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Palestine Polytechnic University

College of Engineering & Technology

Mechanical Engineering Department

Graduation Project

Developing a Method of Treat Air Pollution and Monitoring Air Quality

Project Team

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According to the project supervisor and according to the agreement of the Testing committee members, this project is submitted to the Department of Mechanical Engineering at college of engineering and technology in partial fulfillment of the requirements of (B.Eng) the bachelor's degree.

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2007

Abstract

In this project a method of treating air pollution will be developed and monitoring the air quality in order to help in solving one of the biggest problems facing the all of the world.

The main idea of this project is to clean up the smoke that comes from the chimneys of factories through the use of water. As we know that some of these gases can dissolve in water according to Henrys Law in different percentage of solubility; that depends upon the relation between the water and the gases (combustion gases:CO,SO_X,NO_X,...etc), temperature & pressure applied on the surface of the water. Also some of these gas molecules not dissolve in water but it can reduce its size through the Adhesion force which will appear between the smoke (gases) and water molecules.

In this project also a prototype will be made for the purification process and many experiment will be done to see the reduction percent of the combustion gases.

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CHAPTER ONE

AIR POLLUTION PROBLEM

Air Pollution Problem

This chapter talks about the air pollution problem in general, the history of the problem and the main reasons for choosing the project.

1.1 Introduction

Air Pollution, addition of harmful substances to the atmosphere resulting in damage to the environment, human health, and quality of life. One of many forms of pollution, air pollution occurs inside homes, schools, and offices, in cities, across continents, and even globally. Air pollution makes people sick it causes breathing problems and promotes cancer and it harms plants, animals, and the ecosystems in which they live. Some air pollutants return to Earth in the form of acid rain and snow, which corrode statues and buildings, damage crops and forests, and make lakes and streams unsuitable for fish and other plant and animal life see figure 1.1.

Figure 1.1: Air Pollutants in the Atmosphere

Pollution is changing Earth's atmosphere so that it lets in more harmful radiation from the Sun. At the same time, our polluted atmosphere is becoming a better insulator, preventing heat from escaping back into space and leading to a rise in global average temperatures. Scientists predict that the temperature increase, referred to as global warming, will affect world food supply, alter sea level, make weather more extreme, and increase the spread of tropical disease.

1.2 History of Air Pollution

Air pollution, particularly in cities, is certainly not a new problem. Back in the middle ages, the use of coal in cities such as London was beginning to escalate. The problems of poor urban air quality even as early as the end of the 16th century are well documented.

In the UK the Industrial Revolution during the 18th and 19th centuries was based on the use of coal. Industries were often located in towns and cities, and together with the burning of coal in homes for domestic heat, urban air pollution levels often reached very high levels. During foggy conditions, pollution levels escalated and urban smog's (smoke and fog) were formed. These often brought cities to a halt, disrupting traffic but more dangerously causing death rates to dramatically rise. The effects of this pollution on buildings and vegetation also B vegetation became obvious. The 1875 Public Health Act contained a smoke abatement section to try and reduce smoke pollution in urban areas.

During the first part of the 20th century, tighter industrial controls lead to a reduction in smog pollution in urban areas. The 1926 Smoke Abatement Act was aimed at reducing smoke emissions from industrial sources, but despite the declining importance of coal as a domestic fuel, pollution from domestic sources remained significant.

The Great London Smog of 1952, which resulted in around 4,000 extra deaths in the city, led to the introduction of the Clean Air Acts of 1956 and 1968. These introduced smokeless zones in urban areas, with a tall chimney policy to help disperse industrial air pollutants away from built up areas into the atmosphere.

Following the Clean Air Acts, air quality improvements continued throughout the 1970s. Further regulations were introduced through the 1974 Control of Air Pollution Act. This included regulations for the composition of motor fuel and limits for the sulphur content of industrial fuel oil.
However, during the 1980s the number of motor vehicles in urban areas steadily increased and air quality problems associated with motor vehicles became more prevalent. In the early 1980s, the main interest was the effects of lead pollution on human health, but by the late 1980s and early 1990s, the effects of other motor vehicle pollutants became a major concern. The 1990s have seen the occurrence of wintertime and summertime smog's. These are not caused by smoke and sulphur dioxide pollution but by chemical reactions occurring between motor vehicle pollutants and sunlight. These are known as 'photochemical smog.

In 1995, the Government passed its Environment Act, requiring the publication of a National Air Quality Strategy to set standards for the regulation of the most common air pollutants. Published in 1997, the National Air Quality Strategy has set commitments for local authorities to achieve new air quality objectives throughout the UK by 2005. It is reviewed periodically.[6]

1.3 Justification for Choosing the Project

The main goal for choosing this project is to help in solving one of the biggest problems facing all of the world as mentioned before (air pollution).

There is a scientific belief that these gases cause health problems for humans especially the respiratory system, so this project helps in reduce the chances of infection.

1.4 General description of the project

This project is based on an experiment so that a prototype will be made ,it contains a combustion chamber , fan , water tank and pipes. In the combustion chamber a pices of rubber will burned so as the chamber is connected with fan through pipes then the fan forced the smoke to enter the water tank by centrifugal effect, the tank contains number of metal barriers that force the smoke to follow through tortuous path; the tank is contains water up to 40 cm of its height, along this bath the smoke will be washed by the water because of the fan, since its pressure must be greater than the water pressure, then the smoke continues its trip to the atmosphere .

After that the measuring process of some gases percentage will be done before and after the washing process , see figure (1.2-1.3) .

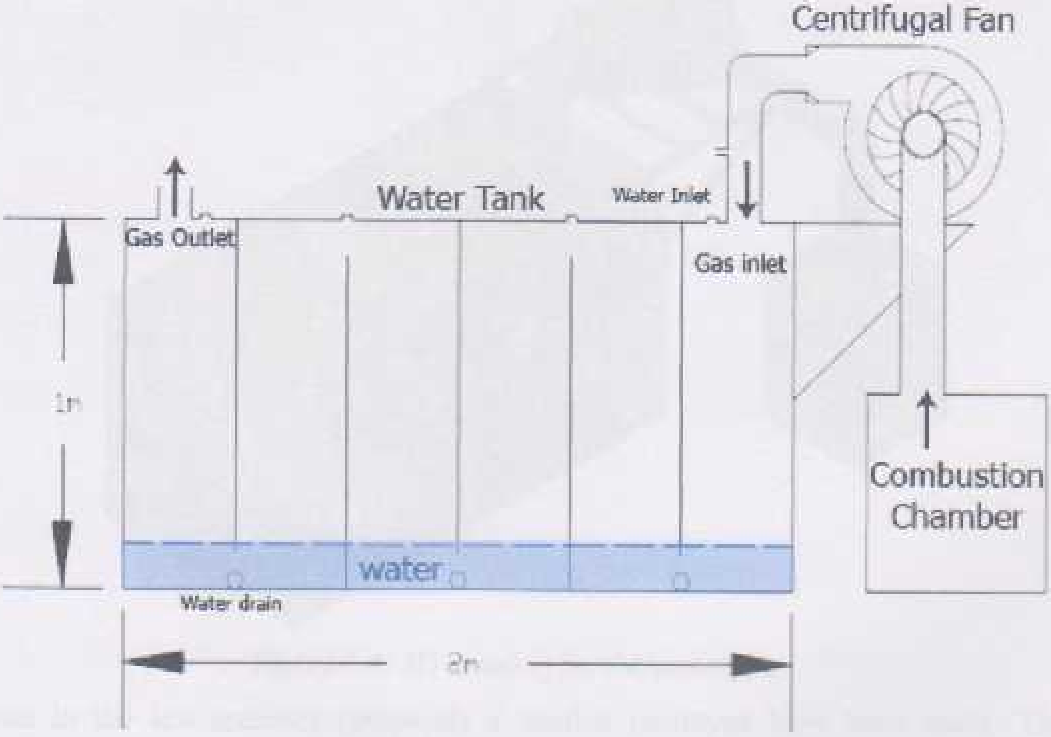


Figure 1.2: schematic diagram of the prototype

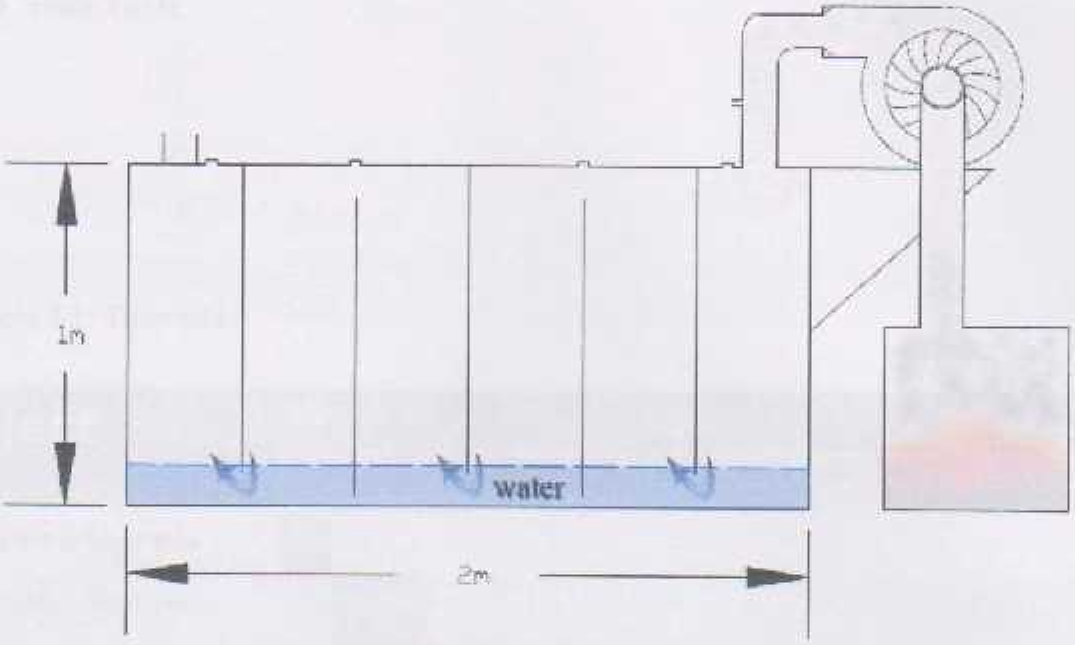


Figure 1. 3:schematic diagram of the project

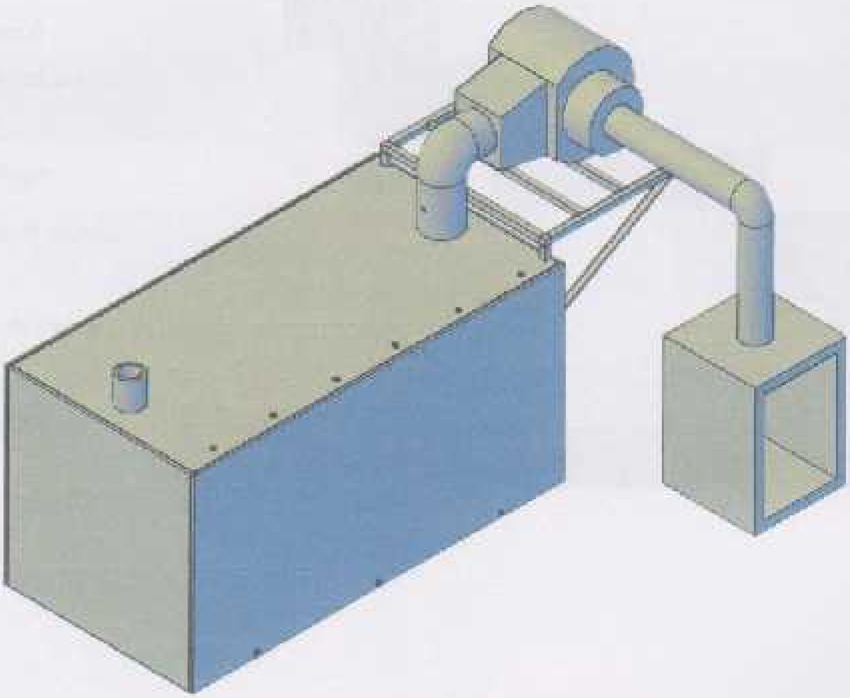
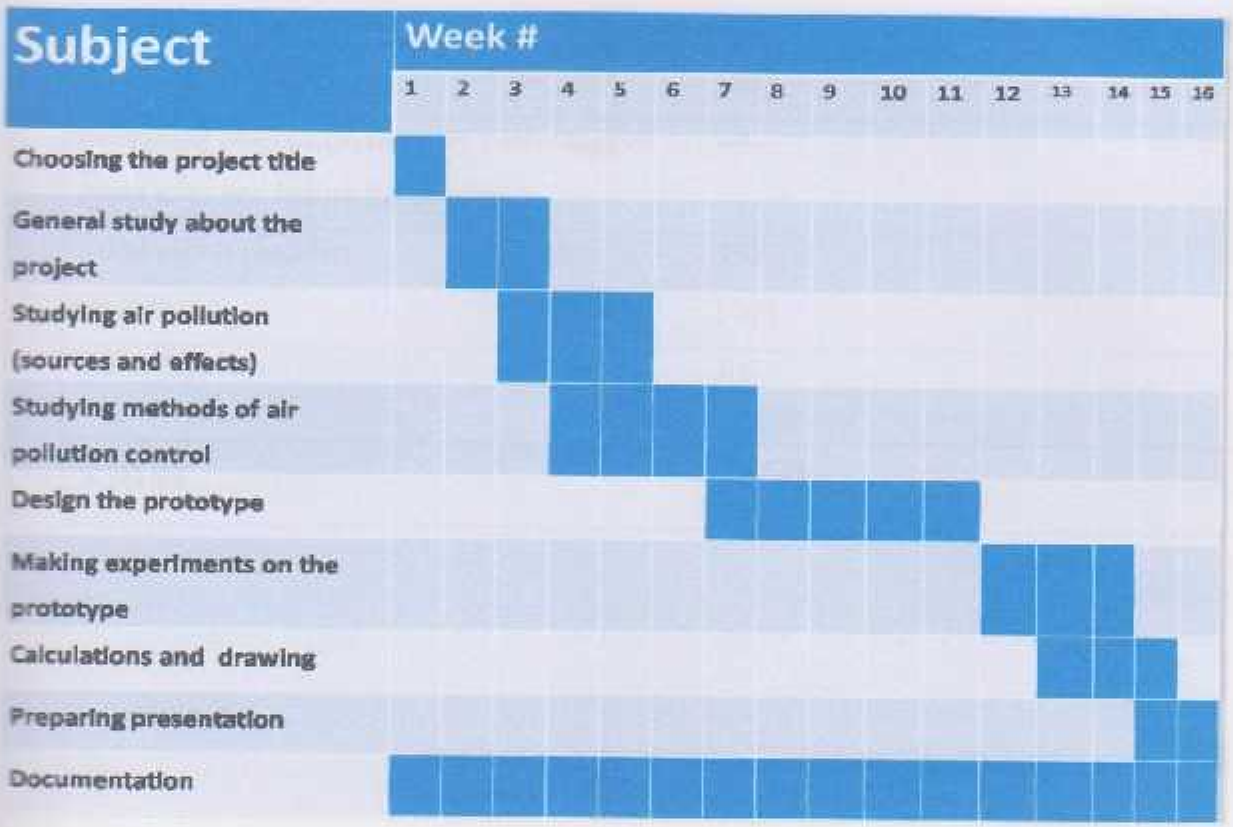


Figure 1.4: 3D drawing for the prototype

Note: in the last semester (proposal) a another prototype have been made. The principle of operation is using number of water jet in order to wash the gas, but a problem was occur is that we need large number of water jets, on the other hand, the circulating water will evaporates during the process , so we use the same idea of scrubbing by water but in large water tank which keeps the same amount of water and to be sure that all the gas will flow throw the water .

1.5 Time Table

Table 1.1: Time table



Subject	Week #															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Choosing the project title	🟦															
General study about the project		🟦	🟦													
Studying air pollution (sources and effects)			🟦	🟦	🟦											
Studying methods of air pollution control				🟦	🟦	🟦	🟦									
Design the prototype							🟦	🟦	🟦	🟦	🟦					
Making experiments on the prototype												🟦	🟦	🟦		
Calculations and drawing													🟦	🟦	🟦	
Preparing presentation															🟦	🟦
Documentation	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦

1.5 Budget

Table 1.2: Budget

Item	*Coast (NIS)*
Pipes and stand	500
Flow control valves	250
Water tank	1850
measuring devices:(to measure percentage of gases after and before the process)	-------
Combustion chamber	350
Blower	1000
Other expenses	500
Total	**4450**

CHAPTER TWO

AIR POLLUTANTS

Air Pollutants

2.1 introduction

This chapter focus on the air pollutant sources, the major classifications of air pollutants and effects of air pollution on human health, animals & all of the planet.

2.2 Air Pollutant Sources

Most air pollution comes from one human activity: burning fossil fuels, natural gas, coal, and oil to power industrial processes and motor vehicles. Among the harmful chemical compounds this burning puts into the atmosphere are carbon dioxide, carbon monoxide, nitrogen oxides(NO_X), sulfur dioxide(SO_2), and tiny solid particles including lead from gasoline additives called particulates. Between 1900 and 1970, motor vehicle use is rapidly expanded, and emissions of nitrogen oxides, some of the most damaging pollutants in vehicle exhaust, increased 690 percent. When fuels are incompletely burned, various chemicals called volatile organic chemicals (VOCs) also enter the air. Pollutants also come from other sources. For instance, decomposing garbage in landfills and solid waste disposal sites emits methane gas, and many household products give off VOCs.[11]

Some of these pollutants also come from natural sources. For example, forest fires emit particulates and VOCs into the atmosphere. Ultrafine dust particles, dislodged by soil erosion when water and weather loosen layers of soil, increase airborne particulate levels. Volcanoes spew out sulfur dioxide and large amounts of pulverized lava rock known as volcanic ash. A big volcanic eruption can darken the sky over a wide region and affect the Earth's entire atmosphere. The 1991 eruption of Mount Pinatubo in the Philippines, for example, dumped enough volcanic ash into the upper atmosphere to lower global temperatures for the next two years. Unlike pollutants from human activity, however, naturally occurring pollutants tend to remain in the atmosphere for a short time and do not lead to permanent atmospheric change.

Once in the atmosphere, pollutants often undergo chemical reactions that produce additional harmful compounds. Air pollution is subject to weather patterns that can trap it in valleys or blow it across the globe to damage pristine environments far from the original sources.

As we know that the land surrounded by the atmosphere which is layer of gases surrounding the planet Earth and retained by the Earth's gravity and the figure below shows the layers of the atmosphere.

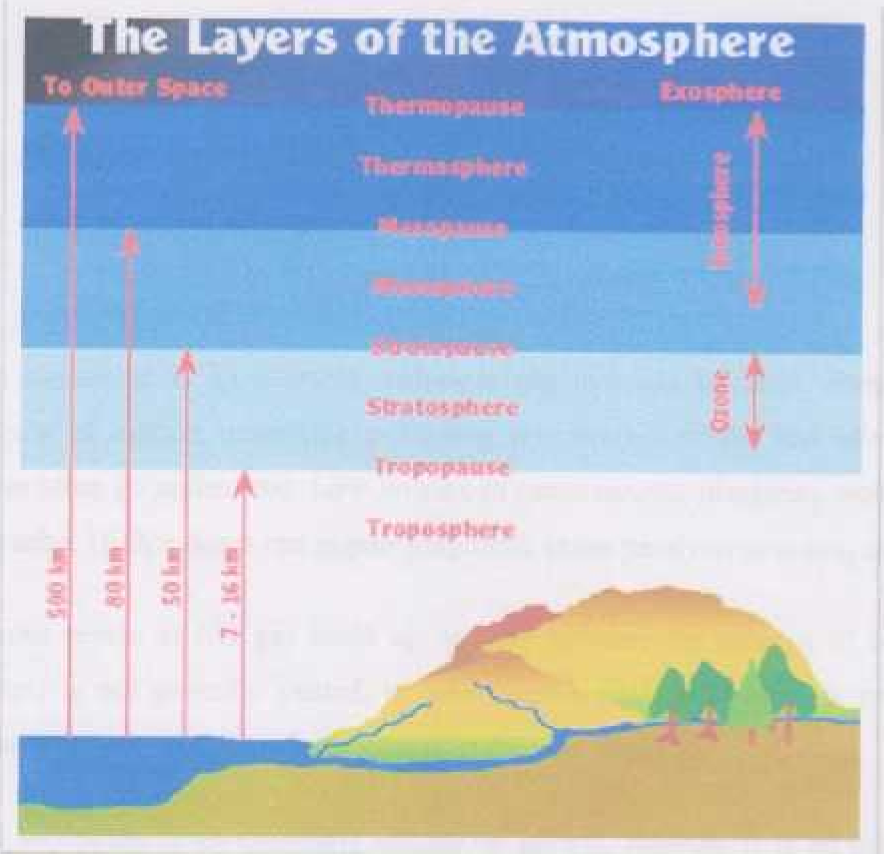


Figure 2.1: The Layers of the Atmosphere.

The bottom layer of the atmosphere (7-16km) is contains most of the air about 75%.

2.3 Major Classifications of Air Pollutants

Air pollutants can be classified into

2.3.1 CO (carbon monoxide)

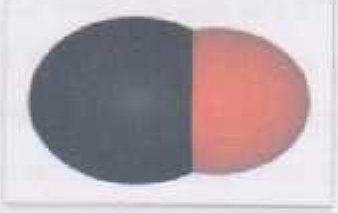


Figure 2.2: Molecule of CO

Carbon monoxide is an odorless, colorless gas that can be fatal when breathed. Symptoms of carbon monoxide poisoning are similar to flu and allergies, and therefore often go undetected. Low levels can cause nausea, dizziness, weakness, and muscle ache. Higher doses can impair judgment, cause paralysis or coma, and death.

Dangerous levels of CO gas build up, usually because the exhaust of combustion appliances is not properly vented, or when combustion equipment is not in good working order and is not regularly inspected for safe operation.

Carbon monoxide is an extremely dangerous poison. Because it is an odorless and tasteless gas, it gives no warning of its presence. It binds to the hemoglobin in blood to form a compound that is so stable that it cannot be broken down by body processes. When the hemoglobin is combined with carbon monoxide, it cannot combine with oxygen; this destroys the ability of hemoglobin to carry essential oxygen to all parts of the body. Suffocation can occur if sufficient amounts of carbon monoxide are present to form complexes with the hemoglobin.

$H_2O + C \rightarrow H_2 + CO$

2.3.2 Sulfur oxides (mainly SO_2, or sulfur dioxide)

Sulfur dioxide is produced by combustion of sulfur-containing fuels, such as coal and fuel oils. Also , in the process of producing sulfuric acid and in metallurgical process involving ores that contain sulfur. Sulfur oxides can injure man, plants and materials. At sufficiently high concentrations, sulfur dioxide irritates the upper respiratory tract of human beings because potential effect of sulfur dioxide is to make breathing more difficult by causing the finer air tubes of the lung to constrict. "Power plants and factories emit 90% to 95% of the sulfur dioxide and 57% of the nitrogen oxides in the United States. Almost 60% of the SO_2 emissions are released by tall smoke stakes, enabling the emissions to travel long distances". As emissions of sulfur dioxide and nitric oxide from stationary sources are transported long distances by winds, they form secondary pollutants such as nitrogen dioxide, nitric acid vapor, and droplets containing solutions of sulfuric acid, sulfate, and nitrate salts. These chemicals descend to the earth's surface in wet form as rain or snow and in dry form as a gases fog, dew, or solid particles. This is known as acid deposition or acid rain. Sulfur oxides (SO_x) are colorless gases that are the result of burning sulfur. All fuels used by man (oil, coal, natural gas, wood, etc.) contain some sulfur. The primary source of sulfur oxides is the burning of these fossil fuels, particularly coal, at power plants for electricity. During the combustion process, sulfur reacts with oxygen to form sulfur dioxide (SO_2). Sulfur dioxide is used as an indicator of all sulfur oxide (SO_x) concentrations in the ambient air, because it is the most easily measured sulfur oxide. The NAAQS for SO_2 is 80 g/m3 on an annual average or 365 g/m3 for a 24-hour average.[6]

Note that the chemical formula of SO_2 is:

$S_8 + 8\ O_2 \rightarrow 8\ SO_2$

2.3.3: Nitrogen Oxides - NO (nitric oxide) & NO_2 (nitrogen dioxide)

Controls, especially in automobiles and in industrial fuel consumption. Nitrogen oxides, or NO_x, are the generic term for a group of highly reactive gases, all of which contain nitrogen and oxygen in varying amounts. Many of the nitrogen oxides are colorless and odorless. However, one common pollutant, nitrogen dioxide (NO_2) along with particles in the air can often be seen as a reddish-brown layer over many urban areas. Nitrogen oxides form when fuel is burned at high temperatures, as in a combustion process. The primary sources of NO_x are motor vehicles, electric utilities, and other industrial, commercial, and residential sources that burn fuels.

Figure 2.3 The percentage of NO_X.

NO_x and the pollutants formed from NO_x can be transported over long distances, following the pattern of prevailing winds in the most countries. This means that problems associated with NO_x are not confined to areas where NO_x are emitted. Therefore, controlling NO_x is often most effective if done from a regional perspective, rather than focusing on sources in one local area.[6]

Also NO_x[6]

- Is one of the main ingredients involved in the formation of ground-level ozone, which can trigger serious respiratory problems.
- React to form nitrate particles, acid aerosols, as well as NO_2, which also cause respiratory problems.
- Contribute to formation of acid rain.
- Contribute to nutrient overload that deteriorates water quality.
- Contribute to atmospheric particles, which cause visibility impairment most noticeable in national parks.
- React to form toxic chemicals.
- Contribute to global warming.

❖ N_2O:

Nitrous oxide, N_2O, is a colorless, almost odorless gas, that was first discovered in 1793 by the English scientist and clergyman Joseph Priestley (who was also famous for being the first to isolate other important gases such as oxygen, carbon monoxide, carbon dioxide, ammonia, and sulfur dioxide). Priestley made N_2O by heating ammonium nitrate in the presence of iron filings, and then passing the gas that came off (NO) through water to remove toxic by-products. The reaction he observed was:

$$2NO + H2O + Fe \rightarrow N2O + Fe(OH)_2$$

2.3.4 Volatile Organic Compounds (hydrocarbons) methane, benzene, propane, & chlorofluorocarbons (CFC's)

Are organic chemical compounds that have high enough vapor pressures under normal conditions to significantly vaporize and enter the atmosphere. (The term VOC is also occasionally used as an abbreviation, especially in biological contexts, for "volatile organic carbon".) A wide range of carbon-based molecules, such as aldehydes, ketones, and hydrocarbons are VOC's.

Also the main source is motor vehicles (evaporation from gas tanks), industry, & various household products, and according to EPA about 18 million tons released each year in U.S, and Concentrations of many VOCs are consistently higher indoors than outdoors. A study by the EPA, covering six communities in various parts of the United States, found indoor levels up to ten times higher than those outdoors-even in locations with significant outdoor pollution sources, such as petrochemical plants. These compounds caused an Eye and respiratory tract irritation, headaches, dizziness, visual disorders, and memory impairment are among the immediate symptoms that some people have experienced soon after exposure to some organics. At present, not much is known about what health effects occur from the levels of organics usually found in homes. Many organic compounds are known to cause cancer in animals; some are suspected of causing, or are known to cause, cancer in humans.

2.3.5 Suspended Particulate Matter (SPM)

Maybe the most critical of all air pollutants

- -mixture of solid and liquid particles.
- -organic and inorganic.

e.g. dust, sand, metals, wood particles, smoke, etc.

Individually, these particles and droplets are invisible to the naked eye.

Collectively, however, they can appear as clouds or a fog-like haze.

The main Sources

- Fossil-fuel combustion.
- Metals and minerals processing.
- Dust.
- Sand.
- Many others.

It acts as respiratory irritants; some is known carcinogens and it can aggravate heart/respiratory diseases.

2.3.6 Toxic compounds

These chemicals are dangerous or extremely dangerous to health and life when inhaled, swallowed or absorbed through the skin.

Trace amounts of at least 600 toxic substances (such as lead and mercury) produced by human activities.

Mercury is an element that occurs naturally in the earth's crust. Because this element is toxic at very low concentrations, even slight increases in the minute concentrations naturally present in the environment can have serious effects on humans and wildlife. Once mercury enters the water it can be converted to its most toxic form, methyl mercury, by bacteria or chemical reactions. Methyl mercury is absorbed by tiny aquatic organisms, which are then eaten by small fish. The chemical is stored in the fish tissue and is passed on at increasing concentrations to larger predator fish. People and wildlife at the top of the food chain are consequently exposed to elevated amounts of methyl mercury through the contaminated fish they consume.

sources of mercury = burning coal and waste (such as medical wastes).

2.3.7 Photochemical Oxidants

Photochemical oxidants are the products of reactions between NO_x and a wide variety of volatile organic compounds (VOCs). The most well known 'oxidants' are ozone (O_3), peroxyacetyl nitrate (PAN) and hydrogen peroxide (H_2O_2). The main impact on the natural environment is mostly due to elevated O_3. Excessive concentrations of troposphere O_3 have toxic effects on both plants and human health.

Because sunlight has a critical role in its formation, ozone pollution is principally a daytime problem in the summer months. The presence of hydrocarbons and nitrogen oxide in sunlight with little air movement leads to the generation of ozone. These two compounds are produced by cars, trucks, factories, and power-generating plants or wherever gasoline, diesel fuel, kerosene, oil, or natural gas are combusted. These gases combine together with sunlight, producing ozone. Urban areas with heavy traffic and large industrialized communities are primary areas for ozone problems.

2.3.8 Smog

The word "smog" is a compound of smoke and fog. Classic smog results from large amounts of coal burning in an area and is caused by a mixture of smoke and sculpture dioxide. And it is more common in cities with sunny , dry ,warm climates.

2.3.9 Acid Precipitation

Acidic pollutants can be deposited from the atmosphere to the Earth's surface in wet and dry forms. The common term to describe this process is acid deposition. The term acid precipitation is used to specifically describe wet forms of acid pollution that can be found in rain, sleet, snow, fog, and cloud vapor. An acid can be defined as any substance that when dissolved in water dissociates to yield corrosive hydrogen ions. The acidity of substances dissolved in water is commonly measured in terms of pH (defined as the negative logarithm of the concentration of hydrogen ions). According to this measurement scale solutions with pHs less than 7 are described as being acidic, while a pH greater than 7.0 is considered alkaline. Precipitation normally has a pH between 5.0 to 5.6 because of natural atmospheric reactions involving carbon dioxide. For comparison, distilled water, pure of any other substances, would have a pH of 7.0. Precipitation is considered to be acidic when its pH falls below 5.6 (which is 25 times more acidic than pure distilled water). Some sites in eastern North America have precipitation events with pHs as low as 2.3 or about 1000 times more acidic than natural.[8]

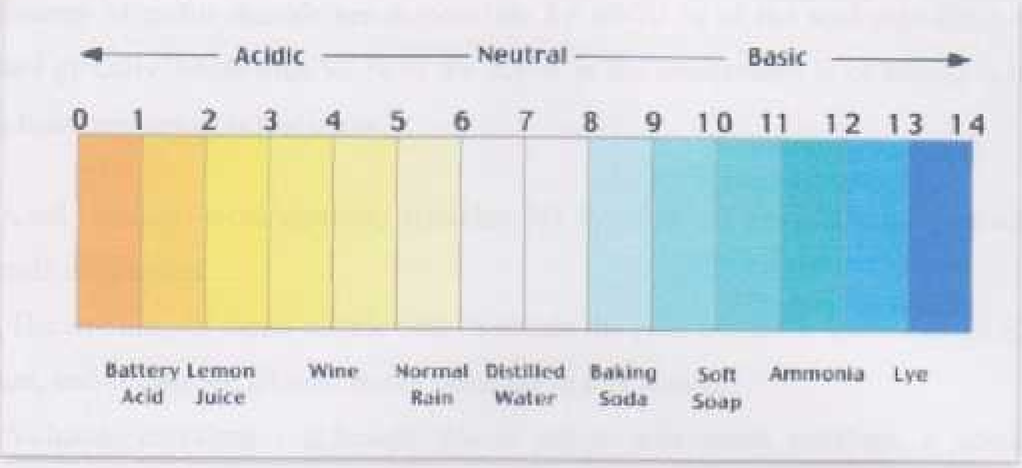


Figure 2.4: The pH scale.

Acid deposition is not a recent phenomenon. In the 17th century, scientists noted the ill effects that industry and acidic pollution was having on vegetation and people. However, the term acid rain was first used two centuries later when Angus Smith published a book called '*Acid Rain*' in 1872. In the 1960s, the problems associated with acid deposition became an international problem when fishermen noticed declines in fish numbers and diversity in many lakes throughout North America and Europe.

2.3.9.1 Acid Deposition Formation

Acid deposition can form as a result of two processes. In some cases, hydrochloric acid can be expelled directly into the atmosphere. More commonly it is due to secondary pollutants that form from the oxidation of nitrogen oxides (NO_x) or sulfur dioxide (SO_2) gases that are released into the atmosphere . Reactions at the Earth's surface or within the atmosphere can convert these pollutants into nitric acid or sulfuric acid. The process of altering these gases into their acid counterparts can take several days, and during this time these pollutants can be transported hundreds of kilometers from their original source. Acid precipitation formation can also take place at the Earth's surface when nitrogen oxides and sulfur dioxide settle on the landscape and interact with dew or frost.

Emissions of sulfur dioxide are responsible for 60-70 % of the acid deposition that occurs globally. More than 90 % of the sulfur in the atmosphere is of human origin. The main sources of sulfur include:

- Coal burning - coal typically contains 2-3 % sulfur so when it is burned sulfur dioxide is liberated.
- The smelting of metal sulfide ores to obtain the pure metals. Metals such as zinc, nickel, and copper are all commonly obtained in this manner.
- Volcanic eruptions - although this is not a widespread problem, a volcanic eruption can add a lot of sulfur to the atmosphere in a regional area.
- Organic decay.
- Ocean spray.

After being released into the atmosphere, sulfur dioxide can either be deposited on the Earth's surface in the form of dry deposition or it can undergo the following reactions to produce acids that are incorporated into the products of wet deposition.

$$SO_2 + H_2O \rightarrow H_2SO_3 \tag{2.2}$$

$$H_2SO_3 + \frac{1}{2}O_2 \rightarrow H_2SO_4 \tag{2.3}$$

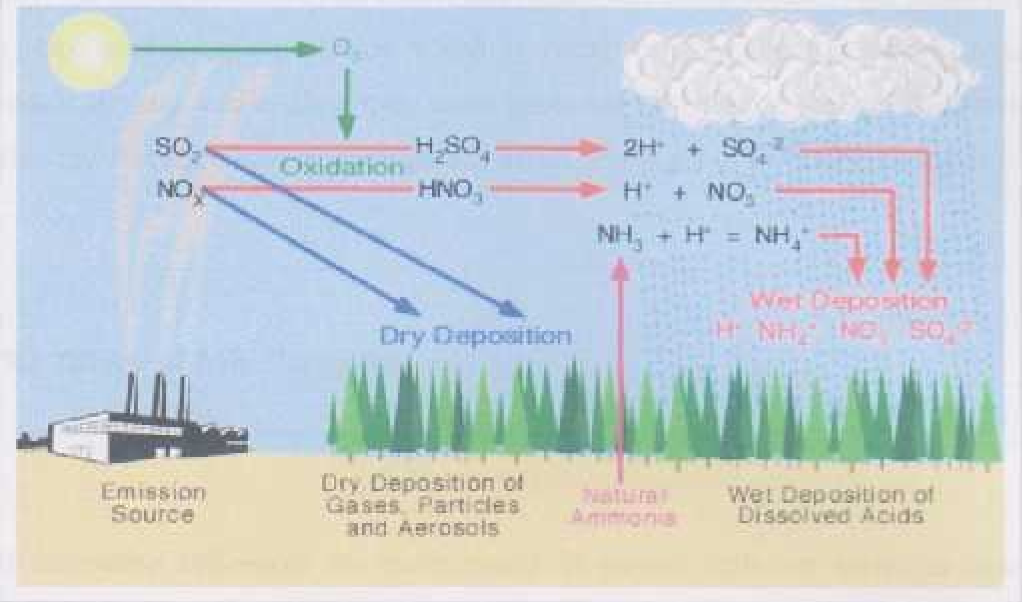


Figure 2.5: Several processes can result in the formation of acid deposition.

Some 95 % of the elevated levels of nitrogen oxides in the atmosphere are the result of human activities. The remaining 5 % comes from several natural processes. The major sources of nitrogen oxides include:

- Combustion of oil, coal, and gas.
- Bacterial action in soil.
- Forest fires.
- Volcanic action.
- Lightning.

Acids of nitrogen form as a result of the following atmospheric chemical reactions (see Figure 2.7 above):

$$NO+\frac{1}{2}O_2 \rightarrow NO_2 \quad (2.4)$$

$$2NO_2+H_2O \rightarrow HNO_2+HNO_3 \quad (2.5)$$

$$NO_2+OH \rightarrow HNO_3 \quad (2.6)$$

Finally, the concentrations of both nitrogen oxides and sulfur dioxides are much lower than atmospheric carbon dioxide which is mainly responsible for making natural rainwater slightly acidic. However, these gases are much more soluble than carbon dioxide and therefore have a much greater effect on the pH of the precipitation.

2.3.9.2 Effects of Acid Deposition

Acid deposition influences the environment in several different ways. In aquatic systems, acid deposition can effect these ecosystems by lowering their pH. However, not all aquatic systems are effected equally. Streams, ponds, or lakes that exist on bedrock or sediments rich in calcium and/or magnesium are naturally buffered from the effects of acid deposition. Aquatic systems on neutral or acidic bedrock are normally very sensitive to acid deposition because they lack basic compounds that buffer acidification. In Canada, many of the water bodies found on the granitic Canadian Shield fall in this group. One of the most obvious effects of aquatic acidification is the decline in fish numbers. Originally, it was believed that the fish died because of the increasing acidity of the water. However, in the 1970s scientists discovered that acidified lakes also contained high concentrations of toxic heavy metals like mercury, aluminum, and cadmium. The source of these heavy metals was the soil and bedrock surrounding the water body. Normally, these chemicals are found locked in clay particles, minerals, and rocks. However, the acidification of terrestrial soils and bedrock can cause these metals to become soluble. Once soluble, these toxic metals are easily leached by infiltrating water into aquatic systems where they accumulate to toxic levels.

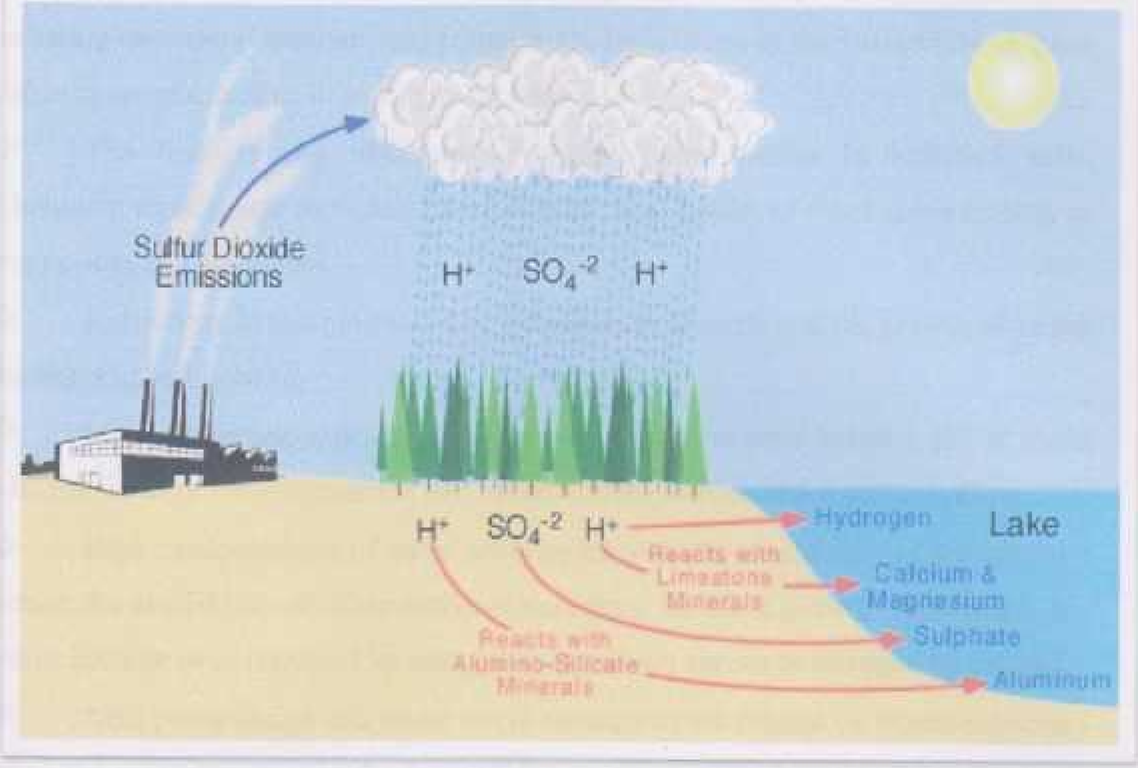


Figure 2.6: Lake Acidification.

In the middle latitudes, many acidified aquatic systems experience a phenomenon known as acid shock. During the winter the acidic deposits can buildup in the snowpack. With the arrival of spring, snowpack begins to melt quickly and the acids are released over a short period of time at concentrations 5 to 10 times more acidic than rainfall. Most adult fish can survive this shock. However, the eggs and small fry of many spring spawning species are extremely sensitive to this acidification.

The severity of the impact of acid deposition on vegetation is greatly dependent on the type of soil the plants grow in. Similar to surface water acidification, many soils have a natural buffering capacity and are able to neutralize acid inputs. In general, soils that have a lot of lime are better at neutralizing acids than those that are made up of siliceous sand or weathered acidic bedrock. In less buffered soils, vegetation is effected by acid deposition because:

❖ Increasing acidity results in the leaching of several important plant nutrients, including calcium, potassium, and magnesium. Reductions in the availability of these nutrients cause a decline in plant growth rates.

❖ The heavy metal aluminum becomes more mobile in acidified soils. Aluminum can damage roots and interfere with plant uptake of other nutrients such as magnesium and potassium.

❖ Reductions in soil pH can cause germination of seeds and the growth of young seedlings to be inhibited.

❖ Many important soil organisms cannot survive is soils below a pH of about 6.0. The death of these organisms can inhibit decomposition and nutrient cycling.

❖ High concentrations of nitric acid can increase the availability of nitrogen and reduce the availability of other nutrients necessary for plant growth. As a result, the plants become over-fertilized by nitrogen (a condition known as nitrogen saturation).

❖ Acid precipitation can cause direct damage to the foliage on plants especially when the precipitation is in the form of fog or cloud water which is up to ten times more acidic than rainfall.

❖ Dry deposition of SO_2 and NO_x has been found to affect the ability of leaves to retain water when they are under water stress.

❖ Acidic deposition can leach nutrients from the plant tissues weakening their structure.

The combination of these effects can lead to plants that have reduced growth rates, flowering ability and yields. It also makes plants more vulnerable to diseases, insects, droughts and frosts.

The effects of acidic deposition on humans can be divided into three main categories. Acid deposition can influence human health through the following methods:

- Toxic metals, such as mercury and aluminum, can be released into the environment through the acidification of soils. The toxic metals can then end up in the drinking water, crops, and fish, and are then ingested by humans through consumption. If ingested in great quantities, these metals can have toxic effects on human health. One metal, aluminum, is believed to be related to the occurrence of *Alzheimer's disease*.

- Increased concentrations of sulfur dioxide and oxides of nitrogen have been correlated to increased hospital admissions for respiratory illness.
- Research on children from communities that receive a high amount of acidic pollution show increased frequencies of chest colds, allergies, and coughs.

Acid deposition also influences the economic livelihoods of some people. Many lakes and streams on the eastern coast of North America are so acidic that the fish decline significantly in numbers. The reduced fish numbers then influence commercial fishermen and industries that rely on sport fishing tourism. Forestry and agriculture are affected by the damage caused to vegetation. In some areas of Eastern North America and Europe, large die-backs of trees have occurred. Finally, acid deposition effects a number inanimate features of human construction. Buildings and head stones that are constructed from limestone are easily attacked by acids, as are structures that are constructed of iron or steel. Paint on cars can react with acid deposition causing fading. Many of the churches and cathedrals in Europe are under attack from the effects of acidic deposition.

2.4 Effects of Air Pollution on Human Health

After the previous introduction of air pollution and air pollutants we must talk about the effects of this on the human and on our planet . The human health effects of poor air quality are far reaching, but principally affect the body's respiratory system and the cardiovascular system. Individual reactions to air pollutants depend on the type of pollutant a person is exposed to, the degree of exposure, the individual's health status and genetics. People who exercise outdoors, for example, on hot, smoggy days increase their exposure to pollutants in the air.

The health effects caused by air pollutants may range from subtle biochemical and physiological changes to difficulty breathing, wheezing, coughing and aggravation of existing respiratory and cardiac conditions. These effects can result in increased medication use, increased doctor or emergency room visits, more hospital admissions and even premature death.

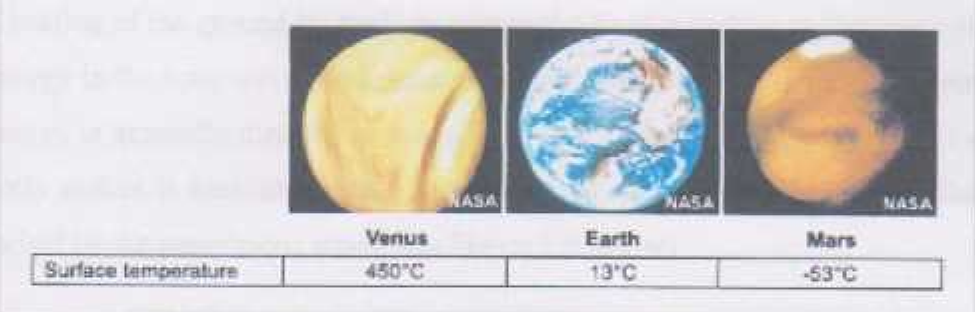
2.4.1: Human Respiratory System

The health of our lungs and entire respiratory system is affected by the quality of the air we breathe. In addition to oxygen, this air contains other substances such as pollutants, which can be harmful. Exposure to chemicals by inhalation can negatively affect our lungs and other organs in the body. The respiratory system is particularly sensitive to air pollutants because much of it is made up of exposed membrane. Lungs are anatomically structured to bring large quantities of air (on average, 400 million liters in a lifetime) into intimate contact with the blood system, to facilitate the delivery of oxygen.

Lung tissue cells can be injured directly by air pollutants such as ozone, metals and free radicals. Ozone can damage the alveoli the individual air sacs in the lung where oxygen and carbon dioxide are exchanged. More specifically, airway tissues which are rich in bio-activation enzymes can transform organic pollutants into reactive metabolites and cause secondary lung injury. Lung tissue has an abundant blood supply that can carry toxic substances and their metabolites to distant organs. In response to toxic insult, lung cells also release a variety of potent chemical mediators that may critically affect the function of other organs such as those of the cardiovascular system. This response may also cause lung inflammation and impair lung function.

2.5 Green House Effect (Global Warming)

The greenhouse effect is a naturally occurring process that aids in heating the Earth's surface and atmosphere. It results from the fact that certain atmospheric gases, such as carbon dioxide, *water vapor*, and methane, are able to change the energy balance of the planet by absorbing long wave radiation emitted from the Earth's surface. Without the greenhouse effect life on this planet would probably not exist as the average temperature of the Earth would be a chilly -18° Celsius, rather than the present 15° Celsius. See figure 2.7.



	Venus	Earth	Mars
Surface temperature	450°C	13°C	-53°C

Figure 2.7: Comparison Between the Plant Earth Venues and Mars

As energy from the sun passes through the atmosphere a number of things take place. A portion of the energy (26 % globally) is reflected or scattered back to space by clouds and other atmospheric particles. About 19 % of the energy available is absorbed by clouds, gases (like ozone), and particles in the atmosphere. Of the remaining 55 % of the solar energy passing through the Earth's atmosphere, 4 % is reflected from the surface back to space. On average, about 51 % of the sun's radiation reaches the surface. This energy is then used in a number of processes, including the heating of the ground surface; the melting of ice and snow and the evaporation of water; and plant photosynthesis.[5]

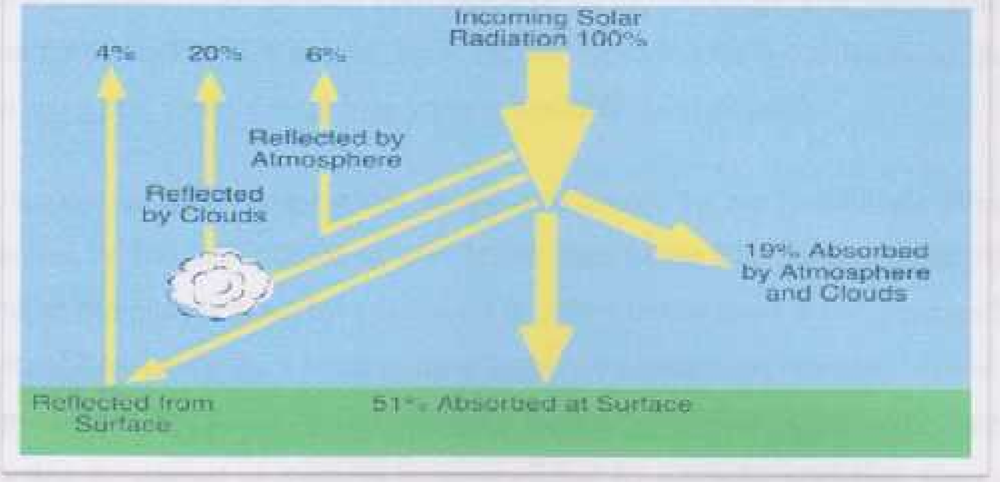


Figure 2.8: The Percentage of all the Sunlight.

The heating of the ground by sunlight causes the Earth's surface to become a radiator of energy in the long wave band (sometimes called infrared radiation). This emission of energy is generally directed to space. However, only a small portion of this energy actually makes it back to space. The majority of the outgoing infrared radiation is absorbed by the greenhouse gases (see Figure 2.9 below).

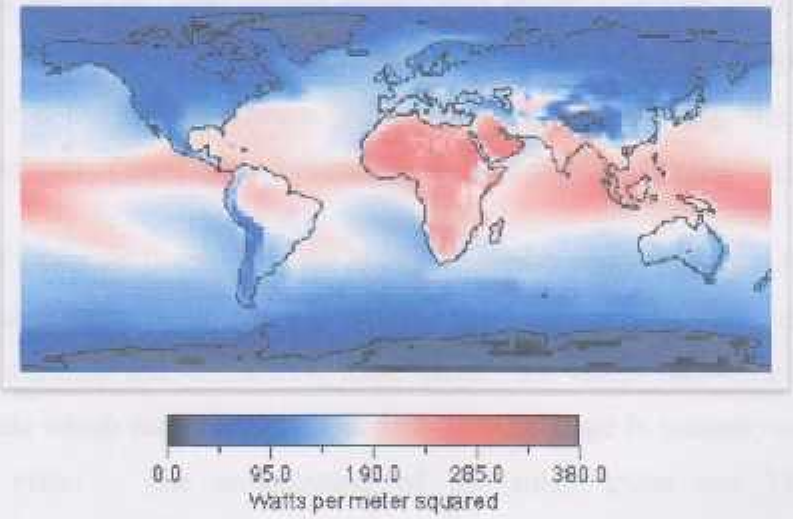


Figure 2.9: Annual (1987) quantity of outgoing long wave radiation absorbed in the atmosphere.

Absorption of long wave radiation by the atmosphere causes additional heat energy to be added to the Earth's atmospheric system. The now warmer atmospheric greenhouse gas molecules begin radiating long wave energy in all directions. Over 90 % of this emission of long wave energy is directed back to the Earth's surface where it once again is absorbed by the surface. The heating of the ground by the long wave radiation causes the ground surface to once again radiate, repeating the cycle described above, again and again, until no more long wave is available for absorption.

The amount of heat energy added to the atmosphere by the greenhouse effect is controlled by the concentration of greenhouse gases in the Earth's atmosphere. All of the major greenhouse gases have increased in concentration since the beginning of the Industrial Revolution. As a result of these higher concentrations, scientists predict that the greenhouse effect will be *enhanced* and the Earth's climate will become warmer. Predicting the amount of warming is accomplished by computer modeling. Computer models suggest that a doubling of the concentration of the main greenhouse gas, carbon dioxide, may raise the average global temperature between 1 and 3° Celsius. However, the numeric equations of computer models do not accurately simulate the effects of a number of possible negative feedbacks. For example, many of the models cannot properly simulate the negative effects that increased cloud cover would have on the radiation balance of a warmer Earth. Increasing the Earth's temperature would cause the oceans to evaporate greater amounts of water, causing the atmosphere to become cloudier. These extra clouds would then reflect a greater proportion of the sun's energy back to space reducing the amount of solar radiation absorbed by the atmosphere and the Earth's surface. With less solar energy being absorbed at the surface, the effects of an enhanced greenhouse effect may be counteracted.

A number of gases are involved in the human caused enhancement of the greenhouse effect (see table 2.1). These gases include :carbon dioxide ;methane ; nitrous oxide ;chlorofluorocarbons and ozone . Of these gases , the single most important gas is carbon dioxide which accounts for about 55% of the change in intensity of the Earth's greenhouse effect . The contribution of the other gases are 25% for the chlorofluorocarbons, 15% for methane and 5% for nitrous oxide . Ozone's contribution to the enhancement of greenhouse effect is still yet to be qualified .

Average concentration of atmospheric carbon dioxide in the year 2005 were about 380 parts per million(see figure 2.10)

Changing Content of Carbon Dioxide in the Earth's Atmosphere

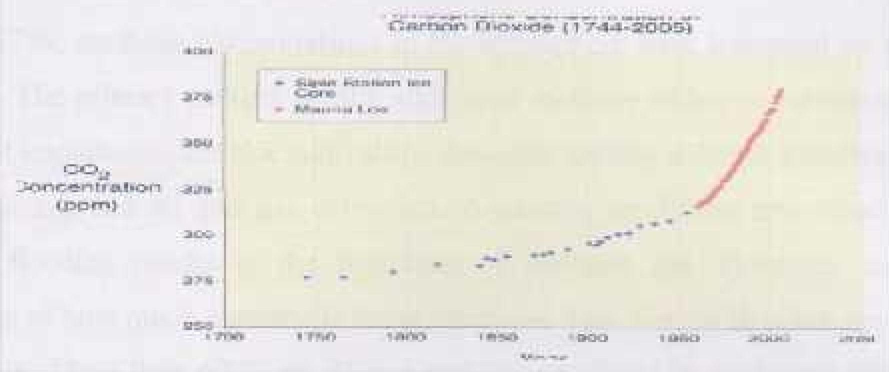


Figure 2.10: The following graph illustrates the rise in atmospheric carbon dioxide from 1744 to 2005.

Prior to 1700, levels of carbon dioxide were about 280 parts per million. This increase in carbon dioxide in the atmosphere is primarily due to the activities of humans. Beginning in 1700, societal changes brought about by the Industrial Revolution increased the amount of carbon dioxide entering the atmosphere. The major sources of this gas include fossil fuel combustion for industry, transportation, space heating, electricity generation and cooking; and vegetation changes in natural prairie, woodland, and forested ecosystems. Emissions from fossil fuel combustion account for about 65 % of the extra carbon dioxide now found in our atmosphere. The remaining 35 % is derived from deforestation and the conversion of prairie, woodland, and forested ecosystems primarily into agricultural systems. Natural ecosystems can hold 20 to 100 times more carbon dioxide per unit area than agricultural-systems.[5]

Artificially created chlorofluorocarbons are the strongest greenhouse gas per molecule. However, low concentrations in the atmosphere reduce their overall importance in the *enhancement* of the greenhouse effect. Current measurements in the atmosphere indicate that the concentration of these chemicals may soon begin declining because of reduced emissions. Reports of the development of ozone holes over the North and South Poles and a general decline in global stratospheric ozone levels over the last two decades has caused many nations to cut back on their production and use of these chemicals. In 1987, in the signing of the Montreal protocol agreement by forty-six nations established an immediate timetable for the global reduction of chlorofluorocarbons production and use.

Since 1750, methane concentrations in the atmosphere have increased by more than 150 %. The primary sources for the additional methane added to the atmosphere (in order of importance) are rice cultivation, domestic grazing animals, termites, landfills, coal mining, and oil and gas extraction. Anaerobic conditions associated with rice paddy flooding results in the formation of methane gas. However, an accurate estimate of how much methane is being produced from rice paddies has been difficult to obtain. More than 60 % of all rice paddies are found in India and China where scientific data concerning emission rates are unavailable. Nevertheless, scientists believe that the contribution of rice paddies is large because this form of crop production has more than doubled since 1950. Grazing animals release methane to the environment as a result of herbaceous digestion. Some researchers believe the addition of methane from this source has more than quadrupled over the last century. Termites also release methane through similar processes. Land-use change in the tropics, due to deforestation, ranching, and farming, may be causing termite numbers to expand. If this assumption is correct, the contribution from these insects may be important. Methane is also released from landfills, coal mines, and gas and oil drilling. Landfills produce methane as organic wastes decompose over time. Coal, oil, and natural gas deposits release methane to the atmosphere when these deposits are excavated or drilled.

The average concentration of Nitrous oxide in the atmosphere is now increasing at a rate of 0.2 to 0.3 % per year. Sources for this increase include land-use conversion; fossil fuel combustion; biomass burning; and soil fertilization. Most of the nitrous oxide added to the atmosphere each year comes from deforestation and the conversion of forest, savanna and grassland ecosystems into agricultural fields and rangeland. Both of these processes reduce the amount of nitrogen stored in living vegetation and soil through the decomposition of organic matter. Nitrous oxide is also released into the atmosphere when fossil fuels and biomass are burned. However, the combined contribution of these sources to the increase of this gas in the atmosphere is thought to be minor. The use of nitrate and ammonium fertilizers to enhance plant growth is another source of nitrous oxide. Accurate measurements of how much nitrous oxide is being released from fertilization have been difficult to obtain. Estimates suggest that the contribution from this source may represent from 50% to 0.2 % of Nitrous oxide added to the atmosphere annually. Ozone's role in the enhancement of the greenhouse effect has been difficult to determine scientifically. Accurate measurements of past long-term (more than 25 years in the past) levels of this gas in the atmosphere are currently unavailable. Concentrations of ozone gas are found in two different regions of the Earth's atmosphere. The majority of the ozone (about 97 %) found in the atmosphere is localized in the stratosphere at an altitude of 15 to 55 kilometers above the Earth's surface. In recent years, the concentration of the stratospheric ozone has been decreasing because of the buildup of chlorofluorocarbons in the atmosphere. Since the late 1970s, scientists have discovered that total column ozone amounts over Antarctica in the springtime have decreased by as much as 70 %. Satellite measurements have indicated that the zone from 65° North to 65° South latitude has had a 3 % decrease in stratospheric ozone since 1978. Ozone is also highly concentrated at the Earth's surface. Most of this ozone is created as an artificial by product of photochemical smog.[5]Table 2.1: Gases involved in the Greenhouse Effect: past and present concentration and sources.

Greenhouse Gas	Concentration 1750	Concentration 2003	Percent Change	Natural and Anthropogenic Sources
Carbon Dioxide	280 ppm	376 ppm	34 %	Organic decay; Forest fires; Volcanoes; Burning fossil fuels; Deforestation; Land-use change
Methane	0.71 ppm	1.79 ppm	152 %	Wetlands; Organic decay; Termites; Natural gas & oil extraction; Biomass burning; Rice cultivation; Cattle; Refuse landfills
Nitrous Oxide	270 ppb	319 ppb	18 %	Forests; Grasslands; Oceans; Soils; Soil cultivation; Fertilizers; Biomass burning; Burning of fossil fuels
Chlorofluorocarbons (CFCs)	0	880 ppt	Not Applicable	Refrigerators; Aerosol spray propellants; Cleaning solvents
Ozone	Unknown	Varies with latitude and altitude in the atmosphere	Global levels have generally decreased in the stratosphere and increased near the Earth's surface	Created naturally by the action of sunlight on molecular oxygen and artificially through photochemical smog production

In summary, the ***greenhouse effect*** causes the atmosphere to trap more heat energy at the Earth's surface and within the atmosphere by absorbing and re-emitting long wave energy. Of the long wave energy emitted back to space, 90 % is intercepted and absorbed by greenhouse gases. Without the greenhouse effect the Earth's average global temperature would be -18° Celsius, rather than the present 15° Celsius. In the last few centuries, the activities of humans have directly or indirectly caused the concentration of the major greenhouse gases to increase. Scientists predict that this increase may ***enhance*** the greenhouse effect making the planet warmer. Some experts estimate that the Earth's average global temperature has already increased by 0.3 to 0.6° Celsius, since the beginning of this century, because of this enhancement. Predictions of future climates indicate that by the middle of the next century the Earth's global temperature may be 1 to 3° Celsius higher than today.[5]

CHAPTER THREE

AIR POLLUTION CONTROL

Air Pollution Control

This chapter talks about methods of air pollution control and how to reduce the emission of pollutants to the air, and talks about the project components.

3.1: Introduction

Air pollution control can be generally described as a "separation" technology. The pollutants, whether they are gaseous, aerosol, or solid particulate, are separated from a carrier gas, which is usually air. Separate these substances because, if don't, these pollutants may adversely affect our health and that of the environment. Primary importance is the effect of the pollutants on our respiratory system, where the impact is most noticeable.

Gaseous pollutants are compounds that exist as a gas at normal environmental conditions. Usually, "normal" is defined as ambient conditions. These gases may have, just moments before release, been in a liquid or even solid form. For the purposes of the air pollution device, however, the state they are in just prior to entering the control device is what is most important. Aerosols are finely divided solid or liquid particles that are typically under 0.5μm diameter. They often result from the sudden cooling (condensation) of a gaseous pollutant, through partial combustion, or through a catalytic effect in the gas phase. In the latter condition, a pollutant in the gas phase may combine to form an aerosol in the presence of, for example, a metal co-pollutant. Acid aerosols such as SO_3, for example, can form in the presence of vanadium particulate that may be evolved through the combustion of oil containing vanadium compounds. Solid metals in a furnace can sublime (change phase from solid directly to gaseous) in the heat of an incinerator, then cool sufficiently to form a finely divided aerosol.

3.2 The Main Processes of Removing Pollutants

There are six main processes by which a gaseous pollutant may be removed from an air stream. Table 3.1, taken from the EPA(Environmental Protection Agency) handbook, lists those processes with the advantages and disadvantages of using each one. The table may be used as a guide to determine which process may provide the best means of cleaning the air stream. Separation processes are used as a means of air pollution control for both particulate matter and gas. These processes essentially remove the pollutant from the carrier gas resulting in a cleaned gas stream. If the pollutant content of the cleaned stream meets the effluent emission standards, the cleaned stream can be discharged to the atmosphere. Absorption and adsorption are both diffusion separation processes that can be used to collect hazardous air pollutants. In the case of absorption, the pollutant is transferred to the solvent which then may need further treatment. Recovery of the solvent might be undertaken by distillation or by stripping the absorbed material from the Solvent. The problem of treating the waste material in the stream separated from the solvent remains. If the pollutant material has a value, adsorption may provide the means for the material to be more readily recovered. In the case of particulate matter, wet scrubbing collects the particles primarily through the mechanism of inertial impaction. Gaseous contaminants such as sulfur oxide, nitrogen oxide, or hydrochloric acid, if present along with the particulates, may be collected simultaneously by absorption. Many organic materials may be removed by condensation, which is essentially a diffusion operation. If a suitable coolant is available and the pollutant concentration is high enough, condensation can be very effective in recovering material that may be used again. For organic pollutants when the concentration is low or recovering the material is not desired, incineration can be used to convert the pollutant to carbon dioxide and water. For large emissions such as would be found in petroleum refineries the pollutant may be flared.

Table 3.1: Air Pollution Control Technologies.

Device	Inlet Conc. PPMV	Efficiency	Advantages	Disadvantages
Absorption	250	90%	Especially good for inorganic acid gasses	Limited applicability
	1000	95%		
	5000	98%		
Adsorption	200	50%	Low capital investment	Selective applicability
	1000	90-95%	Good for solvent recovery	Moisture and temperature constraints
	5000	98%		
Condensation	500	50%	Good for product or Solvent recovery	Limited applicability
	10000	95%		
Thermal incineration	20	95%	High destruction Efficiency	No organic can be recovered
	100	99%	Wide applicability Can recover heat energy	Capital intensive
Catalytic incineration	50	90%	High destruction Efficiency	No organic can be recovered
	100	>95%	Can be less expensive Than natural incineration	Technical limitations that can poison
Flare		>98%	High destruction Efficiency	No organic can be recovered Large emission only

3.2 Basic Mechanisms of Collection pollutants particles

Consider a particle in a gas stream moving toward or being carried toward a target. If the particle touches the target, it likely will stick to the target due to inter surface forces. The target may be a liquid droplet, as in the case of wet scrubbers, or a fiber, as in a fabric filter bag house. Three mechanisms by which the particle touches the target are illustrated in Figures (3.1-3.3). Small, medium, and large size particles are depicted as being carried by the gas stream toward round targets. The gas flow streamlines are shown as diverging as they approach the target, then moving around the target.

In each of these mechanisms, a large number of targets will increase the probability that a particle will touch a target. Therefore, having abundant targets enhances collection efficiency.

3.3.1 Basic Mechanism (Impaction, Interception and Diffusion)

The figure below shows the three mechanisms which are used for cleaning processes.

Figure 3.1: Impaction Process.

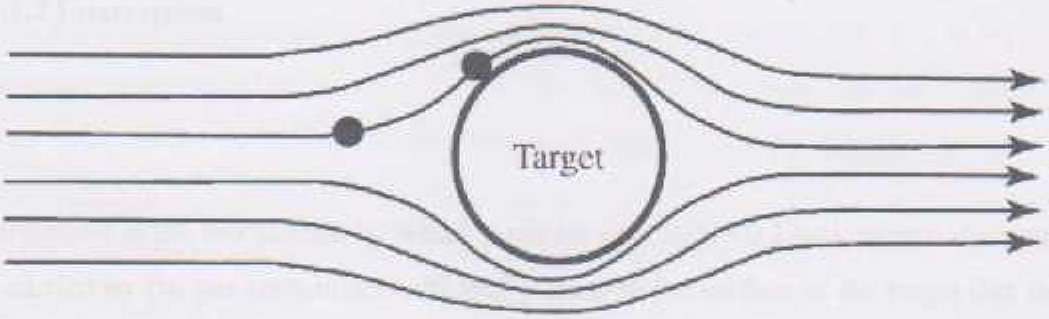


Figure 3.2: Interception Process.

Figure 3.3: Diffusion process.

3.3.1.1 Impaction

In the mechanism called impaction, large particles moving toward the target have mass, and therefore momentum, which causes each particle to travel in a straight line toward the target. The particle leaves the streamline as the streamline bends to move around the target. The greater the mass of the particle, the more likely that it will travel in a straight line. Also, as the velocity difference between the particle and the target increases, the particle will have increased momentum and will be more likely to be carried into the target. The radius of curvature of the bend in the streamline has a very important effect on the probability that a particle will be carried into the target. The smaller the radius of curvature, the less likely that a particle will follow the streamline. Therefore, small targets are more likely to be impacted than large targets.

3.3.1.2 Interception

Interception is the mechanism by which particles of roughly 0.1 to 1 micron diameter are carried by the gas streamline sufficiently close to the surface of the target that the particle touches the target. These particles have insufficient inertia to leave the gas streamline and are carried with the streamline. Some gas will flow very close to the particle. Interception is a relatively weak mechanism for particle collection compared to impaction and, as discussed in the next section, diffusion. It is coincidental that the Path of the streamline and the particle happens to be close to the target. It is for this reason that particles in this size range are difficult to collect compared to larger and smaller particles. For the same reason, particles in this size range are not collected by natural cleaning mechanisms in nasal and trachea bronchial passages, and enter the lungs where they can lodge in the alveoli.

3.3.1.3 Diffusion

Diffusion of extremely small, submicron particles is a result of Brownian motion. These particles are so small that the mass of the particles is very small and the number of collisions with air molecules is low. Therefore, random collisions with air molecules cause the particle to bounce around. They are moved from one gas streamline to the next by random motion. If sufficient time is allowed, and if the distance to the target is small, then diffusion can be an effective collection mechanism. This is why fabric filter bag houses can be effective for collecting submicron particles, and why it is difficult for wet venture scrubbers to collect these particles.

In our project the impaction mechanism will be used for the separation process to get rid of the pollutants.

3.4: Collection Mechanisms and Particle Size

When a gas stream containing particulates flows around a small object such as a water droplet or a sheet of water, the inertia of the particles causes them to move toward the object where some of them will be collected. This phenomenon is known as inertial impaction, which customarily describes the effects of small-scale changes in flow direction. Because inertial impaction is effective on particles as small as a few tenths of a micrometer in diameter, it is the most important collection mechanism for wet scrubbers. Since this mechanism depends upon the inertia of the particles, both their size and density are important in determining the efficiency with which they will be collected. All important particle properties may be lumped into one parameter, the aerodynamic impaction diameter which can be calculated from the actual particle diameter by the following relationship:[1]

$$d_{ap} = d_p (p_p C^{/})^{1/2} \tag{3.1}$$

Where:

d_{ap}: aerodynamic impaction diameter in μm.gms/cm^3.

d_p : physical diameter in μm.

ρ_p: density of particle in gms/cm.

C': Cunningham's correction factor.

By a fortunate circumstance, most methods for measuring particle size determine the aerodynamic impaction diameter. The Cunningham correction factor is given by the following formulas:[1]

$$c' = 1 + \frac{2\lambda}{d_p}\left[1.257 + 0.400 \exp -\left(\frac{0.55 d_p}{\lambda}\right)\right] \tag{3.2}$$

$$\lambda = \frac{\mu}{0.499\rho_g}\sqrt{8RT/\pi MW} \tag{3.3}$$

Where:

λ : mean free path of the gas in m.

d_p : diameter of particle in m.

μ : gas viscosity in N-s/m^2or kg/m-s.

MW : mean molecular weight of the gas.

ρ_g : gas density in kg/m^3.

R : universal gas constant (8.3144 J/kg-mol-K).

T : gas temperature in K.

For air at room temperature and pressure, Equation (3.4) is a good approximation of C':[1]

$$C' = 1.0 + \frac{0.16}{d_p} \tag{3.4}$$

Knowing the value of the mean free path of molecules at a given temperature and pressure, the mean free path at other conditions can be calculated from Equation (3.5):[1]

$$\lambda = \lambda_0 \left(\frac{\mu}{\mu_0} \right) \left(\frac{T}{T_0} \right)^{1/2} \left(\frac{P_0}{P} \right) \tag{3.5}$$

Where:

λ_0 =0.0653 µm for air at 23 c° and 1.0 atm.

μ_0, T_0, P_0 = viscosity, temperature, and pressure, respectively at the same conditions for which λ_0 is known.

3.5 devices for wet scrubbing.

The following figure shows different types of wet scrubbers which uses the principle of inertial impaction.

- Spray Tower:

  In this mechanism there are two currents the first is the dirty gas and the second is the droplets of water and they are oppose each other , and as the gas flows up it will contact with water droplets which is sufficiently large to make the separation process.

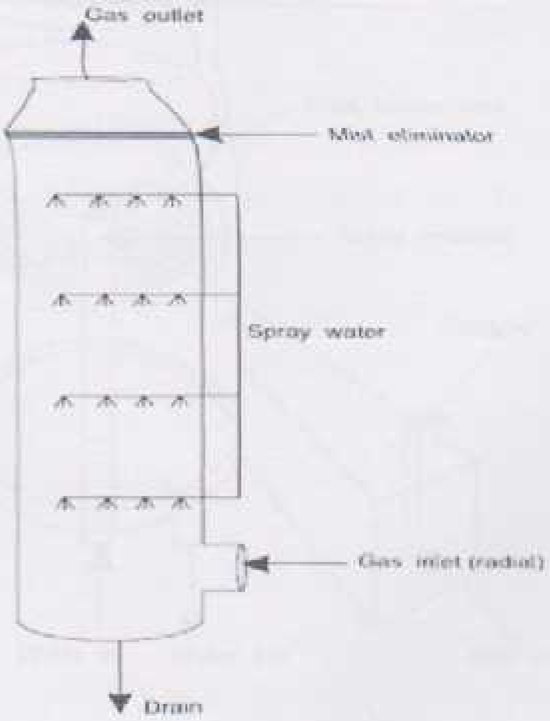


Figure 3.4: Spray Tower.

- Countercurrent vertical tower.
- Droplets sufficiently large so that the settling velocity is greater than the upward gas velocity
- Droplet size controlled to optimize particle contact and to provide easy droplet Separation.

❖ Cyclonic Spray Tower:

Here another type of wet scrubber , in this mechanism the forces of collision is increased because the gas enters the tower in cyclic way which is very effective in collection of particles less than 10 μm .

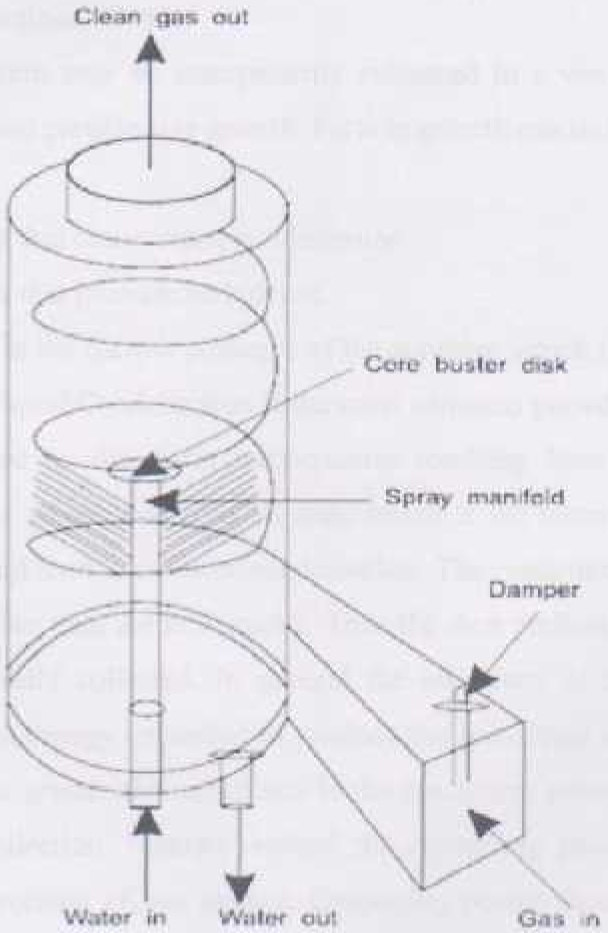


Figure 3.5: Cyclonic Spray Tower.

- Gas is introduced tangentially which increases the forces of collision and relative velocity of the droplets and gas stream
- Well designed cyclonic spray towers greatly increase the collection of particles smaller than 10 μm when compared to simple countercurrent spray towers .
- Droplets produced by spray nozzles
- Droplets collected by centrifugal force

Two types: (1) spinning motion imparted by tangential entry, (2) spinning motion produced by fixed vanes.

In order to capture fine particles, greater energy must be expended on the gas. There are two ways to do this:

1. Increase the gas pressure
2. Atomize large quantities of water

Efficiency of collection may be unexpectedly enhanced in a wet scrubber through methods that will cause particle size growth. Particle growth can be brought about by:

- Lower temperatures that cause vapor condensation.
- Increased flow rates that increase turbulence.
- Thermal gradients in the narrow passages of the scrubber which increases diffusion of particles into the liquid Condensation is the most common growth mechanism. The hot gasses are cooled by the lower temperatures resulting from contact with the scrubbing liquid. The gasses may also be compressed in the narrow passages of the scrubber, which would tend to enhance condensation. The condensation occurs on the existing particles rather than the new nuclei. Thus the dust particles will grow larger and will be more easily collected. In general the efficiency of a wet scrubber is directly related to the energy expended to produce the gas–liquid contact. The more energy expended, the greater the turbulence in the contacting process and the higher the efficiency of collection. Semrau defined the *contacting power* as the energy dissipated per unit volume of gas treated. Contacting power should be determined from the friction loss across the wetted portion of the scrubber. Pressure losses due to the gas stream kinetic energy should not be included. However, energy provided by

the mechanical devices along with the energy provided by the gas and liquid are part of the contacting power. Semrau treated scrubber efficiency by relating the number of transfer units to the contacting power as follows:[1]

$$N_t = \alpha p_t^{\beta} \tag{3.6}$$

where:

N_t: number of transfer units, dimensionless

P_t: contacting power, hp/1000 cfm or kWh/1000 m^3.

A: coefficient to make N_t dimensionless.

β : dimensionless exponent.

The overall efficiency ζ_o, of the scrubber can be calculated from the following equation:[1]

$$\zeta_0 = 1 - \exp(-N_t) \tag{3.7}$$

- Self-induced Spray Tower:

  The particles are collected here in a pool of water by impinges air on a liquid surface and then a series of baffles to change the direction of the gas and then to the outlet some water droplets are carried with the stream but return back by gravity.

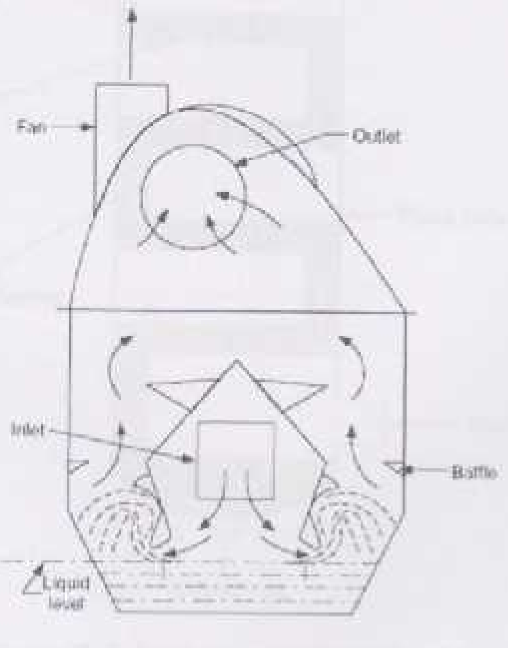


Figure 3.6: Self-induced Spray Tower.

- Air impinges on a liquid surface then on a series of baffles,
- Particles are initially captured in pool of water by direct interception or inertial Impingement,
- Some water is atomized into spray droplets which aids collection,
- A final change in gas direction, or by baffles, serves as an entrainment separator,
- The water circulation rate is low, and water is primarily required to replace evaporation losses,
- Droplets are formed by breaking through a sheet of liquid or by impinging on a pool of water,
- Droplets collected by gravity attraction.,

❖ Impingement Plate Scrubber:

Also in this mechanism or scrubber the gas are impinges with plates that water are flows over in it then reach to the entrainment separator then to the outer

Figure 3.7: Impingement Plate Scrubber.

- Venture Scrubber:

The gas here enters a throat then its velocity will increase and the pressure will decrease and water sprayed in this throat causing the scrubbing process

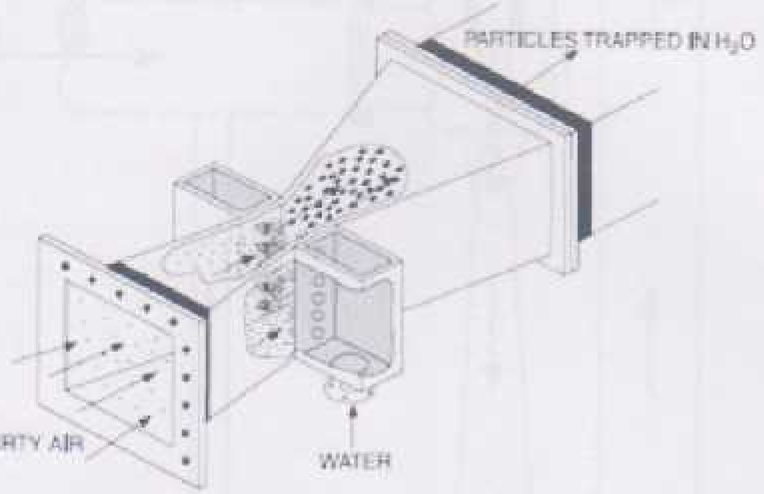


Figure 3.8: Venture Scrubber.

- Gas accelerated at throat,
- Atomized water droplets added at throat as a spray or jet, collect particles,
- Can be combined with a cyclonic collector to disengage water droplets from air Stream,
- Has a large pressure drop,

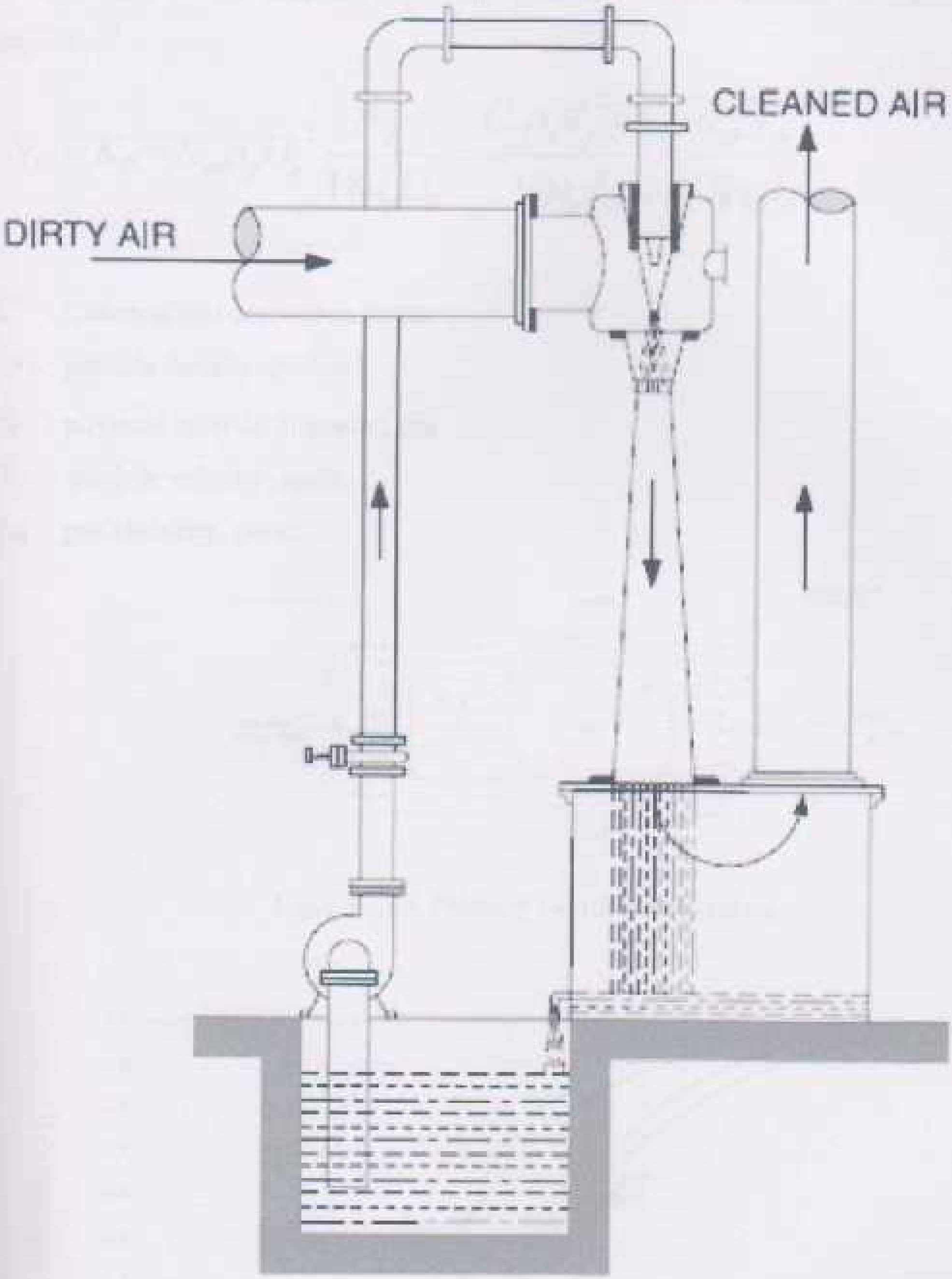


Figure 3.9: Venture Jet Scrubber.

Inertial impaction is depicted in figure 3.9, primary capture mechanism. In this case of inertial impaction, a particle is carried along by the gas stream. Approaching the collecting body which is a water droplet in the case of a spray scrubber, the particles tend to follow the streamlines. However, for many particles, their inertia will result in the particle separating from the gas stream and striking the water droplet. The result is for the water droplet to collect the particle. The separation number in figure 3.9, N_{SI} , is the same as the inertial impaction parameter, Kp , defined by the following equation:[1]

$$N_{SI}=K_P=K_m\rho_p D_p{}^2\,\frac{V_p}{18\mu_g D_B}=\frac{C'\rho_p d_p{}^2 V_p}{18\mu_g d_d}=\frac{d_{ap}{}^2 V_p}{18\mu_g d_d} \qquad (3.6)$$

C' : Cunningham correction factor

ρ_P : particle density, gm/cm^3

d_P : physical particle diameter, cm

V_P : particle velocity, cm/s.

μg : gas viscosity, poise.

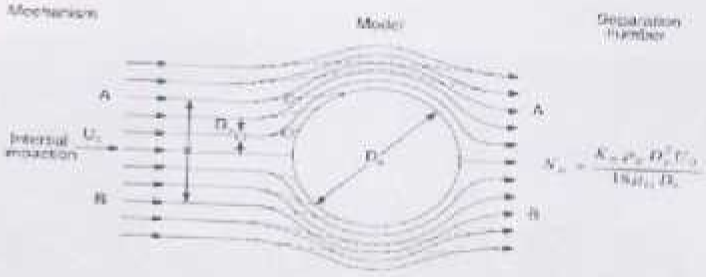


Figure 3.10: Primary capture mechanism.

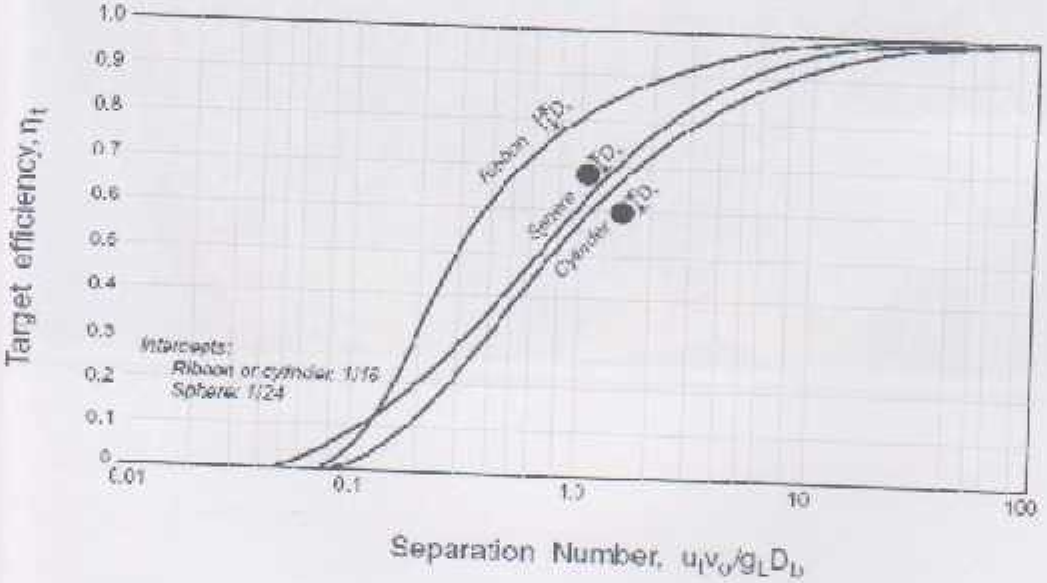


Figure 3.11: Single-droplet target efficiency for ribbons, spheres, and cylinders.

CHAPTER FOUR

MATHEMATICAL MODELING

Mathematical Modeling

4.1 Centrifugal fan

A fan crates air flow by converting mechanical work into air kinetic energy. Two basic types of fan are centrifugal and axial, in this project we use the centrifugal type because of its characteristics. Air enters a centrifugal fan axially and exit radially. Air enters an axial fan axially and exit axially .

Centrifugal fan blades can be :
Forward, radial or backward as in the figure below :

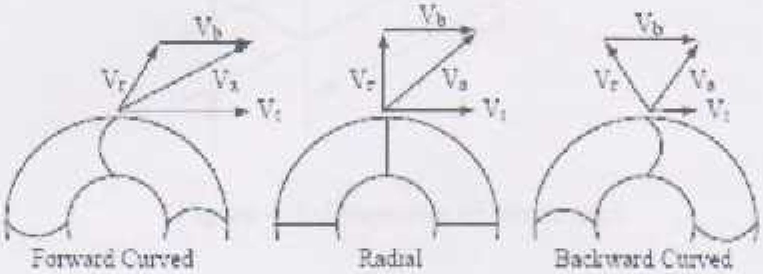


Figure :4.1Centrifugal fan blades.

Velocity vectors (V_b, V_r, V_a, V_t)

Where :

V_b :blade tip velocity .

V_r :fluid velocity relative to the blade.

$V_a : V_r + V_b$ = actual fluid velocity .

V_t ;tangential velocity component of the fluid velocity .

β : blade angle .

The selection of the fan in this project (which used to force the smoke to flow through the tank) was on the basis of the fan pressure greater than the pressure of the water found in the reservoir.

The pressure force inside the tank on the maximum level of the water :

In the experiment the maximum level of the water will be 40 cm .

The figure below shows the dimensions of the water tank .

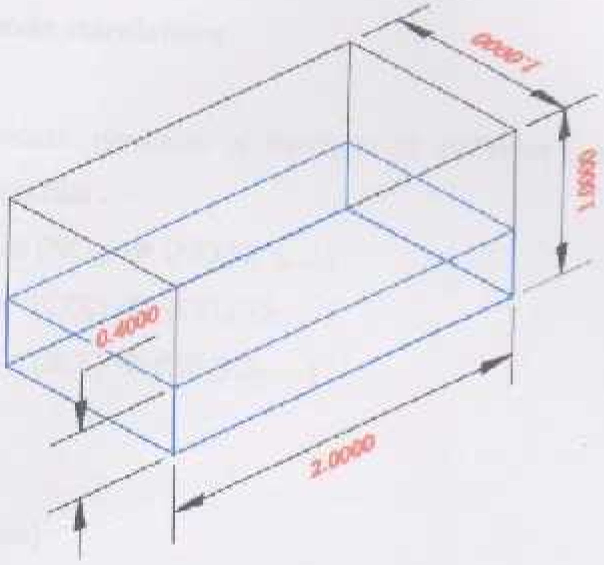


Figure 4.2:dimension of water tank.

$$P_w = \frac{F_w}{A_w} \tag{4.1}$$

$$F_w = mg \Rightarrow m = \rho_{water} \cdot V_w \tag{4.2}$$

Where :

P: static pressure.

F:static force.

V:volume of water.

ρ : density of water.

m: mass of water.

$$m_w = (2)\cdot(1)\cdot(0.4)\cdot(1000) = 800 \ kg$$

$$F_W = (800).(9.81) = 7848 \ N$$

$$P_w = \frac{7848}{(2).(1)} = 3924 \ Pa$$

as mentioned above the fan required can be selected so as its pressure is greater than the water pressure :

Table 4.1: characteristics of centrifugal fan.

Type	working point (Pa)	volumetric flow (m^3/h).
Centrifugal (backward)	4200	2000

4.2 Combustion process calculations

The combustion process produces a mixture of different gases and harmful environmental pollutant like :

- Nitrogen oxides (NO_x) ➔ ($NO, NO_2, \ldots$)
- Carbon oxides (CO_x) ➔ ($CO, CO_2, \ldots$)
- Sulfur oxides (SO_x) ➔ ($SO, SO_2, \ldots$)
- VOCS
- H_2O
- HAP(Air Toxics)

This mixture is forced to enter the water tank by fan, the measurement process begins after few minutes to make sure that we have steady flow for the gas, then we can measure the percentage of these gases before entering the tank, after entering the tank the mixture hits the surface of the water and flow through it This is causing an interaction between mixture and water so a new mixture is resulted with a new properties with acceptable percentage because some of these gases react with water and melts in it as:

$$CO_2 + H_2O \rightarrow H_2CO_3 \quad (4.2)$$

$$SO_2 + H_2O \rightarrow H_2SO_3 \quad (4.3)$$

In addition of solid particles which transferred and suspended with water droplets.

4.2.1Concentration of particles in the gas

The following example shows how to calculate the concentration of particles in the gas and efficiency of scrubbing theoretically.

Suppose that space has the following dimensions: $(\Delta x, \Delta y, \Delta z)$

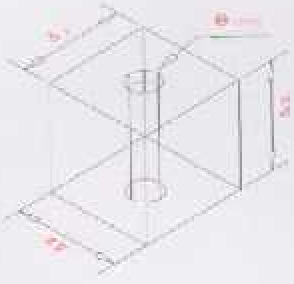


Figure 4.3: the supposed space

The concentration of the particles in the gas in this space is :

C [kg/ m^3].

- Then select a water droplet its diameter is D_0 , Then to calculate how many particles are suspended to this water droplet we must use the equations below :

$$V swept\ by\ one\ drop = \frac{\Pi}{4} D^2{}_D \Delta Z \tag{4.4}$$

- Mass of particles transferred from the gas to the droplet is :

M trans. one droplet = $V_{swept} * c * \tau_t$

$$= \frac{\Pi}{4} D^2{}_D \Delta Z . c . \tau_t \tag{4.5}$$

- To calculate the particles concentration when it passes the selected space $(\Delta x, \Delta y, \Delta z)$.

ND ➔drops / time , equal equation no.2 with the rate of change in concentration

$$\frac{dc}{dt} = \frac{-\frac{\Pi}{4}(D^2{}_b \Delta Z . C\tau_t)}{\Delta x\, \Delta y\, \Delta z}$$

$$\frac{dc}{dt} = -\frac{\pi}{4} D^2{}_D . C . \tau_t \left(\frac{N_D}{\Delta x \Delta y} \right) . \frac{\frac{\pi}{6} D^3{}_D}{\frac{\pi}{6} D^3{}_c}$$

$$\frac{dc}{dt} = -1.5 \frac{C . \tau_t}{D_D} \left(\frac{N_D \left(\frac{\pi}{6}\right) \left(D^3{}_D\right)}{\Delta x \Delta y} \right)$$

Then :

$$\frac{dc}{dt} = -1.5 C . \frac{\tau_t}{D_D} . \frac{Q_L}{A} \qquad (4.6)$$

Where :

Q_L : total liquid volumetric flow [m^3/s].

A : horizontal area of the selected space.

$$\rightarrow \frac{dc}{dt} = -\frac{1.5}{D_D} \tau_t \frac{Q_L}{A} \Delta t$$

$$\rightarrow C = C_0 \exp - \left(\frac{1.5 \tau_t . Q_L . \Delta t}{D_0 A} \right)$$

τ_t :from figure 3.11

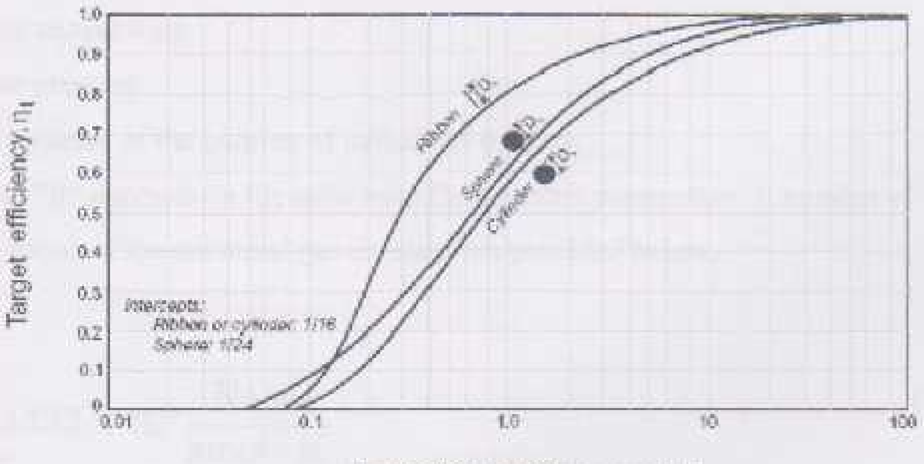


Figure 3.11: Single-droplet target efficiency for ribbons, spheres, and cylinders

4.3Gas flow calculations

The ideal gas law is one of the fundamental principles used in calculations involving gas flow in air pollution-related work. This law is used to calculate actual gas flow rates based on the quantity of gas present at standard pressures and temperatures. It is also used to determine the total quantity of a contaminant in a gas that can participate in a chemical reaction.

The ideal gas law summarizes many of the concepts. It states that the volume occupied by a gas is a function of these three parameters:

- Number of moles of gas
- Absolute temperature
- Absolute pressure

The ideal gas law is expressed using this standard equation:

$$V = \frac{nRT}{P} \quad or \quad PV = nRT \tag{4.7}$$

Where:

V : Volume

n : Number of moles

R : Universal gas constant

T : Absolute temperature

P : Absolute pressure

Moles is a measure of the number of molecules present.

The value of "R" depends on the units used for the other parameters. A number of equivalent forms of the universal gas constant are provided below.

$$R = 8.31432 \text{ x } 10^3 \frac{\mathrm{N \cdot m}}{\mathrm{kmol \cdot K}} \tag{4.8}$$

The ideal gas law is accurate as long as the pressures are relatively similar to normal ambient atmospheric pressures. This is almost always the case in air pollution-related work since the pressures usually range from -100 in. W.C. (absolute pressure of 307 in. W.C. at standard conditions) to approximately 50 in. W.C. (absolute pressure of 457 in. W.C. at standard conditions). This range of pressures is relatively small and does not extend to the pressures at which gases become compressible and the ideal gas no longer applies. The ideal gas law applies to mixtures of gases as well as to pure gases. Accordingly, it is very useful for evaluating gas stream properties.[10]

4.4 Calculation of Reynolds Number

Determine if the gas stream is laminar, transitional, or turbulent by calculating the Reynolds number for the gas stream: Laminar and Turbulent Flow When fluids such as gases are moving slowly, the bulk material moves as distinct layers in parallel paths as illustrated in Figure 4.4 (Laminar Flow). The only movement across these layers is the molecular motion, which creates viscosity. This is termed

- laminar flow

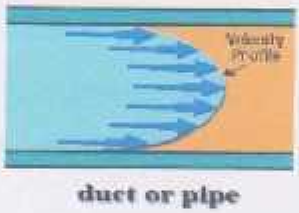


figure 4.4:Laminar flow

As the velocity of the gas stream increases, the bulk movement of the gas changes. Eddy currents develop which cause mixing across the flow stream. This is called turbulent flow, and it is essentially the only flow characteristic that occurs in air pollution control equipment and emission testing-related situations.

- Turbulent flow is illustrated.

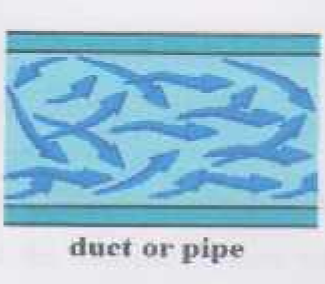


Figure 4.5:Turbulent flow.

A dimensionless parameter called the Reynolds number is used to characterize fluid flow. It is the ratio of the inertial force which is causing gas movement to the viscous force which is restricting movement. The Reynolds number is calculated using Equation (4.9). Consistent units must be used to ensure that the Reynolds number is dimensionless.

$$N_{Re(g)} = \frac{Lv\rho}{\mu} \tag{4.9}$$

L:Linear dimension (usually duct or pipe)

v :Fluid velocity

ρ :Fluid density

μ :Fluid viscosity

Table 4.2: Classification of Gas flow types[10]

Classification of Gas flow types			
Type gas flow	Laminar	Transitional	Turbulent
If Reynolds number is	<2000	Between 2000 and 4000	>4000

Reynolds numbers less than 2,000 are associated with laminar flow conditions. Due to the relatively low velocities associated with this type of flow, they are rarely encountered in air pollution field situations.

Reynolds numbers above 4000 are associated with turbulent flow. In many field situations, the Reynolds numbers exceed 100,000.

Between Reynolds numbers of 2,000 and 4,000 turbulent flow conditions have not fully developed. This is called the transitional flow range. Flow in this transitional range has characteristics of both laminar and turbulent flow.

- Calculation Reynolds number for the project

Assumption: we assume that all the gas entering the water tank is CO_2 and this because we did not know the formula of the rubber piece and the percentage of each gas.

$$N_{Re(g)} = \frac{Lv\rho}{\mu}$$

$v = 8m/s$: the velocity is measured by using special instrument called (pocket weather tracker).

$L = 10$ cm

ρ=1.58842 kg/m^3

μ=17.025*10^{-6}

Then by substituting in equation (4.9) Reynolds number is :

$N_{Re(g)} = 74639.4$

So according to Table (4.1) the flow is turbulent.

4.5 Henry's Law

Henry's law is a function of the type, temperature, and constituents of a liquid. Therefore, Henry's law can be used to determine the condition and type of liquid that will maximize the removal efficiency of pollutants.

Henry's law basically states that the amount (i.e. mole fraction) of a slightly soluble gas dissolved in a liquid is proportional to the partial pressure of the gas. The units for Henry's law constant are expressed in several forms using slightly different formulas. The idea and usefulness of Henry's law is the same. The most common form of the equation for Henry's law in the air pollution control field is given below.

For dilute solutions, the mass transfer equilibrium level for absorption is defined by Henry's law, which is shown in equation 1.

$$y^* = Hx \tag{4.10}$$

Where :

y^*: Mole fraction of pollutant in gas phase in equilibrium with liquid

H : Henry's law constant.

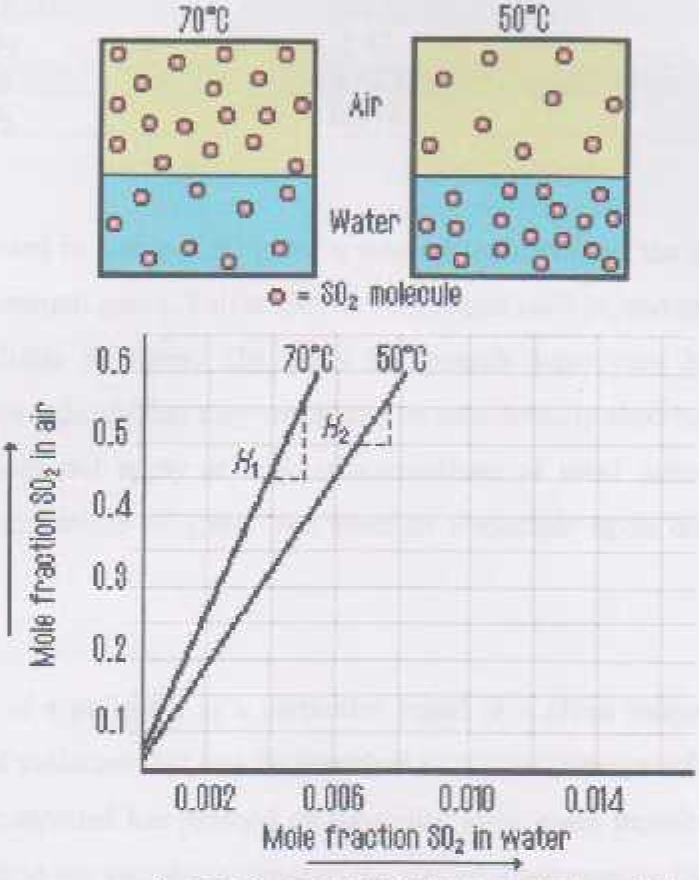
x : Mole fraction of pollutant in liquid phase .

Note: Using Equation (4.10) , the units for H are (mole fraction in gas/mole fraction in liquid). Sometimes Henry's law constant is also expressed in units of atm/mole fraction, 1/mole fraction, or m^3 atm/gm mole.

Equation (4.10) is the equation of a straight line that starts at the origin and has a slope of H. Henry's law can be used to predict solubility only when the equilibrium line is straight, which is the case when solute concentrations are very dilute. Most air pollution applications have relatively low pollutant (solute) concentrations; therefore, Henry's law is often applicable. If more than one gas is reacting with a liquid, Henry's law is applied to each gas individually.

Using the case of the pollutant, SO_2, being absorbed into water, Figure (4.4) illustrates the following points:

1. Henry's law applies at these concentrations of SO_2 in water (i.e. both lines are straight).
2. The Henry's law constants (H_1 and H_2) equal the values for the slopes of the two respective lines.
3. Liquid temperature affects the solubility of gases in liquids and therefore affects the value of Henry's law constant.



H_1 and H_2 are Henry's law constants, which equal the slopes of the two respective lines.

Figure 4.6: Henry's law solubility curve for SO_2- H_2O.

Henry's law constant provides a general indication of the differences in the solubility's of gases. The Henry's law constants for a variety of common gaseous compounds are provided in Table 4.2.

Table 4.3: Henry's law concentration for common gases in water.

Henry's law concentration for common gases in water

Gas	Henry's law constant , $H \times 10^5$ *atm/mole fraction*	
	$(20 \circ C)$	$(30 \circ C)$
N_2	80.4	92.4
CO	53.6	62.0
O_2	40.1	47.5
NO	26.4	31.0
CO_2	1.42	1.86
H_2S	0.483	0.609
SO_2	0.014	0.016

The data provided in Table (4.2) gives a general indication of the differences in the solubility of common gases. Sulfur dioxide, hydrogen sulfide, and carbon dioxide are moderately soluble in water. The other compounds have very high Henry's law constants, which indicate that they would not be substantially absorbed into water. Henry's law does not apply at high concentrations of most gases and at low-to-moderate concentrations of gases that react or dissociate upon entering the liquid phase.

The solubility of a pollutant in a particular liquid at a given temperature limits the quantity of that pollutant that can be absorbed in a given amount of the liquid. once the pollutant compound has reached its solubility limit, mass transfer backward from the liquid phase to the gas phase matches the rate of mass transfer from the gas phase to the liquid phase. However, this equilibrium limit can be removed by reacting the dissolved gas compound into a chemical form that cannot diffuse out of the liquid.

4.6 Gas Velocity:

Gas velocity is one of the fundamental design variables for ventilation systems and air pollution control equipment. Gas streams containing particulate are usually maintained at velocities of 3,000 to 4,500 ft/min in ductwork leading to particulate collectors to minimize particle deposition. The velocity of gas streams without particulate matter is often in the range of 1,500 to 3,000 ft/min. The gas velocities in air pollution control equipment are usually low to allow for sufficient time to remove the contaminants. For example, gas velocities through electrostatic precipitators are usually in the range of 2.5 to 6 ft/sec. The filtration velocities through pulse jet fabric filters are usually in the range of 2 to 10 ft/min. Variations in the gas velocity can have a direct impact on the contaminant removal efficiency.[10]

The average velocity of a gas stream in an emission testing probe, an industrial duct, or an air pollution control device is a function of the actual gas flow rate and the cross-sectional flow area.

$$V = Gas\,velocity = \frac{Gas\ flowrate,actual}{Area} \tag{4.11}$$

This is illustrated in Figure (4.5).

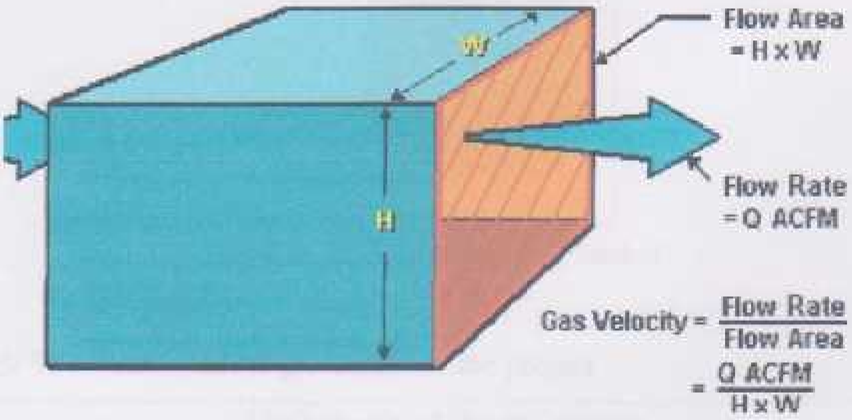


Figure 4.7: Gas velocity calculation based on the flow area and flow rate .

Units of Measure

The units of measure for velocity are provided below. These velocity units of measure are not corrected to standard oxygen or moisture levels because velocity is calculated based on actual conditions.

Table 4.4: Units of measure for velocity

Units of measure for velocity		
	Units for American Engineering system	Cgs system units
Actual velocity	ft/min ,ft/sec	m/min ,m/sec

In our project a measurement device has been used see figure 4.6 below :

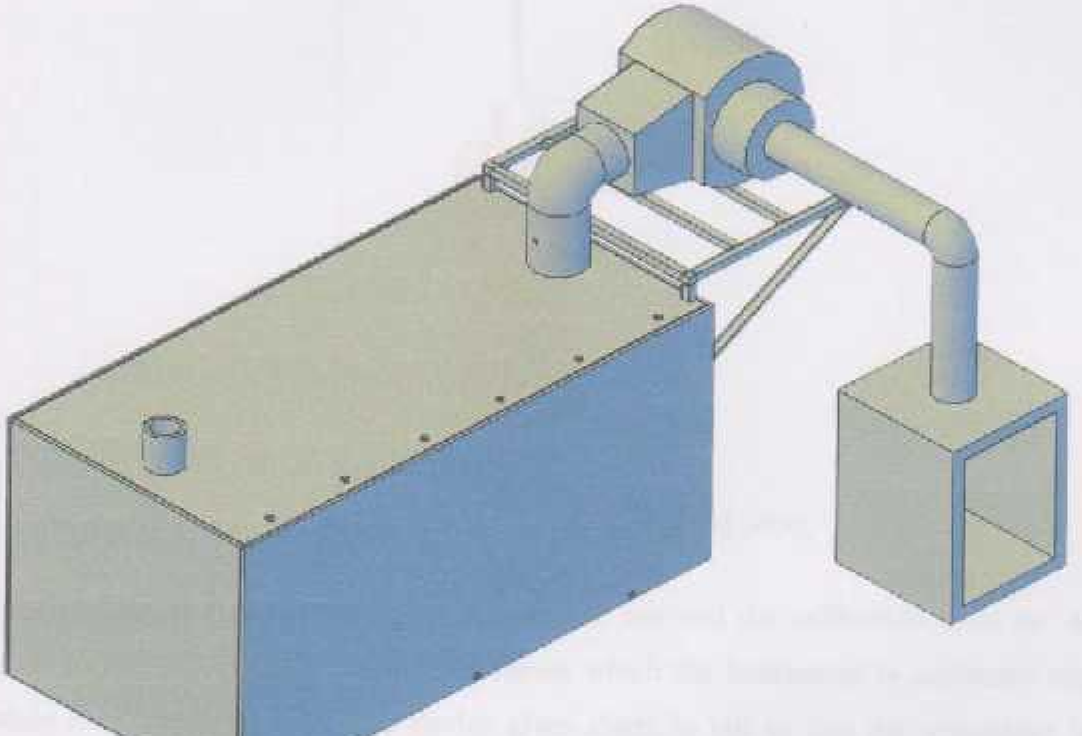
Figure 4.8:Pocket weather tracker

Table 4.5: The velocity of the gas stream of the project

The velocity of the gas stream	
Inlet (m/s)	Outlet (m/s)
8	2.3

CHAPTER FIVE

RESULTS AND CONCLUSION



Results and Conclusion

After the prototype have been designed we did a lot of experiments on it, by using vRAE instruments, gas analyzer and pocket weather tracker. The data which we collect will be shown as graphs to explain the reduction of percentage of each gases measured before and after the treatment process.

5.1: Measuring of NO_2,SO_2,NH_3,HCN

These gases are measured by Multi Gas Monitor PGM 7600 see figure (5.1):

Figure 5.1: Multi Gas Monitor PGM 3000.

This instrument must be calibrated before each use and the calibration must be at fresh air, table(5.1) below shows the values which the instrument is calibrated on; while measurement process the device gives alarm to tell us that the percentage is higher than the rated value but we must continue measuring according to data sheet. This device contains number of sensors for each gas and also a pump which takes a sample of the combustion gas and analyses it then display the percentage of the each gase on the screen.

Table 5.1: high & low level of alarm of vRAE instrument (MGM).

Gas type	NO_2	SO_2	NH_3	HCN	None
High alarm level	10	10	50	50	
Low alarm level	1	2	35	4.7	

Several experiments had been done and the following graph shows the percentage of gases before and after treatment :

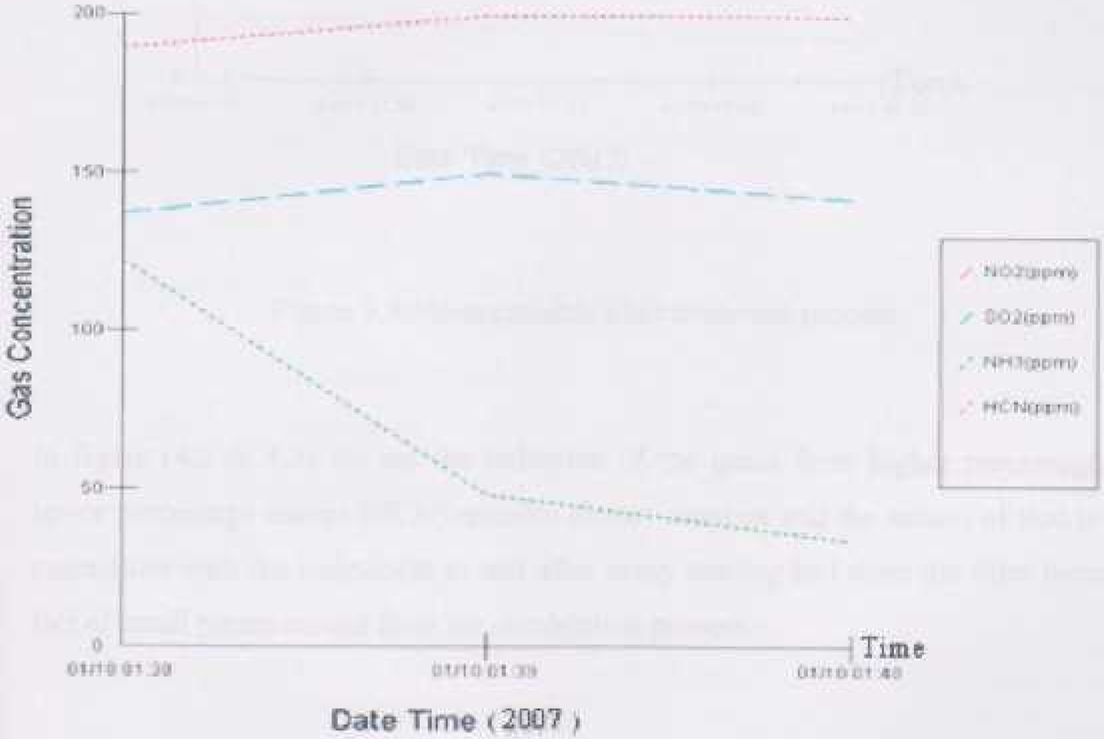


figure 5.2: Measurement before treatment process.

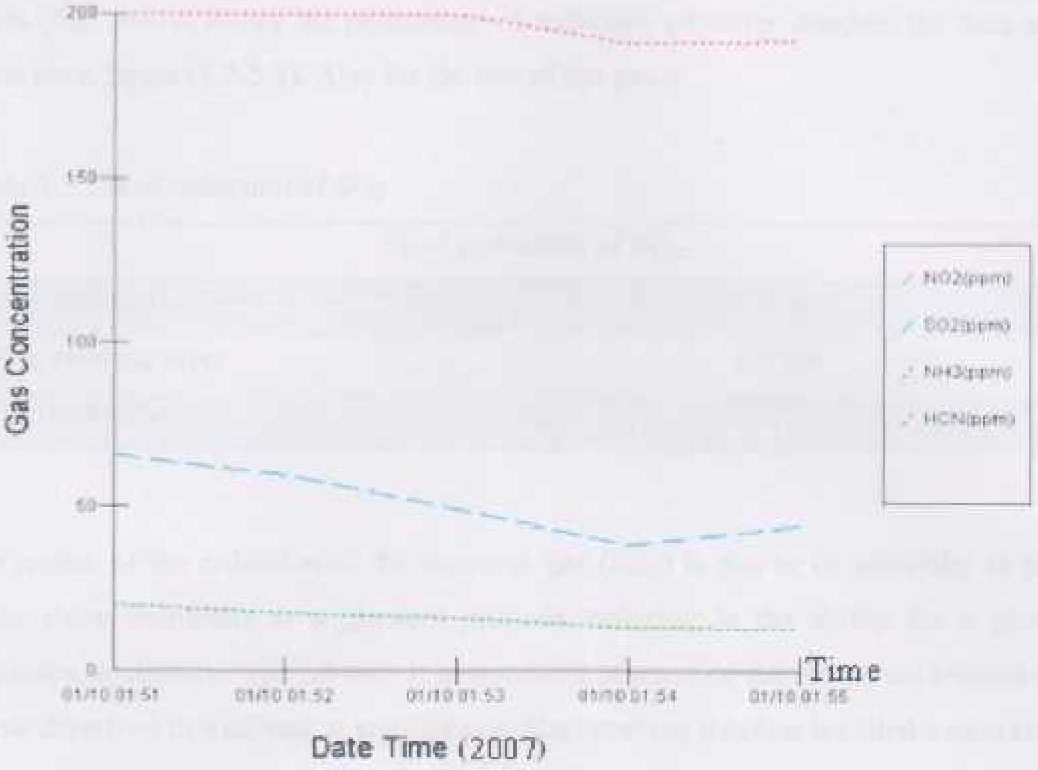


Figure 5.3:Measurements after treatment process.

In figure (4.2 & 4.3) we see the reduction of the gases from higher percentage to lower percentage except (HCN),remains almost constant and the reason of that is no spare filter with the instrument to and after many reading had done the filter became full of small pieces results from the combustion process.

5.1.1: The percentage of reduction of sulfur dioxide

Table (5.2) below shows the percentage of reduction of sulfur dioxide, the data are taken from figure (5.2-5.3), Also for the rest of the gases.

Table 5.2 : % of reduction of SO_2

% of reduction of SO_2	
Max reading before	152ppm
Max reading after	62ppm
% of reduction	60%

The reason of the reduction of the previous gas (SO_2) is due to its solubility in the water **since Solubility** is a physical property referring to the ability for a given substance, to dissolve in a solvent. It is measured in terms of the maximum amount of solute dissolved in a solvent at equilibrium. The resulting solution is called a saturated solution.

- **Factors Affecting Solubility** of any gas
  - Solute-Solvent Interactions.
  - Pressure Effects.
  - Temperature Effects .

→Effects of Pressure on Solubility:

The **solubility of a gas** in any solvent is increased as the pressure of the gas over the solvent increases.

Figure 5.4: Pressure of the gases over the solvent .

Henry's law states that the solubility of a gas in a liquid is directly proportional to the partial pressure of that gas above the liquid, which may be written as:

$$p = kc \tag{5.1}$$

where k is a temperature-dependent constant.

➔Effect of temperature on Solubility:

The temperature is one of the factors that affecting Solubility; the figure below shows that as the temperature increases the solubility decrease.

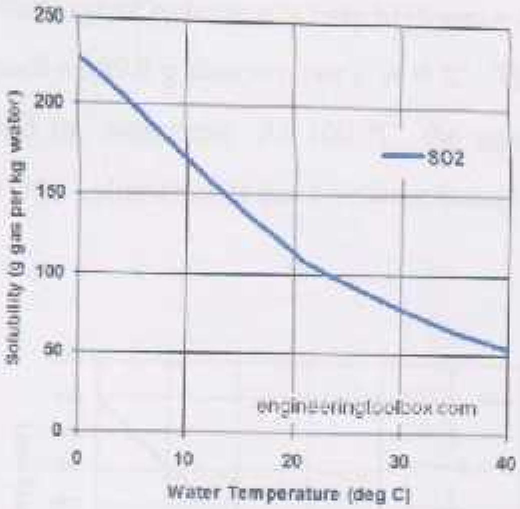


Figure 5.5: Solubility of SO_2 in water.

Sulfur dioxide is highly soluble in water. At room temperature, the dissolving process is exothermic:

SO_2(g) ---> SO_2(aq) DHo = -95.6 kJ (5.2)

At room temperature, the solubility of SO_2 is approximately 200 g SO_2/L. Thus, 1 mL of water could dissolve 76 mL SO_2! The solubility of SO_2 in water is highly temperature dependent and is about 400 times more soluble at 0 °C (228 g/L) than it is at 90 °C (5.8 g/L).[13]

5.1.2: The percentage of reduction of Ammonia

Table (5.3) below shows the percentage of reduction or NH_3, the data are taken also before and after the treatment process.

Table 5.3 : % of reduction of NH_3

% of reduction of NH_3	
Max reading before	145ppm
Max reading after	23ppm
% of reduction	85%

Here we see that the percentage of reduction is very high since Ammonia is extremely soluble in water. As much as 89.9 g dissolve per L at 0 °C. This means that 1 m_L of water will dissolve 1183 m_L ammonia! At 100 °C, the solubility drops to 7.4 g ammonia /100 m_L H_2O (113 volumes NH_3 per 1 volume water).[13]

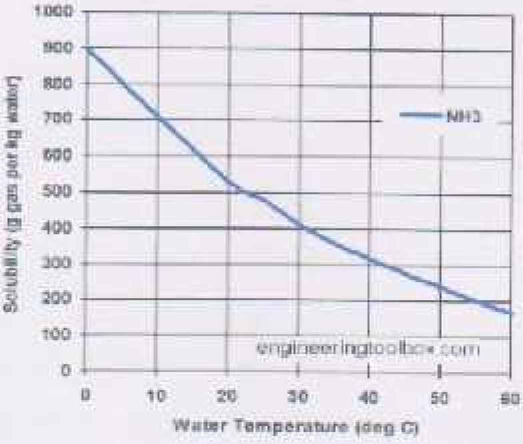


Figure 5.6:Solubility of NH_3 in water

5.1.3: The percentage of reduction of HCN

Table (5.4) below shows the percentage of reduction of hydrogen cyanide in ppm.

Table 5.4:% of reduction of HCN

% of reduction of HCN	
Max reading before	200ppm
Max reading after	198ppm
% of reduction	1%

A solution of hydrogen cyanide in water is called hydrocyanic acid, and it is completely miscible, but as we said before there was an error occurred in the instrument that make the reading very small, since the instrument needs to a special calibration.

→Note that the instrument didn't' gave any reading for the percent of NO_2.

5.2: Measuring of CO,H_2S,O_2,VOC and LEL

These gases are measured by EntryRAE PGM 3000see figure (5.4):

Figure 5.7:EntryRAE PGM 3000.

This instrument also must be calibrated before each use and the calibration must be at fresh air, the information below shows the values which the instrument is calibrated on; while measurement process the device gives alarm to tell us that the percentage is higher than the rated value but we must continue measuring according to data sheet. This device contains number of sensors for each gas and also a pump which takes a sample of the combustion gas and analyses it then display the percentage of the each gas on the screen.

This device is calibrated on the following values :

- Sensor Span Value:

CO(ppm) = 50
H_2S(ppm) = 10
OXY(%) = 20.9

LEL(%) = 50
VOC(ppm) = 100

- Sensor Low Alarm Limits:

CO(ppm) = 35
H_2S(ppm) = 10
OXY(%) = 19.5
LEL(%) = 10
VOC(ppm) = 50

- Sensor High Alarm Limits:

CO(ppm) = 200
H2S(ppm) = 20
OXY(%) = 23.5
LEL(%) = 20
VOC(ppm) = 100

Sensor STEL Alarm Limits:

CO(ppm) = 100
H_2S(ppm) = 15
VOC(ppm) = 25

- Sensor TWA Alarm Limits:

CO(ppm) = 35
H_2S(ppm) = 10
VOC(ppm) = 10

- Sensor Over Range Limit:

CO(ppm) = 1000
H_2S(ppm) = 250
OXY(%) = 30
LEL(%) = 100
VOC(ppm) = 1000

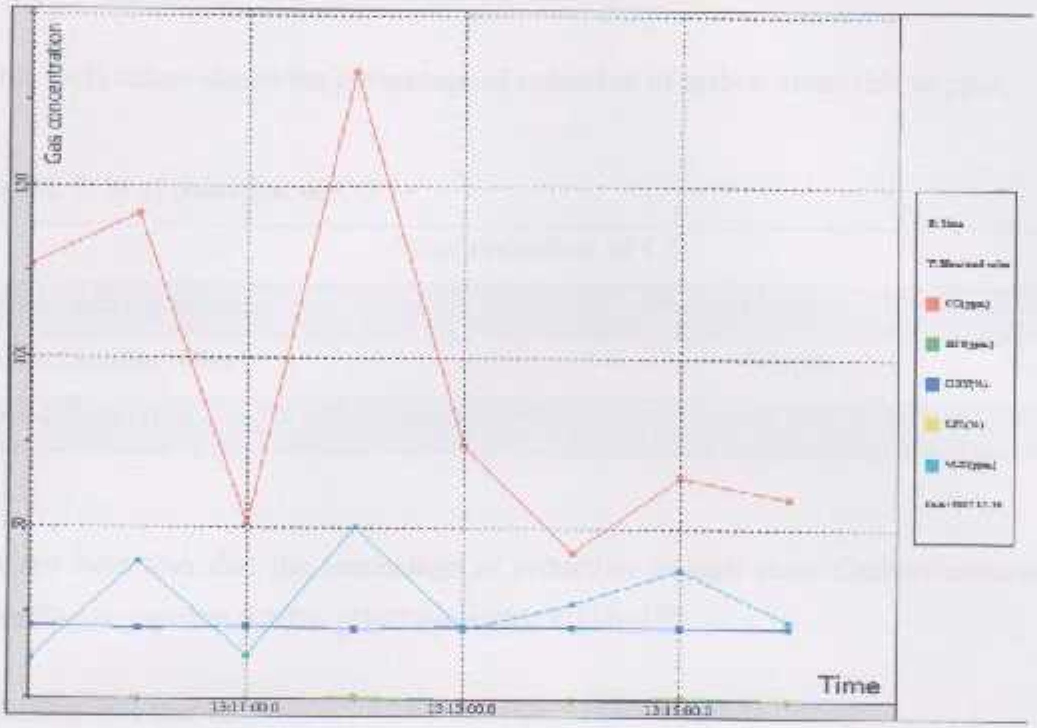


Figure 5.8: Measurement before treatment process.

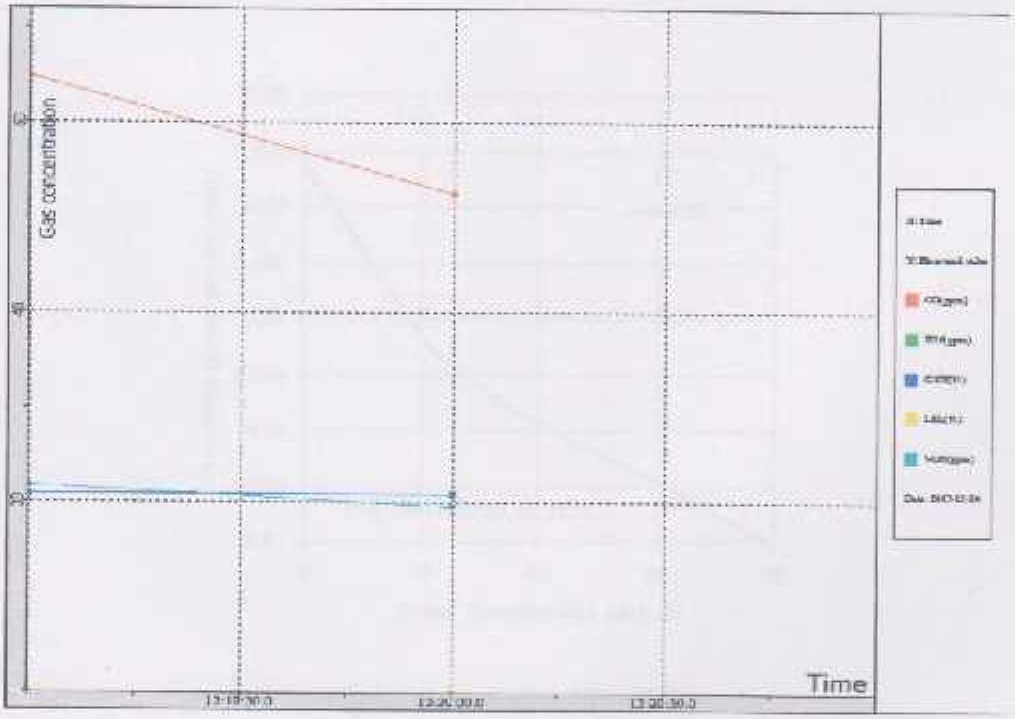


Figure 5.9:Measurment after treatment.

5.2.1: The percentage of reduction of carbon monoxide

Table (5.5) below shows the percentage of reduction of carbon monoxide in ppm.

Table 5.5: % of reduction of CO

% of reduction of CO	
Max reading before	183ppm
Max reading after	70ppm
% of reduction	62%

We see here also that the percentage of reduction is high since Carbon monoxide solubility is equal to 0.0026 g/100 ml at (20 °C),also[13]

Solubility in water at:

- 0° C, 1 atm .... 3.54 ml/100 ml
- 25° C, 1 atm .... 2.14 ml/100 ml
- 37° C, 1 atm .... 1.83 ml/100 ml

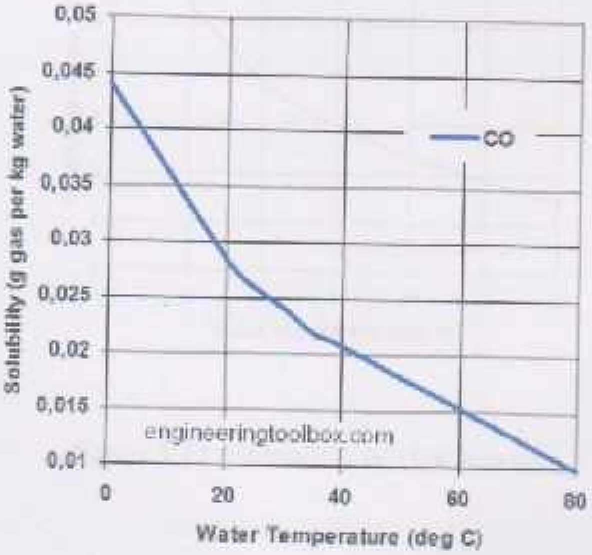


Figure 5.10: Solubility of CO.

5.2.2: The percentage of reduction of hydrogen sulfide

Table 5.6: % of reduction of H_2S

% of reduction of H_2S	
Max reading before	5ppm
Max reading after	0ppm
% of reduction	100%

The table above shows that the percentage of reduction of hydrogen sulfide is 100% and that because Hydrogen sulfide dissolves in water to make a solution that is weakly acidic. At 0 oC 437 mL $H_2S(g)$ will dissolve in 100 mL H_2O, producing a solution that is about 0.2 M. However, the solution process is fairly slow. The figure below represents the percentage of reduction as the temperature increase.[13]

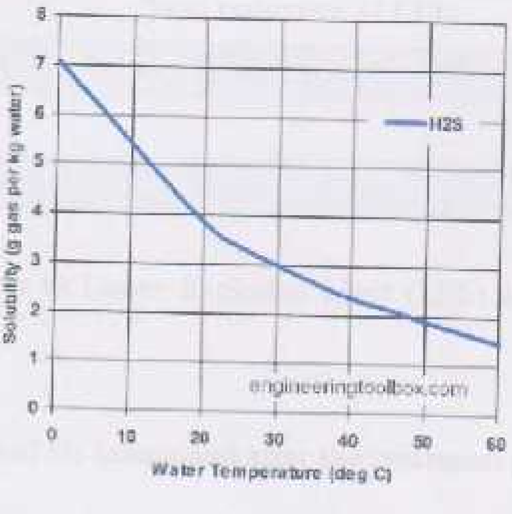


figure 5.11: Solubility of H_2S in water.

5.2.3: The percentage of reduction of volatile organic compounds

Table (5.7) shows the percentage of reduction of VOC in ppm.

Table 5.7: % of reduction of VOC

% of reduction of VOC	
Max reading before	50ppm
Max reading after	24ppm
% of reduction	52%

Also volatile organic compounds are compounds that have a high vapor pressure and low water solubility

5.2.4: The percentage of reduction of Lower Explosive Limit

Table 5.8: % of reduction of LEL

% of reduction of LEL	
Max reading before	3%
Max reading after	0%
% of reduction	100%

These gases are known as Lower Explosive Limit (LEL) also here the percent of reduction is 100%.

5.2.5: The percentage of O_2 before and after the treatment process

Table 5.9 : % of O_2

% of O_2	
Max reading before	19.2%
Max reading after	20.9%

The percentage of O_2 is raised after the treatment process that means good reaction between O_2 and H_2O

5.3 Measuring of (CO_2)

This gas was measured by using ultra 4/5 gas analyzer see figure 5.6:

Figure 5.12: Ultra 4/5 gas analyzer

Table 5.10 below shows the percentage of reduction of carbon dioxide

Table 5.10: % of reduction of CO_2

% of reduction of CO_2	
Max reading before	0.90%
Max reading after	0.60%
% of reduction	34%

After the measuring process we get these results ,when dissolved in water, CO_2 forms weak bonds with the water molecules. The lower the temperature, the stronger the bonds, the greater the amount of CO_2 that can be dissolved.

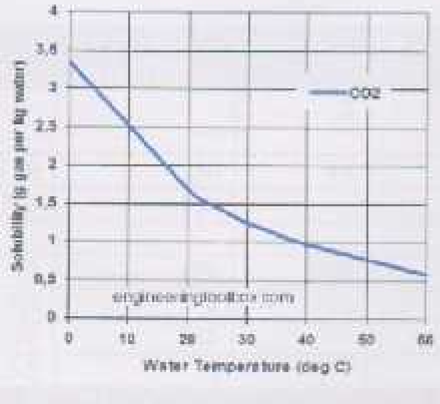


figure 5.13: Solubility of CO_2 in water.

5.4 Water test

After the reduction of the percentage of gases the pH percentage of the water had change so we expect that the water be more acidic. So the test of water has been done also before and after the experiments by using the photometer see figure (5.7):

Figure 5.14: Photometer (Visocolor umweltkoffer.pf-1117371).

The test which done before treatment is for pH

pH=8.1 mg/l.

This value shows that this water is healthy according to table(5.2)

Table 5.12: Guidelines for drinking water

	WHO	EU	The Netherlands	US/EPA	Canada	Oman	Upper limit
orm	0			0	0	10	10
l	50	25-50	50	45	45	45	50
g/l		100	150			75-200	200
						30-150*	150
	250	25	150	250	250	200-600	600
%		<75%	2				75%
g/l	500	150	150			100-500	500
		2-5	5				10
	6.5-9.5	6.5-8.5	7-9.5		6.5-8.5	6.5-9.2	9.2
g/l		0.5-6.5	6				6

5.4 Water test

After the reduction of the percentage of gases the pH percentage of the water had change so we expect that the water be more acidic. So the test of water has been done also before and after the experiments by using the photometer see figure (5.7):

Figure 5.14: Photometer (Visocolor umweltkoffer.pf-1117371).

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pH=8.1 mg/l.

This value shows that this water is healthy according to table(5.2)

Table 5.12: Guidelines for drinking water

	WHO	EU	The Netherlands	US/EPA	Canada	Oman	Upper limit©
tal coliform er 100 ml	0			0	0	10	10
trate mg/l	50	25-50	50	45	45	45	50
alcium mg/l		100	150			75-200	200
agnesium						30-150*	150
hloride	250	25	150	250	250	200-600	600
O mg/l or %		<75%	2				75%
rdness mg/l	500	150	150			100-500	500
OD mg/l		2-5	5				10
H	6.5-9.5	6.5-8.5	7-9.5		6.5-8.5	6.5-9.2	9.2
osphate mg/l		0.5-6.5	6				6

Sulfate mg/l	500	25-250	150-250	250	500	200-400	400
Sodium mg/l	200		120-150		200		200
Total suspended solids mg/l		None	1000				1000
Total Dissolved Solids mg/l	1000	1500	1000	500	500	500-1500	1500
Turbidity NTU	5	5	4			5	5
Ammonia mg/l	1.5	0.05-0.5	0.5				1.5

* Linked with sulfate concentration

© Adopted by this study as drinking water guidelines and used as a comparison tool

The test which had been done after scrubbing process also for pH and its value was:

pH=6.5

Figure 5.15:common pH values

This mean that after a large number of cycle for treatment the pH will decreased

5.6: Recommendations

After all these results and after the design of the prototype we recommend the following :

- Increase the metal plates inside the tank to increase the efficiency of treatment.
- Use another fan inside the tank to add additional pressure upon the surface of the liquid since the increase in pressure make the solubility to increase.
- Using water jet inside the tank to spray the water on the smoke so the efficiency will increase.
- Use cooled water inside the tank since the lower the temperature the higher solubility of the gases in the water.

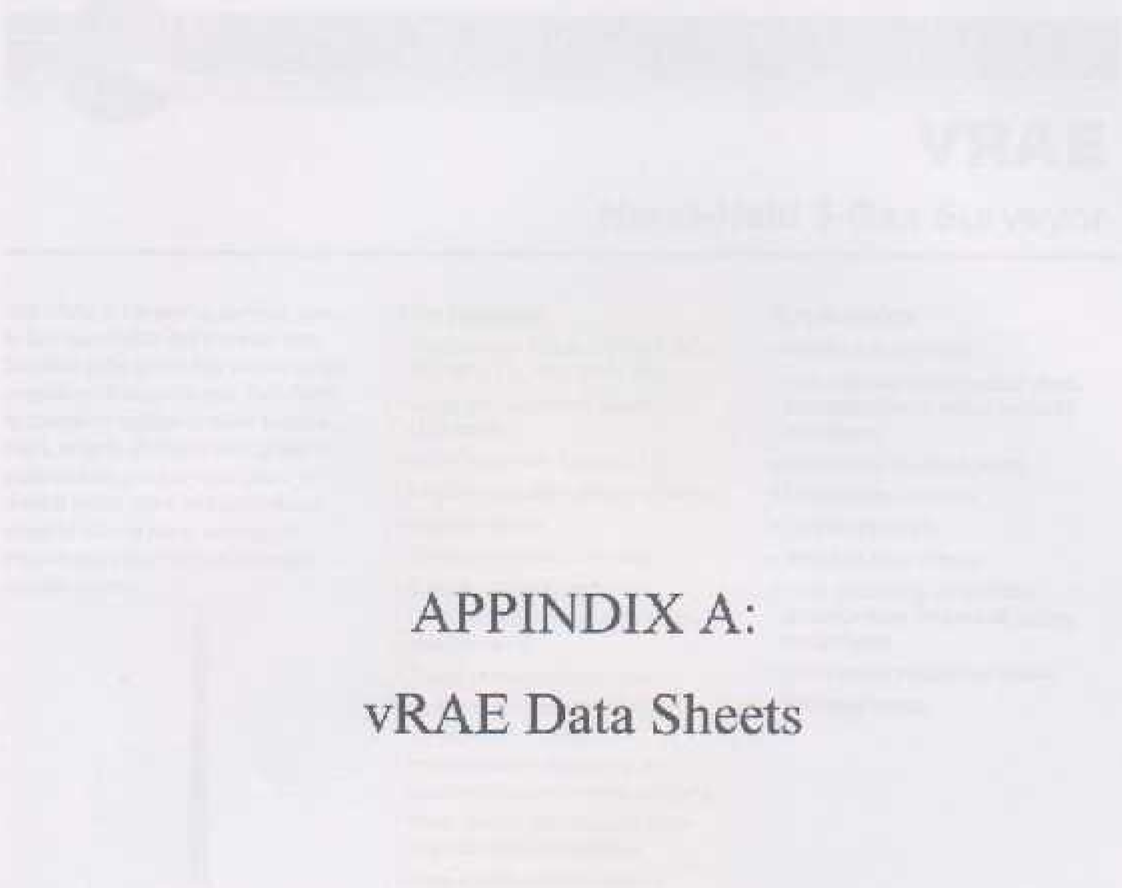
References:

1. Noel de Nevers,2000 air Pollution Control Engineering.2nd ed. McGraw-Hill.
2. George Tchobanoglous ,Hilary Theisen , Samuel Vigil.1993 Integrated Solid Waste Management. McGraw-Hill.
3. Karl B. Schnelle, Jr. and Charles A. 2001 Air pollution control technology handbook. Mechanical engineering handbook series.
4. Richard W. Boubel 1994fundemental of air pollution.3rd ed. united states
5. http://www.ucar.edu/learn/1_3_1.htm
6. http://en.wikipedia.org/wiki/Air_pollution
7. http://edugreen.teri.res.in/explore/air/air.htm
8. http://www.chesapeakebay.net/air_pollution.htm
9. http://www.lbl.gov/Education/ELSI/pollution-main.html
10. http://www.epa.gov/air/topics/comapc.html
11. http://encarta.msn.com/encnet/refpages/search.aspx?q=air+pollution
12. http://www.iupac.org/publications/pac/1998/pdf/7010x1895.pdf
13. http://www.engineeringtoolbox.com/gases-solubility-water-d_1148.html
14. http://en.wikipedia.org/wiki/Partial_pressure

APPENDICES

APPINDIX A:

vRAE Data Sheets



VRAE

Hand-Held 5-Gas Surveyor

The VRAE is a powerful, pumped, one- to five-gas monitor that monitors combustibles in the percent by volume range regardless of oxygen levels. The VRAE is capable of monitoring either combustibles, oxygen, and three toxic gases or combustibles and four toxic gases. Its durable Nickel-Metal-Hydride batteries, powerful internal pump and rugged frame make it ideal for leak detection and site surveys.

Key Features

- Toxic sensors include CO, H_2S, SO_2, NO, NO_2, Cl_2, NH_3, HCN, PH_3
- Large alarm-activated backlit LCD display
- Visual alarm with flashing LED
- Large keys usable with gloved hand
- Rigid inlet probe
- 10 hours continuous operation
- Sample collection port
- Optional 16,000 data points downloadable to PC
- Strong protective rubber boot
- Protected from interference by portable radios (RFI)
- Internal sample draw pump for quick response and remote sampling
- Smart battery charging with status indication and LED indicator
- Snap-in rechargeable NiMH or alkaline battery pack
- 48 built-in Correction Factors for LEL sensor
- 4 toxic sensor version available

Applications

- Confined Space Entry
- Refineries and petrochemical plants including offshore drilling and plant shut downs
- Waste water treatment plants
- Shipyard and maritime
- Landfill operations
- Trenches, silos, railcars
- Food processing, refrigeration, decomposition, process off gasing, poultry farms
- Cable vaults, transformer stations
- Fire departments

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RAE SYSTEMS

VRAE

Specifications*

Detector Specifications

Size	4.7" L x 3.0" W x 1.8" H (11 cm x 7.6 cm x 4.5 cm)
Weight	20 oz with battery pack (568 g)
Sensors	• Catalytic sensor for combustible gas • Thermal conductivity sensor for percentage volume combustible gas • Electrochemical sensors for oxygen and toxic gases
Battery	Rechargeable, snap-in, field replaceable 4.8V, 1.7 AH NiMH battery pack, 4 AA battery adapter
Operating Hours	10 hours continuous operation
Display	2-line, 16-digit LCD with LED backlight automatically turns on in dim light or alarm condition
Keypads	1 operation and 2 programming keys
Direct Readout	Instantaneous reading (up to 5 values) • Oxygen as percentage by volume • Combustible gas as percentage by volume or percentage of lower explosive limit (LEL)
Alarms	90 dB buzzer and flashing red LED to indicate exceeded preset alarms • High: 3 beeps and flashes per second • Low: 2 beeps and flashes per second • STEL and TWA: 1 beep and flash per second • Alarms latching with manual override or automatic reset • Additional diagnostic alarm and display message for low battery and pump stall
Datalogging	Optional 18,000 points (63 hours, 5 channels at one minute intervals) download to PC with serial number of unit, user ID, site ID and calibration date
Calibration	Two-point field calibration of zero and span gas
Sampling Pump	• Internal pump, flow rate 450 cc/minute • Automatic shut off at low flow condition
Hazardous Area Approval	US: UL, cUL, Classified as Intrinsically Safe for use in Class I, Division 1 Groups A, B, C, D, Hazardous Locations T3C rating
Temperature	-4° F to 113° F (-20° C to 45° C)
Humidity	0% to 95% relative humidity (non-condensing)
Attachment	Durable rubber boot and wrist strap
Warranty	Lifetime on non-consuming components (per RAE Systems Standard Warranty), 2 years for O_2, LEL, CO and H_2S sensors, 1 year for all other sensors, 1 year pump, 1 year battery

*Specifications are subject to change

Sensor Specifications

Gas Monitor	Range	Overload Range	Resolution
Combustible	0 to 100% LEL		1%
	0 to 100% VOL		1%
Oxygen	0 to 30.0%		0.1%
Carbon Monoxide	0 to 500 ppm	1500 ppm	1 ppm
Hydrogen Sulfide	0 to 100 ppm	500 ppm	1 ppm
Sulfur Dioxide	0 to 20.0 ppm	150 ppm	0.1 ppm
Nitric Oxide	0 to 250 ppm	1000 ppm	1 ppm
Nitrogen Dioxide	0 to 20.0 ppm	150 ppm	0.1 ppm
Chlorine	0 to 10.0 ppm	30 ppm	0.1 ppm
Hydrogen Cyanide	0 to 100 ppm	100 ppm	1 ppm
Ammonia	0 to 50 ppm	200 ppm	1 ppm
Phosphine	0 to 5.0 ppm	20 ppm	0.1 ppm

Monitor only includes:

- Monitor as specified
- Sensors as specified
- Filter and O-ring pack
- 5" Inlet probe
- Gas outlet port adapter
- Operation and maintenance manual
- Rubber boot with belt clip
- Alkaline battery adapter
- Rechargeable units additionally include:
  - Nickel-Metal-Hydride (NiMH) battery
  - 120 or 230 V AC/DC wall adapter (if specified)

Monitor with accessories kit also includes:

- Hard transport case with pre-cut foam padding
- 15' (5m) Tygon® tubing
- Tool kit

Optional calibration kit also includes:

- Four-gas mix in a 34L cylinder (50% LEL, 20.9% O_2, 25 ppm H_2S, 50 ppm CO)
- Calibration regulator (male) and tubing

Datalogging Monitors also include:

- Software ProRAE Suite Package for Windows® 98, 2000, NT and XP
- Computer interface cable

DISTRIBUTED BY:

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EntryRAE

Confined Space Entry Monitor

Affordable OSHA compliance plus reliable VOC protection

The typical confined space monitor measures oxygen, combustibles, carbon monoxide and hydrogen sulfide. Will it keep you safe in today's industrial environment? No.

When doing confined space work today, you need the added broad-band protection of a PID.

EntryRAE

The **EntryRAE** is a 4-gas monitor, plus photoionization (PID) detector. Reliable, easy to operate, and simple to calibrate, the **EntryRAE** delivers added protection without added complexity.

Simple, Modular, Durable PID

RAE Systems is the leader in PIDs. Our plug & play, patented self-cleaning PID is the most reliable and durable PID available today.

Why PID?

Typical 4-gas monitors do not detect volatile organic compounds (VOCs). VOCs are combustible, and often toxic at levels far below 10% LEL. They are commonly found in:

- Fuels, oils, degreasers
- Industrial cleaners
- Heat transfer fluids
- Solvents, paints
- Plastics, resins, adhesives
- Pesticides and herbicides

These are common industrial compounds you find in – or bring into – a confined space.

LEL sensors can be poisoned by common chemicals, including:

- Silicone compounds
- Lead compounds
- Sulfur compounds
- Phosphates

Just a few parts per million of these compounds can degrade an LEL sensor.

A PID detects VOCs!

A PID is a reliable backup for your LEL sensor. Combine a PID and a 4-gas monitor and you have **true protection from the unexpected.**

Key Features

- Reliable, self-cleaning VOC detector
- Also includes CO, H_2S, LEL and O_2 sensors
- Simple to operate
- Easy to calibrate
- Durable, weather-resistant rubber body
- Datalogging included – and automatic
- Big display with auto-backlight
- Loud alarm
- Bright red flashing LED alarms
- Up to 16 hours of continuous operation
- Interchangeable Lithium-ion and alkaline battery packs
- Charging cradle doubles as an external battery charger
- Powerful pump allows sample draws up to 100 feet (30 meters)
- Low-flow pump alarm

Applications

- Refineries
- Chemical processing
- Water & wastewater facilities
- Semiconductor manufacturing
- Rail car and tank truck cleaning
- Resin and nylon production
- Underground storage
- Sewer entries
- Cable vaults
- Agriculture

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EntryRAE

Specifications*

Sensor Specifications

Sensor	Range	Resolution
PID	0-999 ppm VOC	1 ppm VOC
Oxygen	0-30.0%	0.1%
Combustible Gases	0-100% LEL 0-5% Volume	1% LEL 1% Volume
Carbon Monoxide	0-500 ppm	1 ppm
Hydrogen Sulfide	0-100 ppm	1 ppm

Detector Specifications

Size	6.0"L x 3.3"W x 1.9"H (15 x 8.5 x 4.8 cm) without clip
Weight	20 oz (567 g) with battery and clip
Sensors	5 sensors: • Protected catalytic bead for combustible gases (LEL) • Electrochemical sensors for oxygen (O_2) and hydrogen sulfide (H_2S) and carbon monoxide (CO) • Modular photoionization detector for broadband detection of VOCs using 10.6 eV lamp
Battery	• Drop-in rechargeable Li-Ion battery pack • Standard alkaline battery adapter • Charging cradle doubles as external battery charger
Operating Hours	Up to 16 hours continuous with Li-Ion (typical) Up to 12 hours with alkaline
Display	Large 1.4" x 1.8" (3.5 x 4.5 cm) display with automatic back lighting in dim light or alarm condition
Keypad	Three-button operation
Direct Readout	Instantaneous for 5 values: • Oxygen as percentage by volume • Combustible gas as percentage of lower explosive limit (LEL), percentage by volume • VOCs, CO and H_2S in parts per million • TWA and STEL values for VOCs, CO and H_2S • High and low values for all gases
Alarms	• Audible (95dB at 30 cm), visible, and vibration • High: 3 beeps and flashes per second • Low: 2 beeps and flashes per second • STEL and TWA: 1 beep and flash per second • Low battery displays empty battery symbol, 1 beep per minute
EMI/RFI	Highly resistant to EMI / RFI. Compliant with EMC Directive 89/336/EEC
IP Rating	IP-65: protected against dust, protected against low pressure jets of water from all directions
Communication	PC to monitor via RS232 (USB adapter available)
Calibration	Two-point field calibration for zero and span gas
Sampling Pump	Built-in pump, 300 cc per minute flow rate
Low Flow Alarm	Auto shutoff at low flow condition
Hazardous Area Approval	US/Canada: UL, cUL Class 1 Division 1, Groups A, B, C, D T3C. Europe ATEX II 2G EEx ia dIIC T4
Temperature	UL/cUL: -20° to 50°C, ATEX -20° to 45°C
Humidity	0% to 95% relative humidity (non-condensing)
Attachments	Stainless steel slipper clip (installed), wrist strap
Warranty	Lifetime on non-consuming components (per RAE Systems Standard Limited Warranty) 2 years for O_2, LEL, CO and H_2S sensors 1 year for PID 1 year for pump and battery

---

* Ongoing projects to enhance our products mean that these specifications are subject to change.

Monitor only includes:

- Monitor as specified
- VOC sensor (PID)
- CO, H_2S, LEL and O_2 sensors
- Lithium-Ion rechargeable calibration adapter battery
- Alkaline battery adapter
- 6 external filters
- Charging cradle
  - 120 V wall charger, US plug or 230 V wall charger, Euro plug
- ProRAE Studio software package
- Computer interface cable
  - RS232 to RS232 with USB adapter
- Calibration adapter
- User manual
- Shipping case

Truck Mount

Optional CSK II Calibration Kit

- Hard transport case with pre-cut foam
- Sampling wand with 15 feet (3 meters) of self-coiling Teflon® tubing
- Tool kit
- Four-gas mix – 34L (50% LEL, 20.9% O_2, 10 ppm, H_2S, 60 ppm CO)
- Isobutylene – 34L (100 ppm, balance air)
- Regulators and tubing

Truck Mount (Accessory)

- Cradle attachment for mounting on a wall
- 12 V adapter

AutoRAE Docking Station

AutoRAE Docking Station

(Accessory)

- Automated bump test and calibration system
- Drop-in, push button operation

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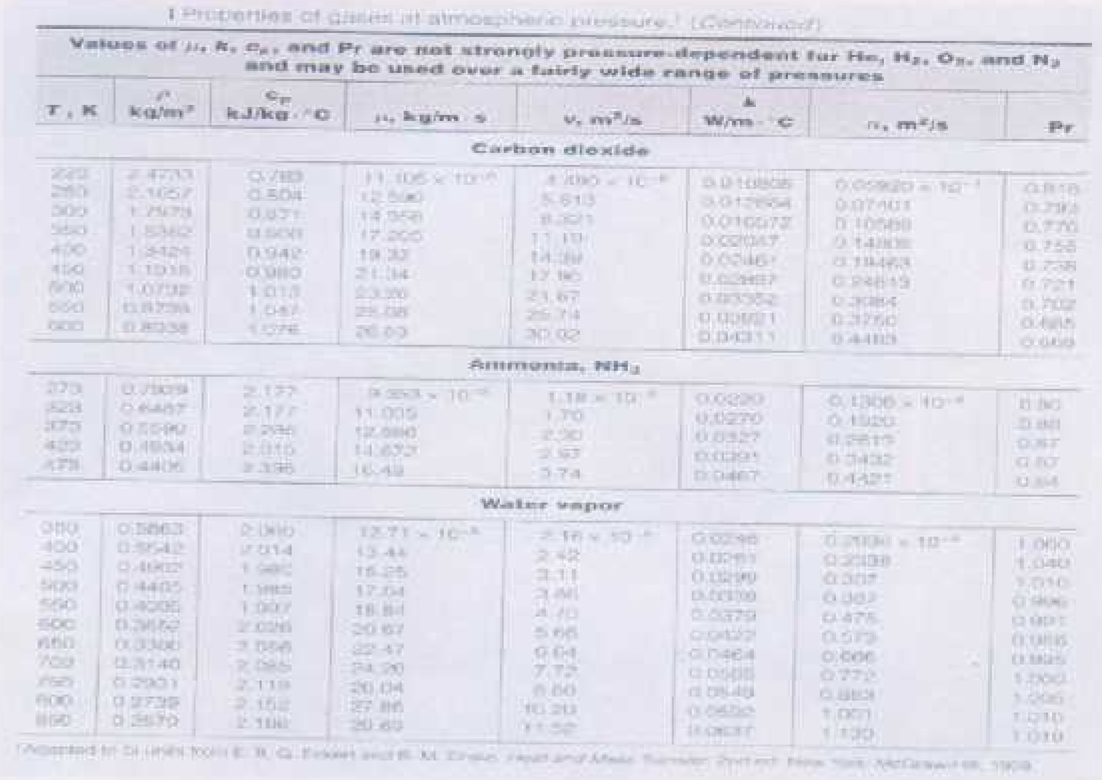
APPINDIX B:

PROPERTES OF CO_2 AT ATMOSPERIC PRESSURE

Table B1: properties of gases at atmospheric pressure



Properties of gases at atmospheric pressure† (Continued)

Values of μ, k, c_p, and Pr are not strongly pressure-dependent for He, H_2, O_2, and N_2 and may be used over a fairly wide range of pressures							
T, K	ρ kg/m³	c_p kJ/kg · °C	μ, kg/m · s	ν, m²/s	k W/m · °C	α, m²/s	Pr
Carbon dioxide							
220	2.4733	0.783	11.105×10^{-6}	4.490×10^{-6}	0.010805	0.05920×10^{-4}	0.818
250	2.1657	0.804	12.590	5.813	0.012884	0.07401	0.793
300	1.7973	0.871	14.958	8.321	0.016572	0.10588	0.770
350	1.5362	0.900	17.205	11.19	0.02047	0.14808	0.755
400	1.3424	0.942	19.32	14.39	0.02461	0.19463	0.738
450	1.1918	0.980	21.34	17.90	0.02897	0.24813	0.721
500	1.0732	1.013	23.26	21.67	0.03352	0.3084	0.702
550	0.9739	1.047	25.08	25.74	0.03821	0.3750	0.685
600	0.8938	1.076	26.83	30.02	0.04311	0.4483	0.668
Ammonia, NH_3							
273	0.7929	2.177	9.353×10^{-6}	1.18×10^{-5}	0.0220	0.1308×10^{-4}	0.90
323	0.6487	2.177	11.035	1.70	0.0270	0.1920	0.88
373	0.5590	2.236	12.886	2.30	0.0327	0.2619	0.87
423	0.4934	2.315	14.672	2.97	0.0391	0.3432	0.87
473	0.4405	2.395	16.49	3.74	0.0467	0.4421	0.84
Water vapor							
380	0.5863	2.060	12.71×10^{-6}	2.16×10^{-5}	0.0246	0.2036×10^{-4}	1.060
400	0.5542	2.014	13.44	2.42	0.0261	0.2338	1.040
450	0.4902	1.980	15.25	3.11	0.0299	0.307	1.010
500	0.4405	1.985	17.04	3.86	0.0339	0.387	0.996
550	0.4005	1.997	18.84	4.70	0.0379	0.475	0.991
600	0.3652	2.026	20.67	5.66	0.0422	0.573	0.986
650	0.3380	2.056	22.47	6.64	0.0464	0.666	0.995
700	0.3140	2.085	24.26	7.72	0.0505	0.772	1.000
750	0.2931	2.119	26.04	8.88	0.0549	0.883	1.005
800	0.2739	2.152	27.86	10.20	0.0592	1.001	1.010
850	0.2579	2.186	29.69	11.52	0.0637	1.130	1.019

†Adapted to SI units from E. R. G. Eckert and R. M. Drake, *Heat and Mass Transfer*, 2nd ed. New York: McGraw-Hill, 1959.