's recommendations with respect to reconditioning, viscous filters are of two types; panel type or disposable type. The former type is used after washing with steam and boiling while the latter type is discarded after exhaustion.

In cases where acc-ess to the filter is difficult due to space limitations or where regular and systematic maintenance is not facilitated, the filter medium is arranged to form a continuous travelling curtain which moves perpendicularly to the air stream and periodically passes through a reservoir of adhesive where it gives up its dust load and is simultaneously recharged. The curtain usually makes one complete revolution in 24 to 48 hours period. The periodic operation of the curtain results in an efficient self cleaning of the media and provides a sufficient draining period as the media leaves the adhesive bath.

b. <u>Dry Filters:</u> These are not given any adhesive coating and are made in sizes similar to the viscous type with usually greater depth. The filter material consists of fabric like or blanket like materials of varying thickness such as cellulose fibers, bonded glass, wool felt, asbestos and synthetic, which may either be self supporting or may be supported by a wire frame. The modern dry filters are made of a mixture of fine fibres. They are available in two designs. In one design the filter media is held in between permanent metal sides and is replacceable while in the other design the entire cell is disposed of after it is exhausted.

In order to clean large volume of air of high dust concentration, an automatic dry filter is used . It consists of a continuous filter curtain which rotates over top and bottom rollers in a vertical casing. The filtering media is a paper type cellulose tissue in roll form. When the resistance to air flow coinsides with a preset value, the curtain is rotated till sufficient clean media is added. The automatic dry filter is used effectively to collect ink mists released from high speed printing operations.

High efficiency and special types of dry filters are made to clean air carrying highly toxic materials.

For radiological filteration a dry asbestos cellulose type filter commonly known as absolute filter is used. It is also used for the removal of air born micro organisms and ~~initating~~ irritating particulate matter associated with smog. For cleaning acid vapours and corrosive gases, glass fibre filters are used.

2. <u>FABRIC FILTERS:</u> The most common filtering medium employed in these filters is a cloth through which the dust-laden air is passed. This results in the dust collection on the cloth surface by impaction. Fabric filters are of the screen, tube, envelope or flat bag type. When sufficient material is collected on the filter surface, it is dislodged by means of mechanically operated shaking device fitted at the top.

Fabric filters are not suitable for high temperatures. Cotton and wool fabrics are limited to temperatures under 200°F. Higher temperature can be handled by using synthetic materials such as nylon, orlon and dacron.

G. <u>Electrostatic Precipitators:</u> An electrostatic precipitator is one of the most versatile devices developed for particulate matter cleaning. In this instrument the contaminated gas stream is passed through a strong electrostatic field. The particles are imparted with a negative charge and this caused them to move and adhere to the grounded collecting surfaces.

According to the type of use, electrostatic precipitators are classified into two groups:

i. <u>Electrostatic Precipitators for General Ventilation</u>: These precipitators are of low voltage design and small dust holding capacity. They are of two stage type. The first stage is an ionizing unit while the second stage is a precipitating unit. About 12000 volts are used for preparation unit while 6000 volts are applied across the separation unit. These precipitators are more efficient than the other type.

ii. <u>Electrostatic Precipitators for Industrial purposes</u>: Industrial precipitators (Fig. 6.14) are of high voltage design and large dust holding capacity. Charging and collection are carried on simultaneously in a single stage. A high intensity electrostatic field is maintained throughout. This charges the particulate matter and exerts a pressure on the precipitated matter so as to hold it on the collecting electrode to prevent redispersion. High potentials of the order of 60,000 to 75,000 volts are used in most of the design.

Industrial precipitators may be of pipe type or plate type. The former type consists of vertical grounded pipes (collecting surfaces), each having a negatively charged wire suspended along its axis. In the latter type the vertical grounded plates serve as collecting surfaces. The cleaning of the deposited material is done by rapping or vibrating the collecting surface either continuously or at predetermined intervals.

Collection efficiency of electrostatic precipitators is high and ranges from 85 to 99% . The collection efficiency can be improved by use of multiple (2 or 3) electrostatic precipitators in series.

Electrostatic precipitators are chiefly used where high degree of cleanliness is required. They are used extensively in high temperature gas cleaning from equipment such as blast furnaces, open hearth furnaces Central station pulverized fuel boilers, chemical industries etc.

6.2.2. Gaseous Emissions Cleaning Devices :

One of the important problems in industrial air and gas cleaning is the removal of soluble, insoluble, or combustible gases and vapours from fluid streams before they are discharged to the atmosphere. Removal of the gaseous pollutants from gas streams may be obtained by absorption , adsorption or combustion devices.

A. Absorption Devices: Absorption devices are mainly employed for the removal of readily soluble gases. In principle, the gaseous contaminants are brought into intimate contact with a liquid in which they are either soluble or react chemically.

Absorption is a diffusional operation, which involves transfer of the gaseous material between phases as the result of molecular or eddy diffusion. Molecular diffusion depends mainly upon nature of fluids involved while eddy diffusion is based primarily upon the nature of the turbulent fluid, conditions of flow and is much more rapid than molecular diffusion. The rate of transfer for both types of diffusion is pro-portional to the concentration of diffusion substances. The process of interface transfer is much more complex than the movement or diffusion of one substance through a single phase.

In the selection of an absorbent for scrubbing a gas some of the factors that must be considered include.

1. Maximum flow of gas or vapour that will be emitted by a prowess.
2. Composition of the gas stream including the concentration of the soluble gas to be removed.
3. Temperature off gas and liquid stream entering the absorber.
4. Heat of solution or reaction in the absorption process.
5. Allowable concentration in the surrounding atmosphere.

The performance of absorption devices depend upon a number of factors such as the solubility of the gas, its vapour pressure, its rate of reaction with the absorbent, the velocity through the device and area of the absorbing surface exposed which may be either in the form of spray droplets or wetted media.

The most common absorption cleaning devices are spray towers, packed towers and jet scrubbers. (These have been dealt previously under wet collectors for particulate emmissions cleaning devices) After absorption of gaseous substances, the absorbing agent may be regenerated or discarded or converted into some useful products. Disposal of the waste product should be so, as to avoid secondary pollution. Attention should be given towards prevention against corrosion and freezing.

B. <u>Gas Adsorption Devices</u>: Adsorption devices are primarily meant for removal of organic vapours in either high concentration (solvant recovery) or low concentration (odour removal) The gases and the vapours ahere in thin layers to solid bodies (adsorbents) with which they come in contact The absorbed gas is retained on the adsorbent surface due to the surface forces existing in the solid. Like absorption, adsorption is also a diffusional operation, which involves the transfer of gaseous material between phases due to molecular or eddy diffusion. The phenomenon of adsorption may be physical, chemical or of ion exchange.

Adsorption units (Fig. 6.15) consist of chambers filled with a granular adsorbent which are arranged in beds or columns of suitable thickness through which gas passes. The adsorbing agent should be porous in nature so as to expose a large surface to the gas stream for adsorption. The adsorbent developed for commercial uses are variety of clays , activated charcoals, aluminums and other treated

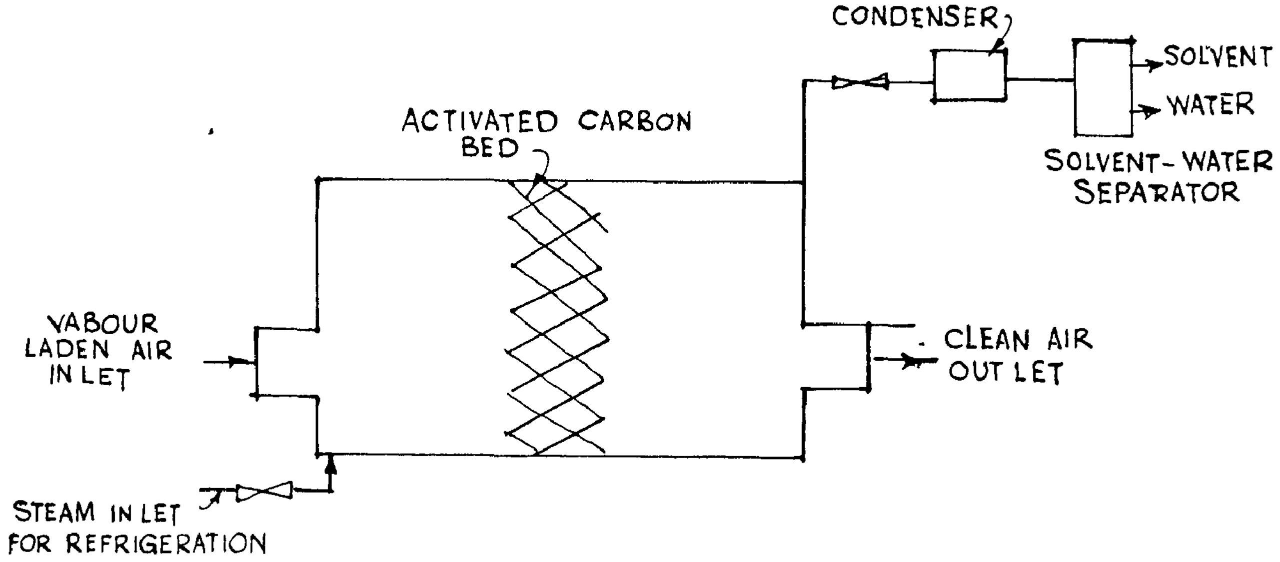


FIG. 6.15

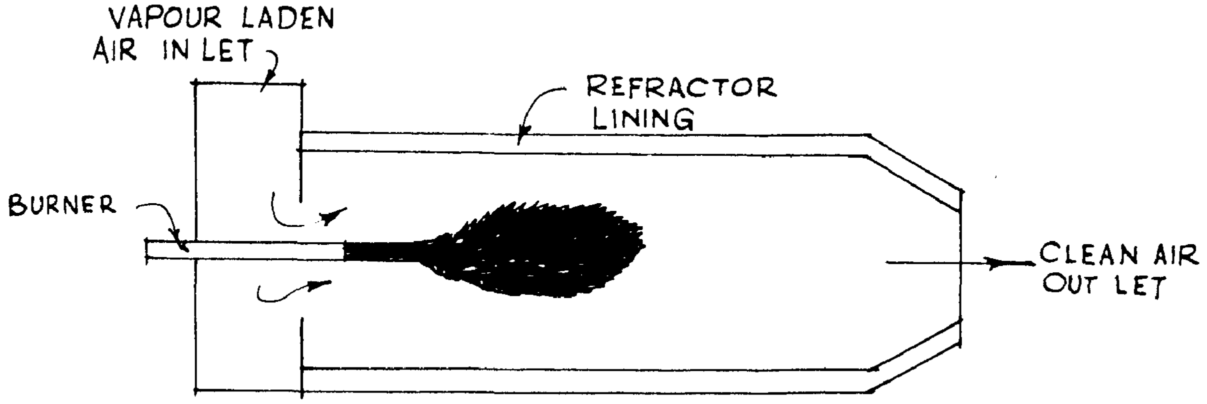


FIG. 6.16.

solids. Activated carbon is the most common among the adsorbents and is made from hard nutshells, wood, coal or other carbonaceous materials. It is used for air recovery in air condition systems and as it has the highest retention per unit weight for organic solvents, it is used to absorb organic vapours. It may be designed to obtain almost the complete removal of organic vapours and some inorganic vapours. Some of the organic vapours that are adsobed by activated carbon include Alcohols, acetone, benzene, carbon tetrachloride, ethyle acetate, gasoline, naphtha , etc.

When the carbon gets exhausted, (or saturated) it may be reactivated by passing steam over its bed. As the bed is heated, the collected vapour gets desorbed and is carried along with the steam. The steam solvent vapour mixture is condensed and the solvent is separated from the water. In order to facilitate the operation, ~~the~~ two adsobers may be arranged in parallel so that one can be regenerated while the other is in operation.

The factors which affect the choice of the adsorbent include:-

1. Quantity of gas to be dealt with.
2. Amount of material to be adsorbed.
3. Allowable pressure drop through bed.
4. Duration of adsorption.
5. Time required for reactivation, purging, etc.

Performance of adsorbent beds depends upon their thickness, velocity of the gas passing, mesh size (surface area) of adsorbent and the temperature of the vapour being removed. Resistance depends upon the adsorbent mesh size, depth and velocity. It may range from less than 1" to several inches of mercury. The efficiency and the capacity both indicate a fall with rising temperature of the adsorbent.

Adsorption units have high installation cost but operation and maintenance costs are low. The solvent recovery generally reduces the cost of the equipment.

C. Combustion Devices: Combustion devices may be employed to destroy or decompose the objectionable gaseous emissions which create obnoxious odours. In case of high concentrations of organic compounds (Gases or particulates) which cannot be economically recovered, combustion may be used to render them innocuous. The compounds resulting from the products of combustion which, in many cases, consist of carbon dioxide and water vapour may be discharged to the atmosphere along with the other gas stream.

Combustion devices may be classified into two systems:

1. Direct Fired After burners: In these devices the gases to be incinerated are brought into intimate contact by turbulence with the combustion gases. The combustion is

obtained by use of oil or gaseous fuels with the secondary air derived from the contaminated stream.

The factors which contribute to good afterburner design are the following :

1. Intimate mixing of the contaminated air stream with the combustion gases to ensure uniform heating.
2. Average temperature of the mixture (objectionable vapour to be removed and combustion gases) should be equal to the kindling temperature of the vapour.
3. Sufficient time should be given to obtain complete oxidation of the vapours since various constituents to be burnt at different rates.

The direct incinevator device (Fig. 6.16) consists of a combustion chamber in which the process gases mix turbulently with a flame produced by an oil or gas-fired burner. The simplest form involves passing the contaminated air through the combustion chamber of a boiler or fire box which is normally a complement of theplant operation. The temperature required to bring up the destruction of the compounds depends upon the nature of the contaminant. The temperature of the mixed gases should normally be at least 1500 deg. F. Sufficient quantities of fuel may be required to build up this high temperature. The economy due to fuel saving may however result in cases where the exhaust gas stream consists of combustible contaminants which may contribute sufficient heat during the combustion process. Heat input rate approximates 10,800 BTU per hour per 100 standard cfm of exhaust air per 100 deg. F temperature rise.

The performance of a combustion device depends upon the retnetion period of the contaminant in the high temperature zone. Thus the contaminant control depends on the velocity and surface area of heat transfer device A residence time of one quarter to one half second and gas velocities of 900 to 1800 fpm result in an efficient operation. An efficiency of the order of 90% is achieved in case of incineration of solvents emitted from baking and drying oven exhausts.

The resistance of the direct combustion unit is negligible. Moreover, it requires little attention as compared to the catalytic oxidation unit.

Direct incinerator finds its application in the control of emissions from coffee roaster, varnish cooking kettles, cocking ovens meant for manufacture of rock wool insulators, etc. It has got a limited usage. It is adopted where there is a demand for the heat generated or the process employing combustion.

ii. Catalytic Oxidation Devices: In catalytic oxidation combustion of objectionable vapours occur at considerably lower temperatures than those required in the direct-fired afterburners. Catalysts used for oxidation reactions are mainly metal and metal oxides. Platinum, Platinum-alumina and platimun rhodium arranged on suitable supports are highly effective oxidation catalysts. Platinum is usually mounted on nickel alloy ribbon . Platinum-alumina is bounded to procelain rods, mounted on brick like unit and these rods are so spaced as to permit gas flow through the assembly The air to be decontaminated, on passing, break down and are reduced to elemental gases of innocuous nature.

Although the presence of the catalyst reduces the heat input, yet it may get contaminated by trace contaminants which may give a surface coating of materials like carbon sulphur, etc. Loss of catalyst may result by abrasion due to the presence of particulate materials in the gas stream. Sometimes, the catalyst may become poisonous under lead, zinc, arsenic, halogens and silicons The useful life of catalyst is found to be more than 20000 hours.

Catalytic incineration of most organic vapours have self sustaining flames at about 500 deg. F. If the gases are colder, they are preheated before coming into contact with the catalyst (Figure 6.17). In cases where the gas stream contains a high concentration of oxidizable constituents, sufficient heat may be evolved during oxidation reactions and the flame may become self sustaining. At times the temperature may shoot up so high that it is

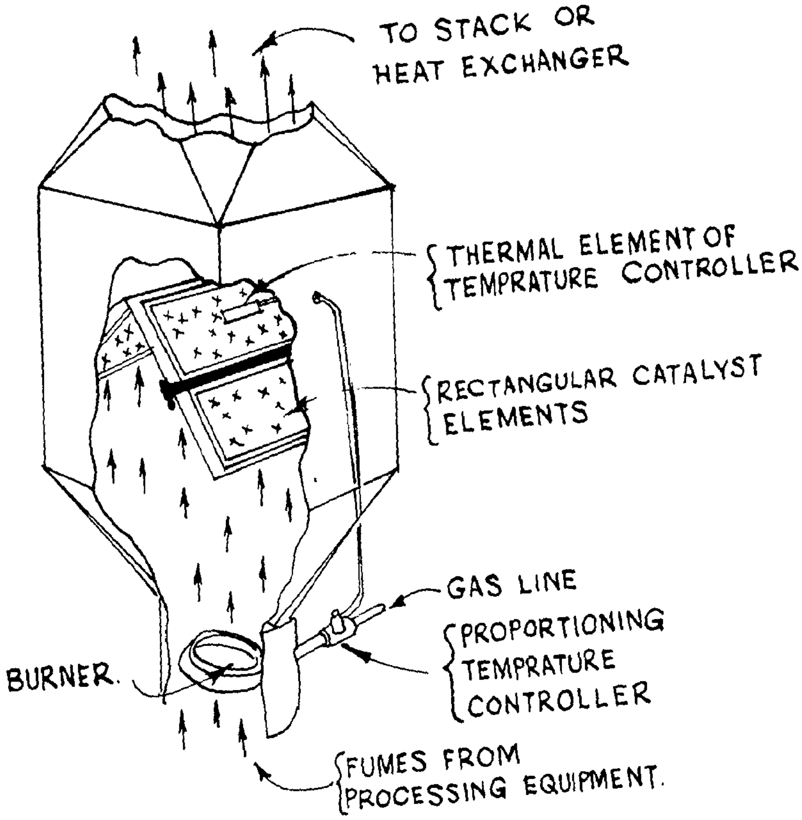


FIG. 6.17

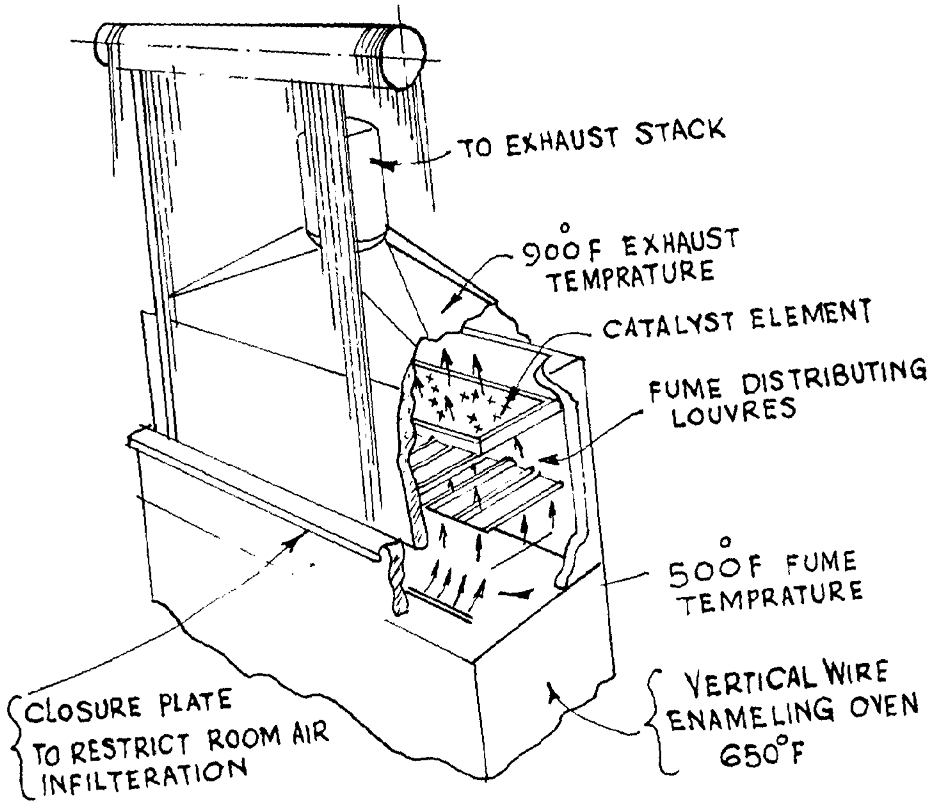


FIG. 6.18

economical to employ a heat exchange to recover the heat for other purposes, such as preheating the effluent gases or generating steam.

Catalytic combustion finds its application in a number of industries to control odours and organic emissions. Among these, specific ones are conditioning effluent gases from Lithographic and paint baking ovens, ceramic kilns, foundry core baking ovens, paint rosin cooking kettles, refineries burning waste cracking gases, etc. It is also used in reducing atmospheric pollution by burning the combustible constituents from automotive exhaust gases which pass through a bed of pelleted catalyst, carried in a stainless steel container. Figure 6.18 shows a typical application of catalytic incineration to exhaust gases from vertical wire enameling oven.

Nitrogen oxides present in the effluents from nitric acid production are also controlled by catalytic decomposition of the oxides to nitrogen. Similarly sulphur oxides present in flue gases can also be removed. But the costs for this control is so high that the process is uneconomical.

6.3. RESPIRATORS

6.3.1. General:

A respirator is defined as a device covering the mouth or nose, to prevent the inhalation of noxious substances. It is probably the oldest method of air cleaning and is used for the safety of a worker who is directly exposed to harmful concentrations of atmospheric contaminants. It is meant to serve as a supplement but not as a substitute for other method.

6.3.2. TYPES OF RESPIRATORS:

All respiratory protective devices may be mainly divided into two groups:

A. Atmosphere - supplying respirators.

B. Air-Purifying respirators.

A. Atmosphere-Supplying Respirators: They separate the wearer from his immediate environment and provide him with respirable air from another source . They are not air cleaning devices and as such unimportant from this thesis point of view

B. Air-Purifying Respirators: They provide protection by removing specific contaminants from the external environment. They are divided into 3 groups.

a. Chemical -filter Respirators.

b. Mechanical-filter Respirators.

c. Combination of Chemical and Mechanical Filter Respirators.

a. <u>Chemical Filter Respirators:</u> These can be divided into two groups : Gas Masks, and Chemical - Cartridge respirators:

i. <u>Gas Masks:</u> Gas Mask consists of a flexible breathing tube connected to a canister which is carried by a ~~weaser~~ wearer. The canister is filled with chemicals in granular form for purifying the air by chemical or physical reaction. The air-purifying material in the container varies with the type of the contaminant to be removed. The service life of the canister depends upon the concentration of the gaseous contaminant, the volume of air inhaled by the wearer the characteristics and amount of chemical absorbents and other factors.

Gas mask is mainly meant for protection against gaseous contaminants but filters may also be provided within the canister for removal of particulate matter. It is generally employed during the operation of chemical processes, handling volatile or gaseous chemical products, repairing refrigerating systems, working around tanks or similar vessels containing poisonous products fire fighting and fumigating.

ii. <u>Chemical Cartridge Respirators:</u> These are infact miniature gas masks, They have the same type of material filling in a cartridge . They are meant for non-emergency purposes and used for protection against solvent vapours encountered during operations, such as spray coating, degreasing, etc; and against low concentrations of acid gases as in ~~smelting~~ smelting of sulphide ores and in many chemical processes. It does not protect against lead mists evolved during paint spraying.

b. <u>Mechanical-filter Respirators:</u> These respirators (Fig 6.19) usually employ fibrous filter or specially treated cellulose fibre filter in the form of a disc or a bag. These filters are designed to catch various particulate contaminants but all of them are not suitable for every purpose. However a finer mesh filter suitable for metal fumes, will remove any particulate contaminant which can be removed by other approved filters.

Mechanical filter respirator are light and compact devices and as such can be used for prolonged period with fatigue. They are used during operations such as welding and cutting; grinding and handling all types of dusty materials; spray coating with enamels or glazes; shaking out and grinding castings; ash handling, etc.

c. <u>Combination of Chemical and Mechanical Filter Respirator.</u> These respirators give protection against particulate as well as gaseous contaminants. Examples of this type include a combination of gas mask with smoke filters for fire fighting; and chemical cartridge respirators with mechanical filters for spray painting, metallurgical operations, and for welding and cutting operations.

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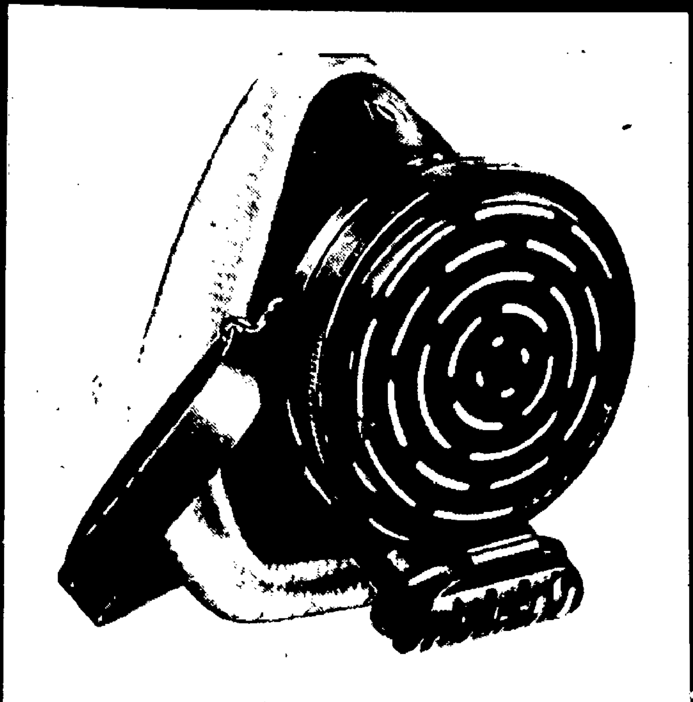

Fig. 6.19

CHAPTER VII

AIR CONTAMINATION CONTROL IN IRON AND STEEL INDUSTRY

With the knowledge of control methods and air cleaning devices from preceding chapters, the air contamination problem of an iron and steel industry is dealt.

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The previous discussion of air contamination control methods and air cleaning equipment is applied to an iron and steel industry to control the contaminants evolved in its various shop operations. The different shops for which discussion is made, are blast furnace, coke ovens, steel melting shop, rolling mills, pattern shop foundry, machine shop and forging shop.

7.1. BLAST FURNACE:

The charge in the blast furnace consists of iron ore coke and lime stone. The blast furnace gas escaping consists essentially of carbon dioxide, carbon monoxide and nitrogen which are accompanied by dust particles. For highest economic efficiency, it is necessary that the blast furnace gas be utilised. It is normally used in preheating the air in the hot blast stoves, producing steam for being used in turbo-generators and as a fuel for soaking pits (steel-ingot heating furnaces) and coke ovens.

Before utilisation, the blast furnace gas must be cleaned of its dust content. If the gas is not cleaned it chokes and carrodes the chequer brick work of hot blast stoves and clogs the furnace values. Moreover, the final dust emission in the combustion products escaping through chimney will be higher. In such a case, the continuous running of the blast furnace may create a dust nuisance in the surrounding area.

The dust content of the gas coming out of the furnace depends upon the furnace conditions and the properties of the ~~fine~~ raw materials charged. It is more in case of ferromanganese production than pig iron production. As the dust concentration~~s~~ is high, the gas cleaning is done efficiently by employing a combination of 3 air-cleaning units in the following order: Dust Catcher (centrifugal collector) Tower Washer and Cottrell precipitator: The dust catcher effectively handles large size particles and reduces the dust load in the washer and the precipitator. The clean gas leaving the cottrell precipitator has a relatively low dust concentration and is used for the desired purpose.

Slipping of blast furnace also leads to the ejection of dust into the atmosphere. This can, however, be reduced by improved ore burdens and practices. Moreover bleeders may be installed on the clean gas side of the blast furnace gas-cleaning system. This prevents the dirty gas from escaping into the atmosphere.

7.2. Coke Ovens:

Carbonisation at a high temperature in the absence of air in a closed chamber removes the volatile matter from the coal and results in the evolution of coke oven gas. The air contamination occurs during operations such as coal charging, coke discharging and quenching operations.

a. **Smoke Nuisance during Coal charging:** Smoke can nearly be eliminated by reducing the time of charging and by providing telescopic connections between the charging hole at the top of the oven and charging car. A gas connecting main way also be provided along each side of the battery of coke ovens and keeping these mains coupled to the ovens during charging operation. Steam injection may also assist in the smoke extraction.

b. **Smoke Evolution during coke Discharging:** It is mainly because the charge has not been uniformly carbonised to the centre. Uniform carbonisation may be attained by proper distribution of heating gas and uniformity in coal quality charged.

c. **Coke Dust Nuisance during Quenching operation:** Steam formed during quenching emerges out of the chimney, gets condensed and comes down in the form of water drops along with the coke particles, creating nuisance in the surrounding area. The coke dust pick up by the steam may be checked by use of a number of fine spreys in a proper direction.

Coke oven gas is poisonous and consists mainly of Hydrogen, Amonia, Methane, Carbon monoxide, and Carbon dioxide and other hydrocarbons. As the gas has high calorific value it is used as a fuel. But before being used as a fuel, the gas is cleaned of the products such as tar, ammonia compounds, naphthalene and benzol which are of immense value.

1. Removal of Tar: The coke oven gas coming out of each oven is carried through a goose neck pipe into a hydraulic main. This results in the removal of heavy tar particles. The liquor sprayed for cooling the gas to avoid cracking also helps in catching the tar particles. The tar removed is collected in a tar tank provided at the end of the main.

To effect further removal of the tar content the gas is led through tar pockets into a primary gas cooler. In addition to the tar removal in the gas cooler, tar pockets also help in catch tar particles. The gas coming out from the primary cooler still contains traces of tar matter which is removed in an electrstatic tar precipitator after further cooling of the gas by refrigorated water in a deep cooler. The tar removed in different stages is collected in a comm-on tar tank.

11. Removal of Ammonium Sulphate.

The undesirable gas ammonia is removed from the coke oven gas as ammonium sulphate. This is accomplished in a multistage washer where the gas is washed with dilute Sulphuric acid, resulting in the formation of ammonical liquor from which ammonium sulphate is recovered.

111. Removal of Benzol: In order to have an effective removal of benzol from the coke oven gas, it is cooled into a deep cooler by refrigerated water. It is then taken into a primary benzol scrubber which employs oil as well as water spray. Some of the benzol is removed in this stage.

Further removal is done in a secondary benzol scrubber (packed bed type). The benzolized oil collected at the bottom of the scrubber is used for the recovery of benzol.

After benzol recovery, the gas is led into a cyclone separater for the removal of oil content carried away by the gas during scrubbing action. Now the use of this purified gas minimizes the air contamination in places where it is used as a fuel.

7.3. STEEL MELTING SHOP:-

The hot pig iron is poured in a Bessemer converter and is blown by the air blast from the bottom. This operation gives rise to lot of fumes which contaminate the surrounding atmosphere. A control may be exercised by using exhaust ventilation. This may necessitate a large hood to collect the blown gases, which may be directed to a waste sheat boiler where they are cooled. The cleaning of the gases may be done by a Pease Anthony Scrubber.

The blown metal from the Bessemer converter is charged into the open hearth furnace. During the refining operation when the temperature of the metal is at a maximum, a large amount of iron oxide fume in the form of strongly coloured brown gases escape through the chimney alongwith the dust content. It creates dust nuisance as well as loss of the metal. This can be minimised by providing the furnace with automatic combustion controls for better combustion and consequently less effluent. The Gas cleaning may be done by subjecting the exhaust gases to a wet scrubbing process. But this process is economical only when the intense fume occurs for a small part of the time and cleaning need only be used during this time. But if the gas cleaning plant is required to run all the time it is cheaper to replace the wet cleaning system by an electrostatic precipitator.

7.4. ROLLING MILL:

As steel igots are heated in a closed chamber, the combustion products which contains little amount of Sulpher Dioxide is safely discharged to the outside atmosphere through tall stacks. Rolling operation does not lead to any air contamination.

7.5. PATTERN SHOP:

Wood working operations do not produce any health hazard but wood dust and shavings are very flammable and create a sort of nuisance hazard. This can be controlled by providing local exhaust ventilation to each wood working machine. A common duct provided with a fan may be used for wood dust exhaust at the top of the shop roof.

7.6. FOUNDRY:

All foundry processes are dusty but they vary in degree. The most harmful foundry dust is free silica. Depending upon the type of the process, the air contamination of the foundry shop is dealt under following heads :

a. Sand Preparation Plant: The used sand is throughly mixed with fresh sand, clay and binders. During this mixing operation, the dust may escape to the surrounding atmosphere and results in contamination. In fact, this is not of higher degree but even then a control can be exercised by carrying the mixing operation in a closed chamber such as muller type mixer from which the conditioned sand is taken out.

b. Moulding Section: The conditioned sand is poured in the moulding box and is properly rammed, This operation is not dusty because the moulding materials are handled in a damp condition.

c. Core Section: Cores are made by ramming sand into the core boxes. Core making is perhaps the least dusty of all foundry process because the core sand is intimately mixed with oil. Hence this operation does not create any air contamination which may be harmful to the coremakers.

d. Drying Ovens: The cores and the moulds are baked in ovens by circulating the products of combustion obtained by burning of coke oven gas. During the drying process, fumes of aldehyde like group may be evolved from the breakdown products of the binding materials, such as oil or dextrin in the moulding and core mixtures. Some of these fumes are irritating to the eyes and mucous membranes of the respiratory tract. So the ~~core~~ drying oven chamber should be provided with an air tight door so as to avoid any chances of fumes escaping to surrounding area of the shop. These fumes along with the flue gases are sucked by a fan and are discharged through a high stack to the outside atmosphere.

e. Melting and Casting Section: An electric arc furnace is employed to molten steel for casting. During the furnace operation, dust and smoke escape to the atmosphere and thus causes pollution. If these contaminants are controlled after they are allowed to escape to the atmosphere, a very large exhaust ventilation rate will be needed. Moreover, as the furnace top raises and swings out of position, the usual stationary type of hood will not serve the purpose. For proper control, a hood of special construction should be attached to the furnace top as an integral part. When in position the hood makes a fairly tight joint with the stationary exhaust duct.

When the molten metal is poured in the mould through the runner, it gives rise to evolution of gases. They may be dealt by general ventilation. But in some cases the fumes from sand additives can be removed by passing the poured moulds under a hood or tunnel before they are brought to the fettling section.

f. Fettling Section: Fettling (Cleaning) is the dustiest operation in the foundry. The contamination due to various operations in fettling section are as follows :

i. **Stripping:** Casting is removed from the mould. Adherent moulding sand, core sand and other readily removable matter are removed with portable pneumatic and hand tools. This operation gives rise to lot of dust in the air. In order to control this dust hazard, the operation is carried out in a closed chamber partly sealed by hanging canvas curtains, known as the "blow box", from which the dust laden air is exhausted into the main dust extraction system.

ii. **Abrasive Blasting:** Abrasive blasting is carried out with a stream of sand or steel shots as the abrasive which is fired at the casting by means of compressed air. This operation gives a very high dust content in the atmosphere which may be harmful to the operator as well as the near-by workers. The health hazard associated with steel shot blasting operations is much less severe than with sand blasting operations. Consequently, steel shots should be preferred But if steel shots are not available or results in an inferior product, sand should be used.

In order to control this dust hazard, the blasting operation is carried out in a well designed mechanically exhaust ventilated cabinets or rooms known as sand or shot blast chambers. This prevents the dust from entering the surrounding atmosphere. The substantial quantities of fine dust are exhausted from the top of the room to the outside atmosphere through a dust separator from the bottom of which the dust can be removed where it has collected in sufficient amount. For the safety of the man who handles the blasting 'gun' inside the cabinet a special type of clothing and helmet, which is supplied through an air line with fresh air are provided.

iii. Hydroblast: This is a recent development in casting cleaning. This operation is carried out in a closed room inside which the casting is placed on a perforated floor A stream of water at a pressure of about 100 Kgm/cm^2 is directed through a gun at the casting. This gun is operated by a man who stands outside the room and can peep through the glass to direct the water jet at the correct spot. The sand goes down along with the water through the perforated floor . The advantage of this type of dust control is that the operator is quite safe as compared to the previously dealt method of cleaning.

iv. Dressing with Pneumatic or hand tools: The burnt-on moulding sand and the rough edges of metal from castings are removed. Hand tools such as brushes, chisels and hammers are used for this purpose. Although the castings are blasted before being brought for dressing, yet the dressing operation is usually a dusty one. It is observed that hand dressing or fettling is a less dusty job than fettling with pnemmatic tools. In order to control the dust hazard due to the use of preumatic tools, a high velocity exhaust ventilation system is provided to the portable chisels and tools.

v. Grinding: In grinding processes, the rough casting is smoothed by being held against a rapidly revolving grinding wheel. The operation is responsible for the escape of metallic dust into the atmosphere. This can, however, be controlled by exhaust ventilation system to the grinding machines.. For small castings, a portable cone wheel type of grinder is used. In this air is exhausted from the gap immediately above the grinding head. For large castings, a swing frame grinder is used. To control the dust hazard in this case, a hood is placed in the direction in which the dust is thrown at a high velocity. The dust caught by the hood is exhausted to the outside atmosphere.

vi. Brushing: This is the last cleaning operation of the casting. The casting is cleaned with the help of a wire brush. This operation also leads to air contamination. It can be controlled by exhausting the dust through the holes in the annular ring surrounding the brush.

f. Annealing: Castings are charged in the furnace where they are heated for a long period and then cooled by closing of the fuel supply . During this operation irritatigg gases such as acrolein are liberated by the processed parts. As such care should be taken to see that furnace charging door is airtight and there are no leakages which may give way to the contaminating gases to the surrounding atmosphere. The combustion gases are then exhasusted by an exhaust controlling valve through the stack to the outside atmosphere.

7.7. MACHINE SHOP:

Machining of casting gives rise to the evolution of metal dust and fumes around the machines. In the operation of machines like grinder and shaper, the metal is thrown out at a very high velocity and creates ~~and~~ metal dust nuisance. This can be controlled by providing local exhaust ventilation systems to individual machines.

7.8. FORGING SHOP:

Forging operation presents a potential health hazard due to carbon monoxide and high temperature.

In order to avoid excessively high temperature and proper dilution of the gas, good natural ventilation should be provided. This may be supplemented by mechanically operated exhaust fans in roof ventilators.

The furnace flue gases can be exhausted by canopy-type hoods through large diameter stacks. If this device is unable to control the concentration of carbon monoxide from exceeding the maximum permissible limit, an impwovement is made by the use of propeller type fans in the discharge stack. This will also help in maintaining suitable temperature in the foom.

CHAPTER VIII

AIR CONTAMINATION LEGISLATION.

To exercise adequate control on air contamination some legislation is necessary. Principles of legislation, relaxations in special cases and proper administrative set up for its execution have been suggested.

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Due to the rapid development of industries and increase in population, the air contamination is increasing day by day and has become a threat to human being, plant, animal life and property. In order to keep down the contamination level, it is necessary to enforce some legislation which should provide protection to all against hazards of air contamination. ~~In~~

Responsibility for enforcement of an air contamination law should be enthrusted in the hands of some responsible body like municipality. The law should be passed by the State legislature and then the local body may be authorized to enact ordinances within the corporate limits of the city. This eliminates a multiplicity of varying regulations and standards within the district which may otherwise lead to evils. An air pollution control officer should be appointed in each district by the State Government . He may be helped in his work by creating an advisory committee which may consist of engineers and scientists. The fruitful result of air contamination legislation depends more on competent administration than adequate legislation.

Blind enforcement of the law can not tackle the air contamination problem. Any air contamination legislation will have to convience the offending industries regarding the useful target to be accomplished. The legislation should be such so as to allow the offender to work out the best suiting solution to its own conditions rather than following blindly the prescribed requirements for all sources of emission, irrespective of the character. Moreover, the rules should be enforced equally on all offenders.

The air contamination problem varies from place to place . The character of the contaminants emitted by the industries at one place may entirely differ from that of the other place. As such the legislation may not be such so as to establish concentration limits for each contaminant at the source of emission and apply them uniformly throughout the State or Nation. Such a legislation may require every industry to meet the worst situation which is against economy . This may miss the target for which the legislation is passed.

The principles, on which the legislation may be based, should include the following:

1. Emissions that exceed specified standards should be treated as an offence in themselves, irrespective of any nuisance that may be caused.
2. Sampling work should be carried out from time to time so as to check the violation of the law. But this should be treated as of secondary importance compared to preventive principle. The plant should be designed,

-- installed, operated and maintained in such a way that smoke is never formed beyond the specified limit and emission of grit and dust are effectively prevented.

3. In case of some specified appliances, the complete prohibition of smoke is necessary and may be obtained directly by use of smokeless fuels.

The law should be such as to provide relaxation in special cases. The variance should be allowed after weighing whether the hardship created by the particular industry on the public is greater than the hardship that will be imposed on industry if the variance is denied. The variance may be granted under the following instances :

i. When the equipment is operated only in an emergency.

ii. To permit the industry to operate while experiments are carried out to determine what equipment is necessary to solve the existing problem.

iii. To permit the industry to operate while corrective equipment is being installed and tested.

iv. To permit industry to operate where the best equipment known to-date and installed dows not bring the operations within the permitted limits.

v. To permit industries that are not financially able to install corrective equipment to operate for a reasonable time to permit them to secure financing.

In order to pass useful ordinances, the air conramination control agency should have knowledge of the facts such as location of the outlet, size of outlet, height of stack, rate of emission from outlet and dompoaition of effluent. These facts can be obtained from the factories.

Permit system may be introduced to enforce the legislation effectively; Construction permits should be obtained prior to the installation, operation, or alteration of equipment capable of producing the specified contaminants in the city. The operating permits should then be granted by the authority. In case of these permits the enforcement agency should be authorised to make periodic inspections of the licensed equipment to determine whether or not it has been constructed and is being operated according to the permit and ordinance.

Attendant to the proper legislation must be an overwhelming desire on the part of the people to rid the city of smoke and other nuisances. In addition the administration must possess the necessary courage to transmit this desire into actuality.

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APPENDIX.

MAXIMUM ALLOWABLE CONCENTRATION

The following maximum allowable concentration values for continuous 8 hr. exposure are recommended by the American Conference of Governmental Industrial Hygienists (1959) and are revised when toxicological data warrants.

(Ref: INDUSTRIAL VENTILATION.)

GASES AND VAPORS.

Substance	M.A.C (ppm)°
Acetaldehyde	200
Acetic Acid	10
Acetic anhydride	5
Acetone	1000
Acrolein	0.5
Acrylonitrile	20
Ammonia	100
Amylacetate	200
isoAmylalcohol	100
Aniline	5
Arsine	0.05
Benzene (benzol)	35
Bromine	1
1,3-Butadiene	1000
n-Butanol	250
2, Butanone	250
n,Butyl acetate	200
Butyl "cellosolve"	200
Carbondisulfide	20
Carbon dioxide	5000
Carbon monoxide	100
Carbon tetrachloride	25
"Cellosolve"	200
"Cellosolve " acetate	100
Chlorine	1
2-Chlorobutadiene	25
Chloroform	100
1-Chloro-1-nitropropane	20
Cyclohexane	400
Cyclohexanol	100
Cyclohexanone	100
Cyclohexene	400
Cyclopropane (Propane)	400
Dibromoethane	25
O-Dichlorobenzene	50

Dichlorodifluoromethane	1000
1, 1-Dichloroethane	100
1,2-Dichloroethane (ethylene dichloride)	100
Dichloroethyl ether	15
Dichloromethane	500
Dichloromonofluoromethane	1000
1,1-Dichloro-1-nitroethane	10
Dichlorotetrafluoroethane	1000
1, 2-Dichloropropane	75
Dimethylaniline	5
Dimethylsulfate	1
Dioxane	100
Ethyl acetate	400
Ethyl alcohol	1000
Ethyl benzene	200
Ethyl bromide	200
Ethyl chloride	1000
Ethylene chlorhydrin	5
Ethylene oxide	100
Ethyl ether	400
Ethylformate	100
Ethyl silicate	100
Fluorine (gas)	0.1
Formaldehyde	5
Gasoline	500
Heptane	500
Hexane	500
Hydrogen chloride	5
Hydrogen cyanide	10
Hydrogen fluoride	3
Hydrogen selenide	00.05
Hydrogen sulfide	20
Iodine	1
Isophorone	25
Mesityl oxide	50
Methanol	200
Methyl acetate	200
Methyl bromide	20
Methyl butanone	100
Methyl "cellosolve".	25
Methyl "cellosolve" acetate	25
Methyl chloride	100
Methylcyclohexane	500
Methl cyclohexanol	100
Methyl cyclohexanone	100
Methyl formate	100
Methyl iso butyl ketone	100
Monochlorobenzene	75
Monofluorotrichloromethane	1000
Mononitrotoluene	5
Naphtha (coal tar)	200
Naphtha (petroleum)	500
Nickel carbonyl	1
Nitrobenzene	1
Nitroethane	100

Nitrogen oxides (other than nitrous oxide)	25
Nitroglycerine	0.5
Nitromethane	100
2-Nitropropane	50
Octane	500
Ozone	1
Pentane	1000
Pentanone (methl propanone)	200
Phosgene	1
Phosphine	0.05
Phosphorous trichloride	0.5
iso-Propanol	400
Propyl acetate	200
iso-Propyl ether	500
Stibine	0.1
Stoddard solvent	500
Styrene monomer	200
Sulfur chloride	1
Sulfur dioxide	10
1, 1,2-Tetrachloroethane	5
Tetrachloroethylene	200
Toluene	200
Toluidine	5
1,1,1 Trichloroethane (methyl chloroform)	500
Trichloroethylene	200
Turpentine	100
Vinyl chloride (chloroethane)	500
Xylene	200

TOXIC DUSTS, FUMES, & MISTS

Substance	mg/M^{3*}
Antimony	0.5
Arsenic	0.5
Barium	0.5
Cadmium	0.1
Chlorodiphenyl	1
Chromic acid and chromates (as CrO_3)	0.1
Cyanide as CN	5
0,0 Diethyl o p nitrophenyl thiophosphate (parathion)	0.1
Dinitrotoluene	1.5
Fluorides	2.5
Iron oxide fume	15
Lead	0.15
Magnesium oxide fume	15
Manganese	6
Mercury	0.1
Pentachloronaphthalene	0.5
Pentachlorophenol	0.5
Phosphorus (yellow)	0.1
Phosphorus pentachloride	1
Phosphorus pentasulfide	1
Selenium, compounds as selenium	0.1
Sulfuric acid	

Tetryl.	1.5
Trichloronaphthalene	5
Trinitrotoluene	1.5
Zinc oxide fumes	15.

MINERAL DUSTS

Substance.	M.P.P.C.F.*
Alundum	50
Asbestos	5
Carborundum	50
Dust(nuisance, no free silica)	50
Mica (below 5 % free silica)	50
Portland cement	50
Silica high (above 50% free SiO_2)	5
Silica medium (5 to 50% free SiO_2)	20
Silica low(below 5% free SiO_2)	50
Soapstone (below 5 percent free SiO_2)	20
Talc	20
Total dust (below 5 % free SiO_2)	50

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* ppm part per million.
* Mg M^3 milligrams per cubic meter.
* M.P.P.C.F. million particles per cubic foot of air, standard light field count.

REFERENCES

1. Heating Piping and Air conditioning, Vol. 31, No. 2 Feb; 1959 Air Pollution control Demands Engineering Analysis, Design.
2. Heating Piping and Air conditioning, Vol. 31, No. 12, December, 1959 How to Control Gaseous Emissions to Abate Air Pollution.
3. Heatin-g Piping and Air Conditioning Vol. 30, No. 5 May, 1958, EJC Policy Statement on Air Pollution and its control.
4. Heating Piping and Air conditioning, Vol. 24, No. 5 May, 1952, Effects of Industrial Atmosphere on Workmen and on Community.
5. Heating Piping and Air Conditioning Vol. 27, No.3, August, 1955, Size distribution and Concentration of Air borne Dust.
6. Heating Piping and Air conditioning, Vol. 31, No.6 June, 1959, How to Control Particulate Emissions to Abate Air Pollution.
7. Heating Piping and Air conditioning, Vol. 27, No.7, July, 1955, Solving the ink Mist Problem in Newspaper Plants.
8. Heating Piping and Air Conditioning, Vol. 24, No.5, May, 1952, Exhaust Ventilation for Machining Metals of High Toxicity.
9. Heating Piping and Air conditioning, Vol. 24, No.5 May, 9 52 , 'The industrial atmosphere - A Symposium.

10. Heating Piping and Air conditioning, Vol. 24, No. 1 Jan, 1952, Self Charging Electrostatic Air filters.

11. Journal of Sanitary Engineering Division Proc. of the ASCE Vol. 84, Feb; 1958, Engineers Joint Council Policy Statement on Air Pollution and its Control,p1541

12. Journal of the Sanitary Engineering, Division, Proc. of ASCE Vol. 85, Ja; 1959, P.75 Radio active Pollutants.

13. Journal of the Sanitary Engineering Division Proc. of ASCE Vol. 85, Nov; 1959, P. 143 Engineering Control, of Air Pollution in Los Angeles Country.

14. Journal of the Sanitary Engineering Division Proc. of the ASCE Vol. 85. Sept; 1958, p. 1776 -1, Simplified Techniques in Air Pollution Measurements.

15. ASHRAE Guide and data Book 1961, Fundamentals and Equipments, Section I, Chapter 10 "Air Contaminant"

16. ASHRAE Guide and Data Book, 1961, Fundamentals and equipment, Section IV, Chapter 48, 'Air Cleaning"

17. 'Air Pollution' Proc. of the UST Conf. on Air Pollution, by Louis C. McCabe, McGraw Hill Book Co;

18. Air Conditioning Heating and Ventilating, Vol. 57, No.5 May 1960, 'Air Cleaning and Purification".

19. Air Conditioning Heating and Ventilating, Vol. 53, No. 9, Sept, 1956, "Methods of Control of Atmospheric Pollution".

20. Journal of the Institution of Heating and Ventilating Engineers, Vol. 22, No. 19 Oct, 1954, "Dust Suppression in Foundries".

21. Foundry Trade Journal, Vol. 100, May 31, 1956, Dust and Fume Extraction in Foundries.

22. Foundry Trade Journal, Vol. 103, Sept, 12, 1957, Dust Control in Foundries.

23. Foundry Trade Journal, Vol 107, Sept 17, 1959 Air Pollution Control.

24. Foundry Trade Journal Vol. 107, December 3, 1959, Atmospheric Dust in Investment Foundries.

25. Industrial Heating Engineer, Vol. 18, No. 6 June, 1956, Foundry Dust Control I.

26. Industrial Heating Engineer, Vol. 18, No. 8, August, 1956, Foundry Dust Control III.

27. Industrial Heating Engineer, Vol. 18No.9, Sept, 1956, Foundry Dust Control IV.

28. Air Pollution Hand book by Paul L. MacGill, Francis R. Holden and Charles Ackley, McGraw Hill Book Co; New York, 1956.

29. Industrial Dust by Philip Drinker and Theodore Hatch, McGraw Hill Book Co; New York, 1954.

30. Air Pollution by M.W.Thring, Butterworth Scientific Publications, London, 1957.

31. Industrial Health Technology By Bryan Harvey and Robert Murray, Butterworth & Co. (Publishers Ltd;) 1958.

32. Industrial Hygiene and Toxicology Vol. I By Frank A. Patty, Inter Science Publishers, New York.

33. Industrial Health Engineering By Allen D. Brandt, John Wiley and Sons, New York Chapman & Hall Litd. London, 1947.

34. Industrial Ventilation - A Mannual of Recommended practice committee on Industrial Ventilation, Lansing, Michigan.

35. Industrial Lung Diseases of Iron and Steel Foundry Workers by A.I.G. Mclanghlin.

36. Problems and Control of Air Pollution by Frederick S. Mellette, Reinhold Publishing Corporation, New York Chapman and Hall, Ltd. London, 1955.

37. The Institution of Mechanical Engineer, Proc. of the Conference on the Mechanical Engineer's Contribution to Clean Air (London 19th-21st Feb, 1957.)

38. Analytical Chemistry , Vol. 24, No. 6, June, 1952 "Evaluation of Particle Concentrations with Collecting Apparatus", p. 996.

39. Analytical Chemistry Vol. 24, No.10, Oct, 1952, p.1586 Determinationof SO_2 by Color Changing gels.

40. Chemical Engineer's Hand book by John H. Perry "Separatio of Dusts and Mists" P. 1850. McGraw Hill Book Co;

41. Air conditioning Heating and Ventilating, Vol 53 No.12, December, 1956 "Electrostatic Precipitator".

42. Journal of the Institution of Heating and Ventilating Engineers, Vol. 22, August, 1954. "Heating and Ventilatin