Final Year Degree Course In
CIVIL ENGINEERING (SEM - II)

SPPU

AIR POLLUTION AND CONTROL

Includes
Sample Question Papers for
In-Semster (30 Marks) &
End-Sem Exams. (70 Marks)

Dr. SANDIP T. MALI
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NIRALI PRAKASHAN
ADVANCEMENT OF KNOWLEDGE

A TEXT BOOK OF

AIR POLLUTION AND CONTROL

(ELECTIVE - III)
FOR
SEMESTER – II

FINAL YEAR (B.E.) DEGREE COURSE IN CIVIL ENGINEERING

As Per the New Revised Syllabus of
Savitribai Phule Pune University
(2012 Pattern)

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PREFACE TO THE THIRD EDITION

We are glad and excited to announce that the Second Edition of this book received an overwhelming response from the engineering student community, compelling us to release its **Third Edition** within a very short period of time.

This thoroughly revised **Third Edition** has been **updated** with additional matter, many solved problems, including **all University Examination Papers** and Numerous Exercises for practice.

Special care has been taken to maintain high degree of accuracy in the theory and numericals throughout the book.

We take this opportunity to express our sincere thanks to Dineshbhai Furia of Nirali Prakashan, a reputed pioneer in the publication field. Our special thanks to Jignesh Furia and Mrs. Nirali Verma for their effective cooperation and great care in bringing out this revised edition. We also appreciate the efforts of M. P. Munde and the entire staff of Engineering Books Deptt. of Nirali Prakashan namely Mrs. Deepali Lachake (Co-ordinator) and Mrs. Shilpa Kale for bringing this book to the students in a timely manner.

We sincerely hope that this "**Third Edition**" will also be warmly received by all concerned as in the past.

Valuable suggestions from our esteemed readers to improve the book are most welcome and highly appreciated.

Pune **Authors**

PREFACE TO THE FIRST EDITION

We are very glad to present a textbook on **"Air Pollution and Control"**. This book is strictly written as per the New Revised Syllabus of Savitribai Phule Pune University, Pune (2012 Pattern) for the students of final year degree course in Civil Engineering.

This book is as per new revised examination scheme which has been implemented from this academic year. According to this, In-semester examination carries 30 Marks over first three units and End-semester examination carries 70 marks for entire syllabus of which the first three units will carry 20 marks and unit 4, 5, and 6 will carry 50 marks.

We have given **Sample Question Papers of In-Semester University Examination (30 Marks) and End-Semester University Examination (70 Marks) in this book for the practice.**

We have tried to provide the best possible material in simple and lucid language to the students preparing for degree course. The subject is divided in to 6 units and each unit is explained thoroughly with diagrams and examples. So, we are sure that this book will fulfill all needs of the subject. Sufficient numbers of questions are also included at the end of each chapter for the revision of the subject.

We would like to express our gratitude to the many people who saw us through this book; to all those who provided support for this book.

We are very thankful to the management of our respective institutes for their continuous support and encouragement.

Above all, we want to thank our family members and friends, who supported and encouraged us in spite of all the time it took us away from them. It was a long and difficult journey for them.

We gratefully acknowledge co-operation from **Shri. Dineshbhai Furia, Shri. Jignesh Furia, Mrs. Nirali Verma**, **Shri. M.P. Munde** and **Mrs. Deepali Lachake** (Co-ordinator) of **Nirali Prakashan.**

Though every effort has been made to eliminate all types of errors, yet some error might have been left unnoticed. However, further improvement if you find any, you can mail on **pravinminde@gmail.com** and **nikhil.bhaleraopm@gmail.com**.

Pune **Authors**

SYLLABUS

Unit I **(6 hrs)**

Meteorological Aspects: Zones of atmosphere, Scales of meteorology, Meteorological parameters, Temperature lapse rate, Plume behavior. Gaussion diffusion model for finding ground level concentration. Plume rise. Types of fuels, Emission Inventory and stack height determination per CPCB norms.

Unit II **(6 hrs)**

Ambient Air Sampling and Analysis: Air pollution survey, basis and statistical considerations of sampling sites, devices and methods used for sampling gases and particulates. Stack emission monitoring for particulate and gaseous matter, isokinetic sampling. Analysis of air samples chemical and instrumental methods. Ambient air quality monitoring as per the procedure laid down by CPCB. National Ambient Air Quality Standards (NAAQS) 2009.

Unit III **(6 hrs)**

Indoor Air Pollution: Causes of air pollution, sources and effects of indoor air pollutants, changes in indoor air quality, control of indoor air pollutants and air cleaning systems. Odour pollution: Theory, sources, measurement and methods of control of odour pollution.

Unit IV **(6 hrs)**

Control of Air Pollution: By process modification, change of raw materials, fuels, process equipment and process operation. Control of particulate matters. Working principle and design of control equipment as Settling chamber, Cyclone, Fabric filter and Electro static precipitator. Control of gaseous pollutants. Control of air pollution from automobiles.

Unit V **(6 hrs)**

Land Use Planning: As a method of control. Economics of air pollution control: Cost/benefit ratio and optimization. Legislation and regulation: Air (Prevention and Control) Pollution Act, 1981. The Environment (Protection) Act 1986. Emission standards for stationary and mobile sources.

Unit VI **(6 hrs)**

Environmental Impact Assessment and Management: Methodology for preparing environmental impact assessment (Identifying the sources of air pollution, calculating the incremental values, prediction of impacts and mitigation measures). Role of regulatory agencies and control boards in obtaining environmental clearance for project. Public hearing. Environmental impacts of thermal power plants sugar and cement industry. Environmental management plan.

CONTENTS

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UNIT I

METEOROLOGICAL ASPECTS

1.1 INTRODUCTION TO AIR POLLUTION

- The present day atmosphere is quite different from the natural atmosphere that existed before the Industrial Revolution, in terms of chemical composition.
- If the natural atmosphere is considered to be "clean", then this means that clean air cannot be found anywhere in today's atmosphere. Defining "air pollution" is not simple.
- One could claim that air pollution started when humans began burning fuels. In other words, all man–made emissions into the air can be called air pollution, because they alter the chemical composition of the natural atmosphere.
- The increase in the global concentrations of greenhouse gases CO_2, CH_4 and N_2O can be called air pollution using this approach, even though the concentrations have not found to be toxic for humans and the ecosystem.
- Air pollution may be defined as the presence of one or more contaminants in the air in such quantities and for such durations which may be or tend to be injurious to human, animal or plant life, or property, or which unreasonably interferes with the comfortable usage of air.

Fig. 1.1 : Air pollution from chimney

1.2 SCOPE OF AIR POLLUTION

- The ancient man burnt the fire, from which time the problem of air pollution was started. Initially, this problem of air pollution was not severe to think for the control of air pollutants.
- Though the air contaminants were present in atmosphere, the concentration was so less that it was not causing any health problem.
- After few centuries the population on the earth was increased. The industrialization took place. The raw materials used in processing and the fuels used for power generation started emitting the particulate matter and various gases into the atmosphere.
- The needs of modern man also brought the revolution in chemical industry. The recent modern technology started using the new organic and inorganic chemicals in manufacturing processes. This concept of new technology actually started the air pollution problem.
- The problem of change in seasons, ozone depletion, global warming, acid rain, imbalance in ecological parameters, pollution of oceans are the recent trends in air pollution study.
- Looking towards the problems due to air contaminants, the scientists are forced to study these aspects.
- The problem has reached at such a stage that the species from earth may vanish within few decades.
- The air pollution due to various sources is required to be controlled. The study is in progress through satellite by NASA, and many other agencies involved in this field.

1.3 UNITS OF MEASUREMENT OF AIR POLLUTANT

- After the air pollution episodes, the pollution control regulations were set up. Till that time, there was no standardization of units of pollutant concentration.
- It became necessary to compare ambient air contaminant concentrations with the standards set forth, in air pollution control regulations.
- For uniformity, the Environmental Protection Agency has recommended following units for particulate and gaseous pollutants.

Sr. No.	Particulate and Gaseous Pollutants	Units
1.	Particulate fallout	$\mu g/cm^3$ month or mg/cm^3 year
2.	Dust fall	Same as above
3.	Suspended particulate	Micrograms per cubic metre
4.	Gaseous contaminant	Same as above

Formerly, the units parts per million (ppm) or parts per billion (ppb) were also used.

1.4 SOURCES OF AIR POLLUTION

- Air is never found absolutely clean in nature. Pollution of air started from the every moment when the primitive man knew to make fire.
- An inventory of air contaminants is a first step towards control of air pollution. The air pollutants can be either natural or may be the result of the various activities of man.
- Atmosphere, i.e. air sector is continuous which diffuses and disperses the air pollutants at a greater rate with faster action. The pollutants like dust, smoke, gases and fumes may be either from natural or manmade sources.

Following are the Major Sources of Air Pollution:

1. **Natural Sources :** The natural sources of air pollution are volcanic erruptions releasing poisonous gases such as SO_2, H_2S and CO, etc., forest fires, natural organic and inorganic decays or vegetative decay, marsh gases, deflation of sand and dust, extra terrestrial bodies, cosmic dust, pollen grains of flowers, soil debris, comets and fungal spores. All these are produced naturally and released in the air, making it foul and injurious to health. Among all natural contaminant pollen grains are important, because of its peculiar irritating properties to some individuals. These pollen grains are discharged from weeds, grasses and trees. Green plants through evapo-transpiration release huge amount of CO_2. Accidental fires in forests emit huge amount of dust, smoke, unburnt hydrocarbons and other gases. Reactions between natural gas emissions also constitute a source of air pollution.
2. **Man Made Sources :** Man is the main culprit for producing pollution in the air due to use of coal, oil and natural gas as fuel and exhaust gases from automatic vehicles. To satisfy the demands of modern man, the rapid industrialization and urbanization took place. This has become one of the important sources of air pollution. Following are the man made sources of air pollution.

(a) Rapid Industrialization : The industries such as pulp and paper, chemical, metallurgical plants and smelters, petroleum refineries, mining, iron and steel works, and synthetic rubber industries are responsible for about 20% of air pollution. The most common pollutants are CO_2, SO_2, CO, NO, H_2S, etc. In addition, the smoke coming out from stacks contain particulate matter, metals, radioactive materials etc. Food processing factories and tanneries produce repulsive odours. A large quantity of benzene is emitted at petrol filling station.

(b) Transportation : Automobile exhausts release smoke and to a little extent lead particles. This smoke is produced primarily from the incomplete combustion of carbonaceous matters. It contains gaseous pollutants, nearly two thirds of CO and one half of the hydrocarbons and nitrous oxides.

In Mumbai, Kolkatta and Chennai this exhaust accounts for 70% of CO, 50% of all hydrocarbons, 30 to 42% of all oxides and 30% Suspended Particulate Matter (SPM). The chief sources from automobiles are (i) Exhaust system, (ii) Fuel tank, (iii) Carburetor, (iv) Crank case. All these release unburnt hydrocarbons, NO, CO and lead oxides.

(c) Burning of Fossil Fuels and Fires : The conventional sources of energy are wood, coal and fossil fuels. About 97% of the energy we use in our homes and factories is generated by coal, oil and natural gas which are called fossil fuels. The byproducts of burning of fossil fuel, wood, coal are nothing but poisonous gases such as CO, CH_4, SO_2, NO, etc.

(d) Deforestation : The balance of O_2 and CO_2 in the nature is maintained by the vegetation. The plants purify the air by taking in CO_2 for their use in photosynthesis and liberating O_2 to be used by animals during respiratory activities; again liberating CO_2 used by the plants. The deforestation by man for his own needs has disturbed the balance of CO_2 and O_2 concentration in atmosphere.

(e) Increase in Population : The rapid explosion of population is one of the most important factors of air pollution. By the year 2000, the world population will be about 7 billion. This increase in population creates several serious problems including air pollution. An increase in population leads to global warming and emission of green house gases. It also contributes to loss in forest cover and loss in Wild life species.

(f) Agricultural Activities : Various biocides are used for agricultural purposes. These biocides include pesticides, insecticides, herbicides, etc. These biocides cause air pollution because some amount of these poisonous substances is carried away by wind; and thus make the air foul.

(g) Solid Waste Disposal : Backyard burning and open burning of heaps of solid wastes results in the emission of smoke and pollutants like NO, CO, CO_2, etc.

(h) Radioactive Fallout : Nuclear reactions, nuclear weapon testings, chemical processing plants, hospitals, research laboratories contribute numerous radio nuclides to the air. Nuclear effluents, when released into the air, are potentially more hazardous to man, animal and vegetation.

(i) Wars : The various types of sophisticated explosives used in wars is also the source of air pollution. Radioactive rays coming out from reactors or nuclear explosions pollute the air extensively.

(j) Construction Activities : During construction activity various pollutants are emitted into atmosphere. Rapid urbanization has put a tremendous stress on construction industry resulting in increase in construction rate.

Table 1.1 describes the various sources and the pollutants emitted into air.

1.5 CLASSIFICATION OF SOURCES

The sources of man-made pollution cover a wide spectrum of types. Following Table 1.1 gives classification of major types, categories and examples of air pollution sources and their characteristic pollutant emissions.

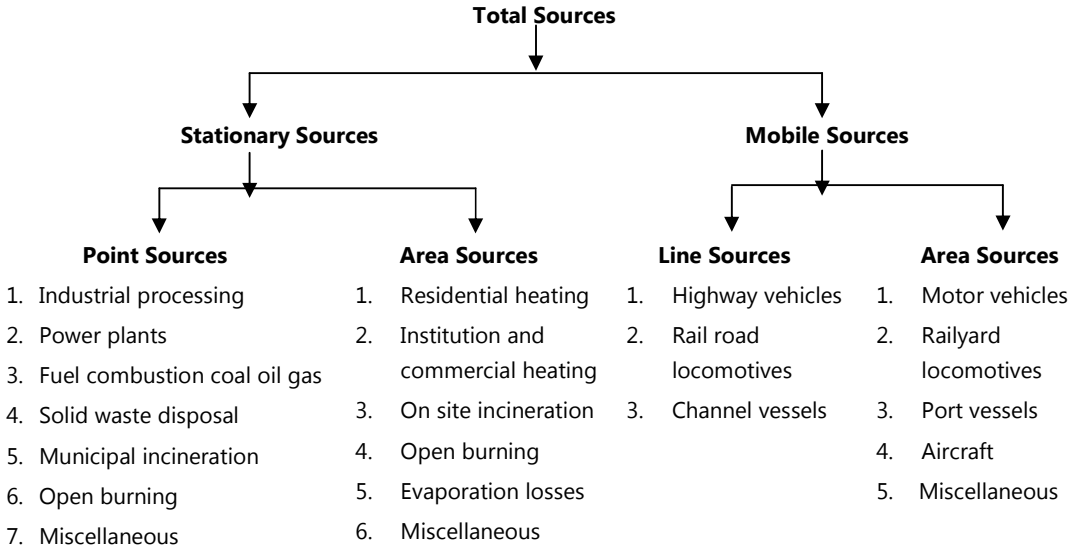
Table 1.1 : Classification of Air Pollution Sources and Emissions

Sr. No.	Source Type	Category	Examples	Pollutants
1.	Dust producing processes	(a) Crushing, grinding, screening (b) Milling	Road mix plants grain elevators	Mineral and organic particulars
2.	Combustion	Fuel burning	Power plants and home heating units	Oxides of sulphur, oxides of nitrogen, carbon monoxide, smoke, flyash.
		Motor vehicles Refuse burning	Autos, Buses, Trucks Community incinerator Open burning dumps	Organic vapours, Metal oxide particles and odours.
3.	Manufacturing processes	Metallurgical plants	Smelters, Steel mills, Aluminium refiners	Metal fumes (lead, arsenic, zinc) fluorides and oxides of sulphur, Hydrogen sulphide, Oxides of sulphur fluorides, Organic vapours particles odours.
		Chemical plants	Petroleum refineries fertilizer/cement/pulp mills	
		Waste recovery	Metal scrap yard, auto body burning	Smoke, Soot, Organic vapours, odours
4.	Agricultural activities	Crop spraying and dusting	Pest and weed control	Organic phosphates Chlorinated hydrocarbons, arsenic, lead
		Field burning	Stubble burning	Smoke, flyash and soot
5.	Solvent	Spray Painting	Automobile assembly furniture etc.	Hydrocarbon and other organic vapour
		Inks Solvent cleaning	Photogravure and printing, Dry cleaning, degreasing	
6.	Nuclear energy activities	Ore preparation	Crushing, grinding and screening	Uranium and Beryllium dust
		Fuel fabrication Nuclear fission Nuclear device testing	Gaseous diffusion Nuclear reactor Atmospheric explosion	Fluoride Argon – 41 Radioactive fall out (Strontium 90, Carbon – 40 etc.)

Stationary and Mobile Sources (Define)

Another method of classifying emission sources is by

1. Point source (Large stationary sources)
2. Area source (Small stationary sources and mobile sources with indefinite routes) and
3. Line source (Mobile sources with definite routes).



1.6 CLASSIFICATION OF POLLUTANTS

- Basically air pollutant is defined as "Any substance in air that could, in high enough concentration, harm animals, humans, vegetation and/or materials."
- All air pollutants are broadly classified as :

Board Classification :

(A) According to origin

(B) According to chemical composition

(C) According to state of matter.

(A) According to Origin

Air pollutants are further classified as follows

- Primary pollutants and
- Secondary pollutants.

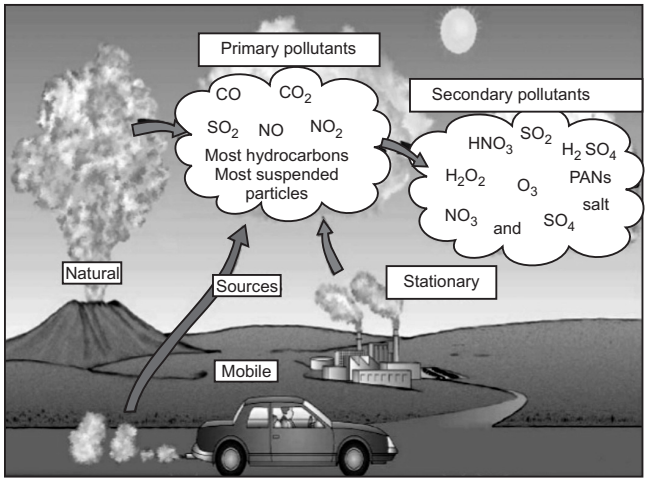


Fig. 1.2 : Primary and secondary pollutant

Primary Pollutants

- Primary pollutants are those emitted directly from identifiable sources.
- These pollutants are emitted directly to the atmosphere and found there in the form in which they were emitted.
- These primary pollutants will not react with other to found in the other type. They will be available in the atmosphere in the discrete manner.

Following are the examples of primary air pollutants

(a) Particulate matter (PM)

(b) Oxides of sulfur (SO_x)

(c) Oxides of nitrogen (NO_x)

(d) Carbon monoxidev (CO)

(e) Halogen and organic compounds

(f) Radioactive compounds.

Secondary Air Pollutants

- Secondary air pollutants are those which are produced in the air by the interaction among two or more primary pollutants or by reaction with normal atmospheric constituents with or without photoactivation. Secondary pollutants such as ozone and PAN are those formed in the atmosphere by a photochemical reaction or by hydrolysis or oxidation.

Following are the examples of secondary air pollutants

(a) Ozone (O_3)

(b) Formaldehyde

(c) Photochemical smog

(d) Peroxy Acetyl Nitrate (PAN)

(e) Peroxy Butyl Nitrate (PBN)

(f) Formation of acid mist.

(B) According to Chemical Composition

All the air pollutants are classified according to the chemical composition as follows

- Organic
- Inorganic.

Organic Air Pollutants

Organic compounds contain carbon and hydrogen. Some air pollutants also contain nitrogen, sulphur, oxygen and phosphorus. Following are the examples of organic compounds.

(a) Hydrocarbons

(b) Aldehydes and ketones

(c) Alcohols, acids, ethers, esters and amines

(d) Organic sulfur compounds.

Inorganic Air Pollutants

Inorganic compounds do not contain carbon and hydrogen as basic atoms. Following are the examples of inorganic air pollutants.

(a) Carbon monoxide (CO)

(b) Carbon dioxide (CO_2)

(c) Carbonates

(d) Oxides of sulfur and nitrogen (So_x and NO_x)

(e) Ozone (O_3)

(f) Hydrogen fluoride and hydrogen chloride

(C) According to State of Matter

Air pollutants according to the state of matter can be classified as follows

- Natural contaminants
- Particulate matter
- Gases and vapor.

Natural Contaminants

- The air contaminants, which are produced from natural sources, are called natural contaminants. During the growing season the pollens will be emitted.
- Following are the examples Natural fog, pollen grains, bacteria and products of volcanic erruption.

Pollen : Pollen grains are emitted into the atmosphere from weeds, grasses and trees. Due to pollination, thousands of pollen grains are emitted which are irritating to some individuals.

Size : 10 to 50 microns.

Particulate Matter : (PM)

- These may be liquid or solid. The standards identify the particulates as any dispersed matter, solid or liquid, in which the individual aggregates are larger than a single small molecule (about 0.002 μm in diameter) but smaller than about 500 μm.
- These are further classified according to their physical or biological characteristics.
- Physical characteristics include size, mode of formation, settling properties and optical qualities.
- Following are the examples of particulate matter Dust, smoke, mist, fog, fumes, flyash and spray.

Dust :

- These are small solid particles created by break up of larger masses through processes such as crushing, grinding or blasting.
- Dust particles that are picked up by the wind and carried over long distances tend to sort themselves to the sizes between 0.5 and 50 μm in diameter.
- Size : 1 to 10,000 microns.

Smoke :

- It consists of finely divided solid particles produced by incomplete combustion of organic particles such as coal, wood or tobacco.
- Size : 0.5 to 1 microns.

Mist :

- These are the liquid particles formed by the condensation of vapour or the dispersion of the liquid.
- If the mist concentration is high enough to obscure the visibility, the mist is called a fog.

Fog :

- This is visible aerosol in which the dispersed phase is liquid. This is formed by the condensation of liquid. It reduces the visibility to less than 1/2 km.
- Size : 1 to 40 microns.

Fumes :

- These are fine solid particles formed by the condensation of vapours of solid materials.
- Whenever the metal processing is performed in forging industry, the fumes are given out in the atmosphere. These fumes are generally from sublimation, distillation or molten metal processes.
- Size : 0.03 to 0.3 microns.

Fly Ash :

- These are finely divided, non combustible particles contained in the flue gases arising from combustion of coal.
- When the organic portion of coal is burned, the minerals and the metallic substances are released into the atmosphere in the form of fly ash.
- Size : 1 to 1000 microns,

Spray :

- These are liquid particles formed by atomization of parent liquids such as pesticides and herbicides.
- Size : 10 to 1000 microns.

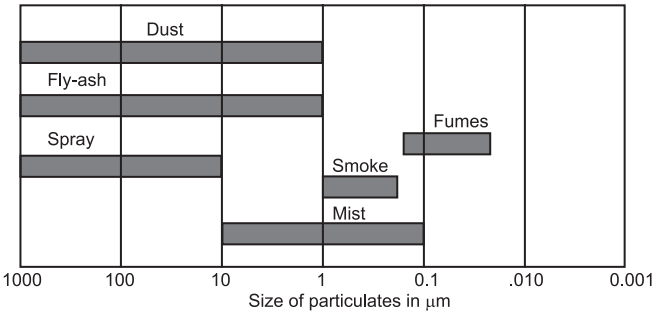


Fig. 1.3 : Sizes of particulates

1.7 GASES AND VAPOURS

Following is the list of gaseous air pollutants :

1. Carbon monoxide (CO)
2. Oxides of sulphur (SO_x)
3. Oxides of nitrogen (MO_x)
4. Hydrocarbons
5. Photochemical oxidants
6. Chlorine and hydrogen chloride
7. Hydrogen sulphide (H_2S)
8. Hydrogen fluoride (HF)
9. Radioactive gases
10. Lead (Pb)

1. Carbon Monoxide (CO)

This is an odourless, tasteless, colourless gas and chemically inert under normal conditions. The major origin of CO is from incomplete combustion of carbonaceous materials. The natural anaerobic decomposition of carbonaceous material by soil micro-organisms releases methane (CH_4) to the atmosphere. The oxidation of methane results in CO.

$$CH_4 + OH \longrightarrow CH_3 + H_2O$$

$$CH_3 + O_2 + 2(h\upsilon) \longrightarrow CO + H_2 + OH$$

Anthropogenic sources include motor vehicles, fossil fuel burning for electricity and heat, industrial processes, solid waste disposal, and miscellaneous burning of such things as leaves and brush. The chief source of CO in the atmosphere is combustion,

especially due to automobile exhausts. Motor vehicles account for more than 60% of the emission. It is observed that the CO concentration is reduced due to its reaction with hydroxyl radicals to form CO_2 and its removal by soil micro-organisms.

2. Oxides of Sulphur (SO_X)

The oxides of sulphur are one of the principle constituents of air pollutants. Sulphur oxides may be both primary or secondary pollutants. They include four different gaseous compounds viz. sulphur monoxide (SO), sulphur dioxide (SO_2), sulphur trioxide (SO_3), and sulphur tetraoxide (SO_4).

Sulphur dioxide is a colourless, non-flammable and non-explosive gas with a suffocating odour. This gas is released from sulphuric acid plants, paper manufacturing plants, power plants, volcanoes and open burning of refuse. In addition, H_2S released from some industrial processes gets oxides into SO_2.

The most important reactions in SO_2 formation are as follows

$$H_2S + O_3 \longrightarrow H_2O + SO_2 \uparrow$$
$$S + O_2 \longrightarrow SO_2 \uparrow$$

The reactions involved in formation of acid rain are as follows

$$SO_2 + h\upsilon \longrightarrow SO_2^* \quad \text{(Photoexcitation of } SO_2\text{)}$$

The excited molecule then readily reacts with O_2 to form SO_3.

$$SO_2^* + O_2 \longrightarrow SO_3 + O$$

Highly hydroscopic SO_3 gets converted into sulphuric acid.

$$SO_3 + H_2O \longrightarrow H_2SO_4$$

3. Oxides of Nitrogen (NO_X)

Oxides of nitrogen includes four known gaseous compounds viz Nitric oxide (NO), Nitrogen dioxide (NO_2), Nitrous oxide (N_2O), Nitrogen pentoxide (N_2O_5).

In air pollution, nitiric oxide (NO) and nitrogen dioxide (NO_2) are of primary concern. Generally, highest concentration of nitrogen oxides in gaseous emissions occurs in effluents from industries where nitric acid is produced or used in chemical reactions. The next highest concentration is in automobile exhausts. Bacterial action in soil releases nitrous oxide to the atmosphere. At higher altitudes the atomic oxygen reacts with the nitrous oxides to form nitric oxides.

$$N_2O + O \longrightarrow 2\,NO$$
$$NO + O_3 \longrightarrow NO_2 + O_2$$

(Ultimately the NO_2 is converted to either NO_2^- or NO_3^- in particulate form). The particulates are then washed out by precipitation. The dissolution of nitrate in a water droplet allows for the formation of nitric acid causing '*acid rain*'.

4. Hydrocarbons

Organic compounds containing only carbon and hydrogen are classified as hydrocarbons. These are classified into two major groups.

They are

- Aliphatic hydrocarbons.
- Aromatic hydrocarbons.

Hydrocarbons present in the atmosphere are from both natural and anthropogenic sources. Natural sources like biological processes, geothermal areas, coal fields, petroleum fields emit methane and terpens.

The major anthropogenic sources are partially burned gasoline and incinerator, emissions, industrial processes and solid waste disposal.

Table 1.2 : Sources and Quantities of Hydrocarbon Emissions

Sr. No.	Sources	1975	1977	1980
1.	Transportation	10.4	11.5	7.8
2.	Fuel combustion in stationary sources	1.3	1.5	0.2
3.	Industrial processes	2.7	10.1	10.8
4.	Solid waste disposal	12.6	5.2	3.0
	Total	**27.0**	**28.3**	**21.8**

5. Photochemical Oxidants

Oxidising agents, ozone, Peroxy Acetyl Nitrate (PAN), Peroxy Benzoyl Nitrate (PBN) and other trace substances, which can oxidise iodine ion of potassium iodide are termed as photochemical oxidants. These pollutants results from atmospheric reactions. These are formed through a series of reactions that are initiated by the absorption of photon by an atom, molecule, free radical or ion. Ozone is the principal photochemical oxidant. Its formation is usually attributed to the nitrogen dioxide photolytic cycle. Ozone is poisonous and smelty. It is present in the upper stratosphere. The photochemical oxidants are involved in 'smog' formation.

6. Chlorine and Hydrogen Chloride

Chlorine is found in polluted atmosphere as the element itself (chlorine). The most common sources of chlorine in atmosphere are from operations in which it is manufactured or used to produce other chemicals.

7. Hydrogen Sulphide (H_2S)

This is a foul smelling gas. This is produced in anaerobic biological decay processes on land, in marshes and in the oceans. The major source of hydrogen sulphide is kraft-pulp industry.

8. Hydrogen Fluoride (HF)

The major sources are the manufacture of phosphate fertilizer, the aluminium industry, brick plants, pottery, and ferro-enamel works. This gas is important in terms of injury to vegetation and animals.

9. Radioactive Gases

The major source is nuclear power plants and related fuel handling facilities.

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