"Ozone Depletion & Role of CFC"

Neil Mahesh Pachkude

Department of Chemistry, VPM's B. N. Bandodkar College, Thane

University of Mumbai.

neilpachkude5@gmail.com

ABSTRACT:

The Earth is shielded by the ozone layer in the stratosphere, which is 10 – 50 km above the Earth's surface. Ozone layer absorbs most of Sun's UV rays making Earth habitable for life. But, during the Third industrial revolution, humans all over the world were emitting large quantities of Ozone depleting substances (ODS), particularly chlorofluorocarbons (CFCs). This led to the creation of ozone holes at the earth's poles, exposing life to higher levels of ultraviolet radiation and increasing the risks of skin cancer in humans.

During the 1980s, the world came together to form an international agreement to reduce – and eventually eliminate – emissions of these depleting substances. The political agreements, especially the Montreal protocol, were very effective. Since then, global emissions have fallen around 99%.[1] This review discusses the mechanisms of ozone depletion, detection of ozone layer and holes using different instruments, the role of CFCs, and the environmental consequences. Additionally, it highlights international efforts to mitigate ozone depletion, particularly through agreements like the Montreal Protocol, which have successfully curbed ODS emissions, leading to the gradual recovery of the ozone layer. The paper also explores laboratory techniques for CFC degradation and their potential in accelerating ozone restoration. By addressing these aspects, the review underscores the importance of sustained global cooperation and innovation in safeguarding the ozone layer.

Keywords: Ozone layer, Ozone depletion, ultraviolet radiation, CFCs, degradation methods.

INTRODUCTION:

Ozone is a colorless gas with a distinct pungent odor, composed of three oxygen atoms (O_3). It plays a vital role in the Earth's atmosphere, occurring both in the upper atmosphere (stratosphere) and at ground level (troposphere). The ozone found in the stratosphere forms the 'ozone layer' which acts as a protective shield by absorbing most of the Sun's harmful ultraviolet (UV-B) radiation. This layer is crucial for sustaining life on Earth by preventing excessive UV radiation from reaching the surface, where it can harm living organisms.

The formation of ozone in the stratosphere results from the photodissociation of oxygen molecules (O_2) by high-energy solar photons. These reactions release single oxygen atoms, which combine with intact oxygen molecules to form ozone. This natural process maintains a dynamic equilibrium, continuously regenerating and depleting ozone molecules.

In contrast, ground-level ozone, often referred to as 'bad ozone' is a pollutant formed by photochemical reactions involving nitrogen oxides (NO_x) and volatile organic compounds (VOCs) in the presence of sunlight.These compounds are emitted by cars and trucks, industrial facilities, refineries, power plants, household products and cleaning supplies, and paints and solvents. The long-range transport of ozone and precursor emissions from local, regional, and international sources can also impact air quality. This type of ozone contributes to air quality issues and poses risks to human health and the environment.

During the mid-20th century, industrialization and the widespread use of chlorofluorocarbons (CFCs) disrupted the delicate balance of ozone in the stratosphere. CFCs, widely used as refrigerants, propellants, and solvents, were found to release chlorine atoms upon exposure to UV radiation. These chlorine atoms act as catalysts in the breakdown of ozone molecules, leading to significant depletion of the ozone layer. The discovery of the Antarctic ozone hole in the 1980s marked a turning point, highlighting the urgent need for global action to address this environmental crisis.[1]

This paper explores the science behind ozone depletion, the role of CFCs, and the international response to mitigate the issue. By examining the success of global agreements like the Montreal Protocol and the advancements in CFC degradation technologies, it emphasizes the importance of continued efforts to protect and restore the ozone layer.

CONTEXT:

The ozone layer plays an important role in the biology and climatology of the Earth's environment. Radiations below the wavelength of 3000 Å are biologically harmfuland ozone helps to filter-out these radiations. The stratospheric ozone layer protects life on earth by absorbing the damaging, high-energy UV-C radiation. Depletion of stratospheric ozone increases the concentration of terrestrial ozone, which is considered harmful for health.[2] Ozone depletion resulted in global warming by increase of the atmospheric temperature

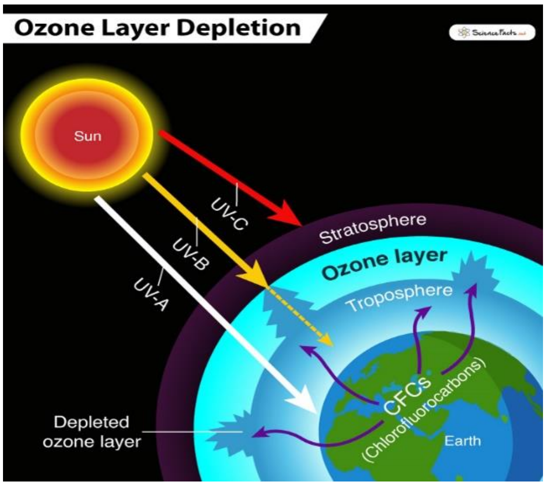


Figure 1 : Ozone layer depletion.[10]

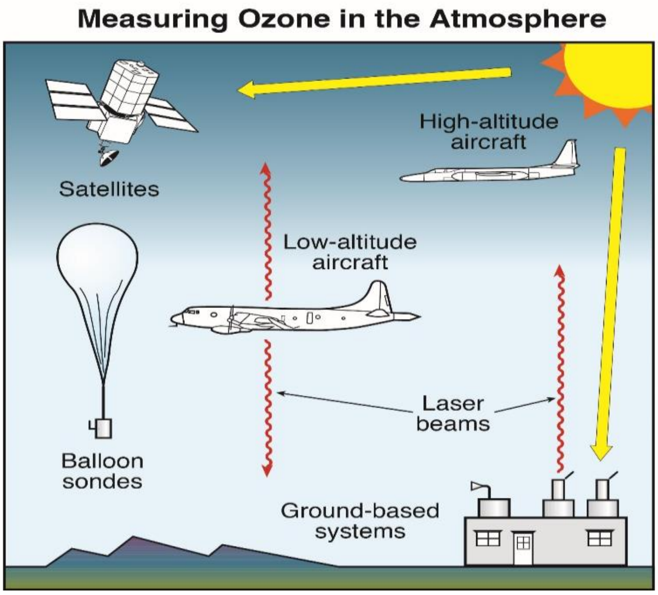
by 5.5˚C. The UV rays are of shorter wavelengths ranging from 100 - 280 nm(UV-C), 280 - 315 nm (UV-B) to 315 - 400 nm (UV-A). Of the UV rays, UV-C is completely absorbed by the ozone layer and only 5% of UV-B reaches the earth surface, while nearly 95% of UV-A is able to penetrate the atmospheric layers. UV radiations affect all the elements of the biome including plants, pathogens, herbivores, carnivores and microorganisms. These radiations are harmless to DNA but can cause genetic damage to the skin and are responsible for increasing the total reactive oxygen level.[3] {1}

The ozone depletion over the Antarctic has been noticed since 1970s and the Arctic region has also been witnessing the occurrence of an ozone-hole during the last decade. The overall depletion has been increasing at the rate of 0.5% per year since 2000, because of the extensive use of ozone depleting substances (ODSs) such as propellants (in the manufacture of soft and hard foams), refrigeration, air conditioning and as cleaning solvent.

- Methodology for Observing Ozone layer and it's depletion

Various instruments as well as methods are to observe the ozone layer. The first instrument for routine monitoring of total ozone was developed by Gordon M. B. Dobson in the 1920s. The instrument, now called a Dobson spectrophotometer, measures the intensity of sunlight at two ultraviolet wavelengths: one that is strongly absorbed by ozone and one that is weakly absorbed. The difference in light intensity at the two wavelengths is used to provide a measurement of total ozone above the location of the instrument. A global network of ground-based, total-ozone observing stations was established in 1957 as part of the International Geophysical Year. Today, there are about 100 sites distributed throughout the world (from South Pole, Antarctica (90°S), to Ellesmere Island, Canada (83°N)), many of which routinely measure total ozone with Dobson instruments. Because of their stability and accuracy, the Dobson instruments are now routinely used to help calibrate space-based observations of total ozone. Pioneering scientists have traditionally been honored by having units of measure named after them. Accordingly, the unit of measure for total ozone is called the 'Dobson unit'.

Ozone is measured throughout the atmosphere with instruments on the ground and on board aircraft, high-altitude balloons, and satellites. Some instruments measure ozone locally in sampled air and others measure ozone remotely some distance away from the instrument.



Instruments use optical techniques, with the Sun and lasers as light sources, or use chemical reactions that are unique to ozone. Measurements at many locations over the globe are made regularly to monitor total ozone amounts.[9]

- Role of CFCs in Depleting Ozone layer

During the Third Industrial revolution, CFCs were in widespread use in refrigeration, air conditioning and aerosol spray cans. CFCs (Freons) are a group of colorless, non-combustible liquids which are highly volatile substances and poorly soluble in water. Hence, they are mainly released into the air through evaporation during their production and use. These do not bind to soil strongly and thus they can easily leach to the groundwater.
CFCs when released in air, slowly rise into the stratosphere. Here the ultraviolet radiation coming from the Sun acts as a catalyst in breaking down of CFC molecule with the release of Chlorine atom. Chlorine atoms attack stratospheric ozone with the formation of the free radical ClO which reacts further to regenerate atomic chlorine. This chain reaction can cause the removal of 100000 molecules of ozone per Cl atom. 100000 molecules of ozone per Cl atom.[4]

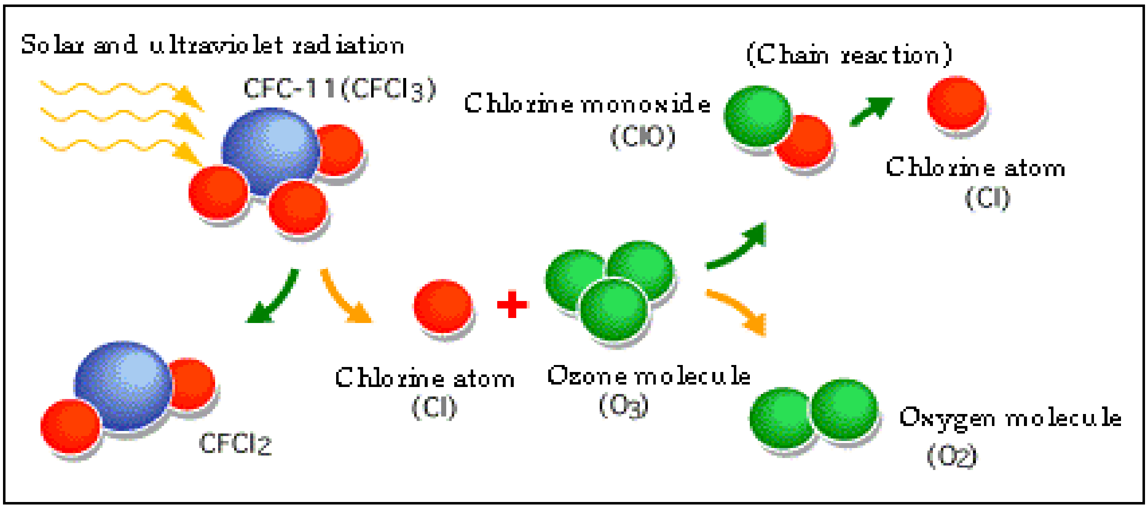


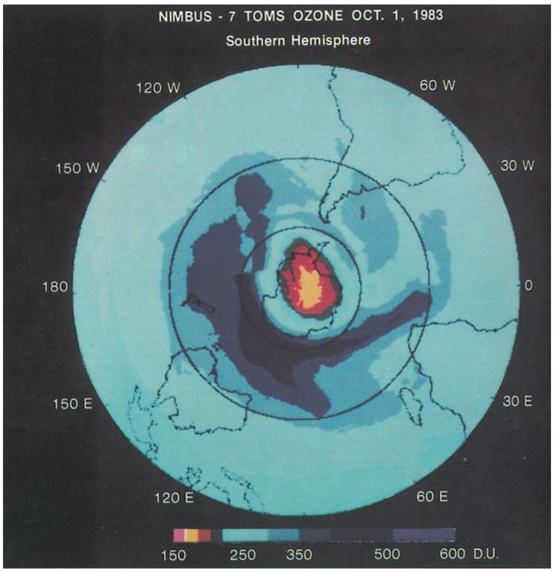
Figure 3 : Reaction of Ozone in Atmosphere.[12]

A lots of amount of these Ozone Depleting substance(ODS) were released in air, unknowing the after effects of these substances. In the 1960s, scientists were beginning to understand the reactions that determined the photochemistry of the upper atmosphere. At the time, many scientists used models that were built around the interactions between OH radicals and ozone molecules. Only a few years on, the scientists Frank Rowland and Mario Molina proposed that human emissions of chlorine substances might have impact on ozone.

These substances – the most well-known ones being chlorofluorocarbons (CFCs) – were being widely used in refrigerators, freezers, air conditions, aerosol sprays and in industrial production. By measuring concentrations of chlorine molecules throughout the lower atmosphere, they realised it was clear that they were not breaking down: the amount in the atmosphere was almost exactly equal to the cumulative production to date. The chemical inertness that made them great for technology was also preventing them from breaking down in the lower atmosphere.During the mid 1980's British Antarctic Survey scientists, Farman, Gardiner and Shanklin, published their finding in 'Nature'.[5]This finding was so sudden, and implications so big, that they had to be sure it wasn't simply a measurement error. The visual imagery of a growing ozone hole put pressure on governmental and industrial actors to take action.The image shows ozone hole formed over the Antartic region. This findings lead to the formation on Montreal treaty signed in 1987 between Forty seven countries, agreeing to phase out ozone-depleting substances.

The effectiveness of the Montreal Protocol in preventing large increases in UV-B radiation (280–315 nm) at the Earth's surface has been confirmed by comparing UV measurements with model simulations of the "World Expected" and "World Avoided" scenarios at many clean-air sites. The recently reported non-compliance with the Montreal Protocol implied by increased emissions of the ozone-depleting substance (ODS) CFC-11 has had, at present, no effect on surface UV radiation, but continuing large emissions into the future could lead to environmentally important increases in UV-B radiation.

Figure 4 : Ozone hole in Antartic region.[13]



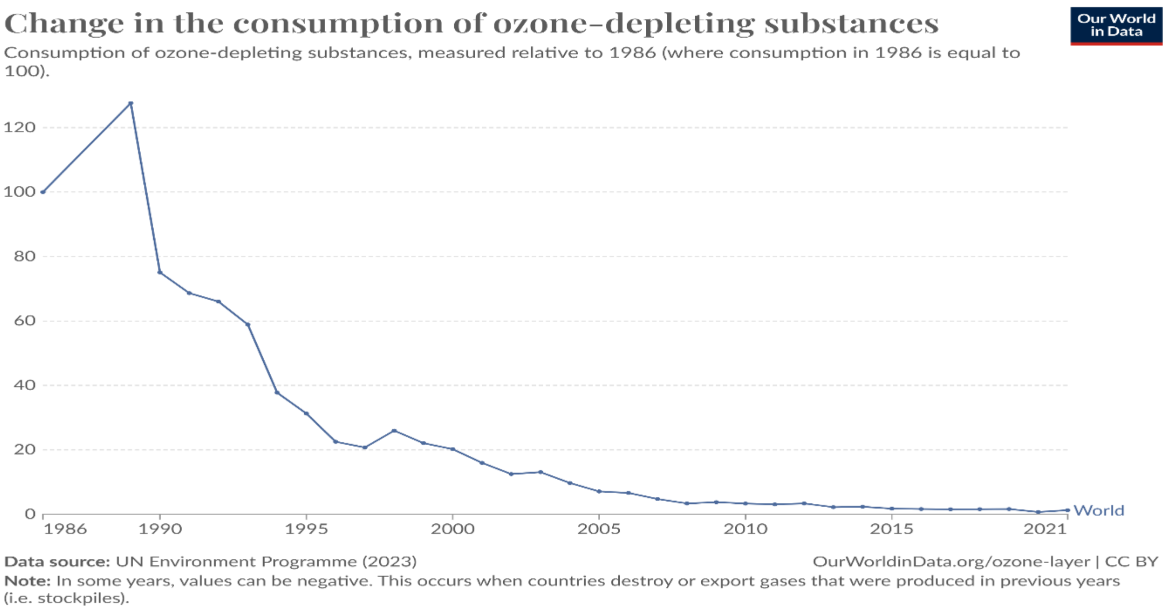


Figure 5 : Graph representing decrease in usage of ODS.[14]

The result of this treaty is truly remarkable, as from the studies we have confirmed that around 99% of ODS usage has been dropped down since 1986.Because of the intensive study and efforts of the researchers, a global issue was resolved before going out of hand.

Techniques used for CFC degradation:

After the Montreal protocol treaty was signed by various countries, many researchers began to develop ways to degrade CFCs without forming byproducts that will harm the environment. Here are some of the methods to degrade CFCs.

1. **Photocatalysis of CFC:** Chlorofluorocarbons (CFCs) are highly stable compounds resistant to photo-oxidation and degraded only by UV-C radiation at higher altitudes in the atmosphere. It is known that fine particles of TiO_2 in the presence of moisture and oxygen, efficiently catalyse photo-oxidation reactions. Ultraviolet light absorbed by TiO_2 particles creates electrons and holes respectively in the conduction and valence bands. Electrons are accepted by oxygen molecules forming superoxide ions O_2^- , whereas holes are consumed by hydroxyl ions on the surface of TiO_2 generating hydroxyl-free radicals OH. This property of TiO_2 is used to oxidise organic contaminants in water and also initiate the photocatalytic reaction in gaseous phase. Experiments are conducted in the gaseous phase using TiO_2 immobilized on glass plates. Results indicate that photogenerated hydroxyl-free radicals are instrumental in oxidative photodegradation of dichlorodifluoromethane. By using TiO_2 as catalyst, the byproducts formed are formaldehyde (HCHO) along with carbon dioxide (CO_2), water (H_2O) and mineral acids.[6]

1. **Biodegradation:** CFC-11 and CFC-12 have been evaluated to ascertain their potential consumption by peat soil from a conifer swamp and a temperate bog. The analysis consisted of collecting several peat cores and injecting them in different concentrations of CFC gases into the cores within a closed and controlled anaerobic bioreactor. This analysis show that CFC degradation occurred quicker under anaerobic methanogenic conditions and that 95% of the CFC-11 and CFC-12 can be degraded within 100 days. The gases produced as a result of degradation of CFCs were carbon dioxide (CO_2) and Methane (CH_4).[7]

2. **Sono-chemical Process:** The Sono-chemical effect is due to the formation of cavitation bubbles, in fluids, which grow through several cycles of the ultrasonic wave and collapse. The collapse is adiabatic and leads to surprisingly high local pressures and temperatures. In water, the local pressure may exceed 500 atm, and the local temperature may exceed 5000˚C. the reaction which take place in this environment, specifically near the bubble or liquid interface are similar to combustion, though reduction as well as oxidation has been observed. The advantage using this method is the complete degradation of CFC-11 in a short amount of time and also less capital intensive. However, some of the drawbacks are the requirement of high operation and maintenance costs associated with creating high frequency sound.[7]

3. **Inductively coupled Radio Frequency plasma:** Since 1990 considerable experiments have been performed in radio frequency plasma destruction systems. Unlike typical DC plasma destruction generation, radio frequency thermal plasma generation inductively heats gases in a magnetic field. The system is composed of

CFC and steam feeders, a plasma generator is connected to a plasma torch, a destruction reactor, a cooling chamber, a gas scrubber, a wastewater treatment unit and other pollution controlling equipment. The CFCs decompose as they come. In contact with steam, which promotes the chemical reaction.[7]

- Transforming CFCs into Useful products

Many studies were carried out to decompose CFCs into desirable useful products to recover marketable commodities. Techniques such as Mineralization and Aromatization of CFCs into various salts, transforming CFC gases into high purity calcium halides, etc. These techniques convert the CFCs into products like sodium fluoride, sodium chloride, calcium chloride, and also carbon dioxide. The release of CO_2 gas is the main disadvantage as it contributes to global warming through greenhouse effect. Though these processes are not perfect but research efforts are made so the degradation of CFCs will not evolve any kind of ODS.[7]

CONCLUSION:

From the review we can understand the significance of Ozone layer for life to be sustainable on Earth. The Earth is the only planet that supports life, and thus preserving ozone layer and reducing the release of greenhouse gasses are the essential steps required for the protection of life. The stratospheric ozone helps in limiting the influx of harmful UV-B and greenhouse gas. Numerous studies have also reported the positive aspects of UV radiations wherein it plays an important role in the evolution of plant and animal species. Therefore, one has to take the larger argument of the protective role of ozone layer along with its phytogenic response. For this purpose, different conventions and protocols have been adopted to control ozone depletion and its impacts on all life forms. These include Vienna Convention in 1985 followed by the Montreal Protocol in 1987 and the Kyoto Protocol in 1997. These protocols banned the use of ozone depleting substances (ODS) in both developed and developing countries. Chlorofluorocarbons (CFCs) have been found to be the main cause of ozone depletion and have many health impacts. On the other hand researchers found and researched on many alternatives for CFCs such as HCFCs and HFCs. According to the studies, it is predicted that the ozone hole formed over the Antartic region will recover on its own till the year 2050-2060. But this outcome is only possible if humans control the pollution and do not release any kind of ODS into the atmosphere in the coming years.

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