Global Warming

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Introduction

Our planet, the earth has been experiencing a continuous increase in its atmospheric temperature for the past 150 years. This has resulted in an enhancement of the warmth of the globe. The additional warmth occurs as a result of entrapment of the earth's outgoing radiation by some tropospheric gases (which are called greenhouse gases) like carbon dioxide, methane, nitrous oxide and chlorofluorocarbons (CFCs) *via* a physical phenomenon known as greenhouse effect.

Greenhouse gases are generated from natural and anthropogenic processes. The dominant natural process is of biogenic nature and occurs due to microbial action on organic matter associated with soils, wetlands, waste dumps etc., The type and the magnitude of gas flux depend largely on the chemical characteristics of organic matter, type of microorganism, redox condition and temperature. Other major natural processes responsible for greenhouse gases are volcanic eruptions and forest fires. The anthropogenic processes vary widely from wetland and soil management for agriculture to fossil fuel combustion for energy needs. Invention of purely synthetic gases in the halogenated hydrocarbon series for use as refrigerants, fire retardants, etc., aggravated the problem.

The earth has undergone numerous natural climatic changes during its 5 billion year history. However, the present day climate started at the beginning of the last ice age about 18000 years ago. Until the beginning of industrialization in the early 19th century only natural processes were responsible for the presence of greenhouse gases in the atmosphere. The greenhouse effect in that era acted in an environment friendly manner since the earth's thermal balance was maintained by it. In the absence of greenhouse gases in that era, the surface temperature of the earth would have been around -18°C and, as such, life would not have evolved on the planet. The nature itself adapted a self consistent balance among its spheres (i.e. atmosphere, lithosphere, hydrosphere and biosphere) to maintain global temperature, on the average, at 15°C. The cause for concern is, therefore, the enhanced greenhouse warming due to continuous addition of gases that accompanied scientific and technological development. With the advent of industries, better medical facilities and enhanced food production as direct benefits of scientific and technical developments, the world's population grew unabetedly. Within just 37 years between 1950 and 1987, the global population doubled from 2.5 billion to 5 billion. In line with the increase of the inhabitants, the demand for necessities and luxuries of life rose rapidly. Today, about 25% of the world's population living in economically developed countries consume 80% of the world's natural resources to fulfil their food and energy requirements. About 40% of all carbon dioxide injected into the atmosphere is emitted by only 11% of the world's population living in seven most economically developed countries. The demand for necessities and luxuries were not met without a heavy cost on the atmospheric environment in terms of additional burden of greenhouse gases. During the last four decades, a remarkable increase in carbon dioxide and methane have been observed.

It has been estimated that the earth's average surface temperature has risen by about 0.5°C during the past 100 years and model predictions suggest an acceleration of the increase if the current rate of emissions continues unabated. Severe consequences of this could be expected commencing from mid 21st century. Sea level rise due to polar ice cap melting followed by flooding of low lying areas and fertile deltas, change in weather patterns and loss of some biological species and vegetation are the main dire consequences. Scientific investigations on the methods and means of averting such a catastrophe are well underway in many parts of the world. In the meantime, intergovernmental agreements have been manifested to curtail present greenhouse gas emissions down to 1990 level, on country basis.

Greenhouse effect

As early as in 1861, the similarity between a greenhouse made of glass roof and walls and the earth's atmosphere with respect to heat trapping was recognized by John Tyndall. However, the famous Swedish chemist, Arrhenius is reputed to have originally coined the term, greenhouse effect, in 1896 to represent the impact of the CO_2 content of the atmosphere on the vertical contribution of temperature in the atmosphere. The sunlight which is the source of energy of the earth is received as radiation, mainly in the visible region of the eléctromagnetic spectrum (Figure 1). The radiation from this segment of the spectrum is not absorbed significantly by atmospheric gases. However, harmful UV radiation of the incoming light is largely cut off by stratospheric ozone and only a small percentage penetrates the ozone barrier. Of the incoming radiation, 31% is reflected by clouds, atmospheric particles and earth's surface while remaining 69% is absorbed by stratospheric ozone, by clouds, aerosols and water molecules in the troposphere and, mostly, by the earth's surface. The earth's surface absorbs 48% of the total incoming radiation (or 70% of the total non reflecting component). To maintain the energy balance, long wave radiation equivalent to that of absorbed shortwave radiation needs to be emitted to space. The bulk of this energy should be emitted from the primary absorber of incoming radiation, the earth's surface. In the emission process, the earth's surface acts like a black body and emits radiation within the infra red segment (i.e. thermal radiation) of the electromagnetic spectrum. As shown in Figure 1, some gases in the troposphere (i.e. 0-12 km region of the atmosphere) absorb the outgoing long wave radiation and re emit in all directions, thus, redirecting a significant amount of the heat radiation back to earth. As a result, the earth's surface goes through the same cycle of processes until energy balance is established.

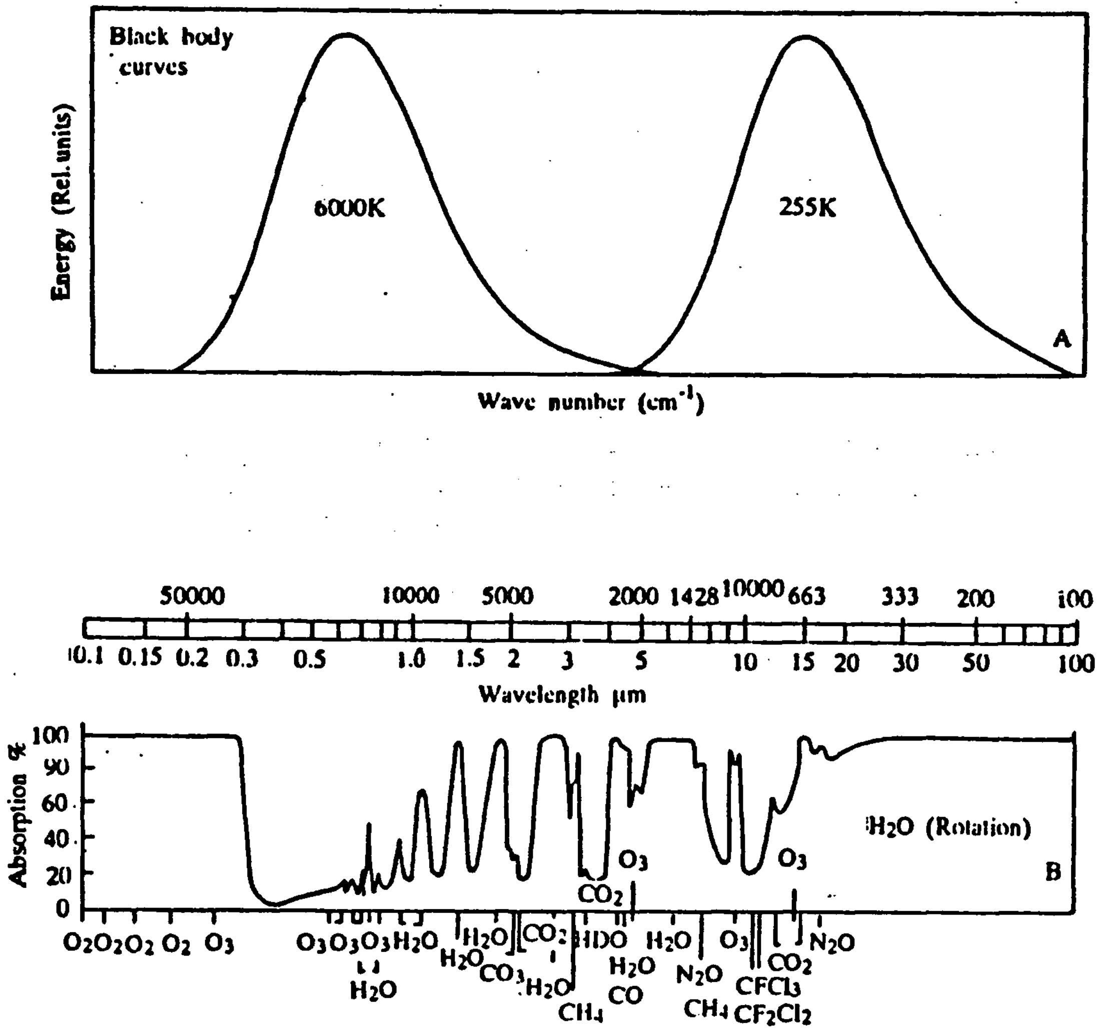

Figure I (a) Spectral distribution of black body radiation emitted by the sun (6000K) and the surface of the earth (255K)

(b) Spectral distribution and percentage of atmospheric absorption of incoming solar radiation.

This gives rise to an increased warmth in the atmosphere. The gases in the stratosphere (i.e. 12-50 km of the atmosphere) or above do not contribute to greenhouse warming.

The contribution of each greenhouse gas to the global warming potential is an integrated effect of its average mixing ratio (i.e. atmospheric concentration by volume), radiative forcing (i.e. extent of radiation absorption) and life time. Table 1 summarizes some important data of the principal greenhouse gases. Carbon dioxide, methane and nitrous oxide levels in the atmosphere increased rapidly since the beginning of industrial era and now stand at 350 ppmv, 1.72 ppmv and 310 ppbv, respectively. Man made chlorofluorocarbons did not exist in the atmosphere before 1920. Their present levels vary from 10 pptv for CFC -115 to 470 pptv for CFC 12. Their average life times in the atmosphere (i.e. 55-550 years) are much greater than that of CH_4 (10.5 years) and, as a whole, falls within the same domain of those of CO_2 (120 years) and N_2O (132 years). The radiative forcing of a gas is dependent on the strength of its absorption band. Relative to CO_2, the radiative forcing of CH_4, N_2O and CFCs are 21, 206 and 10,000-18,000 times greater. Therefore, even if the actual mixing ratios of some gases like CFCs are much lower than that of CO_2, their contribution to global warming potential is quite significant. The fact that the existing tropospheric CO_2 concentration absorbs almost all outgoing infra red radiation specific to its adsorption frequency but that there is an ample opportunity for CH_4, N_2O and CFCs to trap radiation corresponding to their absorption region (i.e. 7-15 μm) further emphasizes the danger of increases in latter gases (Figure 1). The present contribution of greenhouse gases to global warming follows the order CO_2 (50%)> CFCs (25%)> CH_4(15%)> N_2O(5%).

In the absence of human interferences, greenhouse gases were generated entirely by natural processes which were maintained at an equilibrium by the natural biogeochemical cycles occuring among the different spheres of the earth, atmosphere, hydrosphere, lithosphere, and biosphere. With the intervention of human beings, enhanced emissions of greenhouse gases from purely anthropogenic (e.g. fossil fuel burning, CFC gases) and altered natural (e.g. wetland management, animal husbandary) processes have come into the picture. The natural sinks were not sufficient to cope up with the rising abundance of gases. This created a surplus of gases in the atmosphere giving rise to additional global warming.

Table 1. Some characteristics of greenhouse gases

Greenhouse gas	Average mixing ratio, ppmv	Lifetime (years)	Greenhouse heating, Wm^{-2}	Rediative forcing per molecule change relative to CO_2	Growth rate % per year
Water vapour	3000	-	100	-	-
CO_2	350	120	50	1	0.45
CH_4	1.72	10.5	1.7	21	0.9
N_2O	0.310	132	1.3	206	0.25
CFC 11	0.000028	55	0.06	12400	4
CFC 12	0.000047	116	0.12	15800	4
CFC 115	0.000010	550	-	14500	12
HCFC 22	0.000081	16	-	10700	6
*O_3 (Tropospheric)	0.01-0.1	-	1.3	-	-

* Note: Tropospheric O_3 is also a minor greenhouse gas

Water vapour

Water vapour is the chief greenhouse gas. Its amount in the atmosphere is controlled by natural processes and it has a self consistent balance. Therefore, water vapour is considered as an internal constituent of the earth-atmosphere system. However, the global warming due to other greenhouse gases has a positive feedback on the contribution of water vapour to the global warming because the higher the atmospheric temperature, the greater will be the water vapour content in the atmosphere.

Carbon dioxide

The mean annual CO_2 concentration is relatively homogeneous throughout the troposphere because of the mixing of CO_2 within a time scale of about 1 year. The pre industrial atmospheric CO_2 concentration has been estimated to be about 280 ppmv and, today, the level is about 350 ppmv with an annual growth rate of 1.6 ppmv. Model calculations predict a CO_2 concentration of 480 ppmv by the year 2050 if the present rate of emission continues. Fossil fuel combustion and deforestation coupled with biomass burning are the two main sources of atmospheric CO_2.

$$[C] + O_2 \rightarrow CO_2$$

The biomass left to decay in the deforested areas also produce CO_2 as a result of microbial action on organic matter. If organic matter is represented as CH_2O for simplicity, the above process can be shown by

$$CH_2O + O_2 \rightarrow CO_2 + H_2O \qquad -475\ KJ$$

Deforestation also contributes indirectly to CO_2 accumulation in air since the fixing of the gas by the vegetation through photosynthesis is reduced. In fact, one of the means of sinking CO_2 is reforestation but it cannot be realistically done in par with the level of CO_2 growth because of limitation of land and other resources.

$$6CO_2 + 6H_2O \xrightarrow[\text{light}]{\text{Chlorophyll}} C_6H_{12}O_6 + 6O_2$$

The exchange between the atmosphere and the ocean also plays a significant role in controlling atmospheric CO_2. The ocean becomes a source of CO_2 if the surface mixed layer has a higher partial pressure of CO_2 than the atmospheric air and acts as a sink otherwise.

Methane

The present global average methane mixing ratio is about 1.72 ppmv and the rate of increase is about 1% per year. Annually, about 505 Tg of methane is released to the atmosphere, predominantly due to anaerobic microbial activity on organic matter. The major sources of biogenic methane production include wetlands (including rice fields), waste dumps and enteric fermentation in ruminant animals. The biogenic decomposition process starts with the action of aerobic microbes on organic matter in the presence of oxygen

$$CH_2O + O_2 \rightarrow CO_2 + H_2O \qquad -475\ kg$$

When free oxygen in the surrounding environment gets depleted the organic matter decomposition continues by anaerobic microorganisms using oxygen, sequentially, from NO_3^-, MnO_2, $Fe(OH)_3$ and SO_4^{-2} in the medium and finally from the organic matter itself. CO_2 or carbanate species are produced in the initial phases but CH_4 is also generated in the last phase.

$$5CH_2O + 4NO_3^- \rightarrow 2N_2 + 4HCO_3^- + CO_2 + 3H_2O \qquad -448\ KJ$$

$$CH_2O + 2MnO_2 + 3CO_2 + H_2O \rightarrow 2Mn^{2+} + 4HCO_3 \qquad -349\ KJ$$

$$CH_2O + 4Fe(OH)_3 + 7CO_2 \rightarrow 4Fe^{2+} + 8HCO_3^- + 3H_2O \qquad -114\ KJ$$

$$2CH_2O + SO_4^{2-} \rightarrow H_2S + 2HCO_3^- \qquad -77\ KJ$$

$$2CH_2O + H_2O \rightarrow CH_4 + CO_2 + H_2O \qquad -58\ KJ$$

Furthermore, incomplete combustion of biomass and fossil fuel gives rise to relatively small quantities of methane.

The main methane sink is the chemical loss due to the reaction with OH radical in the troposphere

$$CH_4 + OH \rightarrow [CH_3O_2] \rightarrow [CH_3O] \rightarrow CO \rightarrow CO_2$$

and the reaction with photolytically generated O in the stratosphere (methane diffuses upwards to the stratosphere).

$$CH_4 + O \rightarrow [CH_3O_2] \rightarrow [CH_3O] \rightarrow [CH_2O] \rightarrow [CHO] \rightarrow CO \rightarrow CO_2$$

Soils also adsorb a small amount of atmospheric CH_4 and, in the presence of aerobic conditions, convent CH_4 to CO_2 by microbial action. The annual atmospheric increase of CH_4 is about 9% of the total emission.

Nitrous oxide

The global average nitrous oxide concentration has been relatively stable at 285 ppbv for almost 2000 years prior to 1700. The mixing ratio started to rise slowly since then and now stands at 310 ppbv. Current atmospheric growth rate is about 0.6 ppbv (0.2%) per year. The total input of N_2O to the atmosphere is estimated to be 8-16 Tg per year which mainly comes from the denitrification process occurring in anaerobic nitrogenous soils and the ocean by the action of denitrifying bacteria.

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

Chemical fertilizers also contribute a significant amount due to evaporation, chemical decomposition etc. Combustion of biomass and fossil fuel also emit several Tg of N_2O to the atmosphere. However, there are significant uncertainties associated with the estimated inputs from the ocean, fertilizer and the soil.

Nitrous oxide is primarily removed by photochemical decomposition and reaction with O in the stratosphere (after diffusing into this region from the troposphere).

$$N_2O + h\nu \rightarrow N_2 + O$$
$$N_2O + O \rightarrow 2NO$$

Tropospheric sinks such as surface loss in the aquatic and soil systems due to nitrification process are considered to be small. Because of the high uncertainties in the estimates of sources and sinks, the net input to the atmosphere varies between 5-7 Tg/year (i.e. ±17 %).

Halocarbons

Halocarbons that are mainly responsible for global warming belong to chlorinated and brominated hydrocarbon series. The former series popularly known as chlorofluorocarbons (CFCs) came to existence in 1920 as a result of research in synthetic chemistry and, since then, has been widely used as refrigerants and aerosol propellants and in plastic industry. Approximately 85% of the manufactured CFCs have already been released to the atmosphere. It is estimated that approximately a total of 1 million tons (i.e. about 1 Tg) of various CFCs are released to the atmosphere every year. The volume mixing ratios of CFCs which were non existent in the atmosphere before 1920, currently stands at 0.20 ppbv and 0.48 ppbv, respectively, for CFC -11(CCl_3F) and CFC-12 (CCl_2F_2), two widely used members of the CFC family. Other significant CFCs, as far as the global warming is considered, are CFC 113 ($C_2Cl_3F_3$) and HCFC-22 ($CHClF_2$). Simple halocarbons such as CCl_4 and CH_3Cl also behave like greenhouse gases.

Almost all brominated hydrocarbons (excluding few gases such as CH_3Br which may have both anthropogenic and natural origins) are man made. Frequently used members of this class of compounds are Halon 1211 (CF_2BrCl) and Halon 1301 (CF_3Br) for fire retardation and CH_3Br for cereal fumigation. Halon 1301 has increased from an average tropospheric value of 1.25 pptv in 1987 to about 2.0 pptv in 1990.

The halocarbons are very stable in the troposphere. With time, they diffuse into the stratosphere and get destroyed by photodissociation. However, this process generates Cl radical which is a precursor of ozone destruction process.

$$CFCl_3, CF_2Cl_2 \xrightarrow[180\text{-}220\ \text{nm}]{h\nu} Cl_2 \xrightarrow[240\text{-}450\ \text{nm}]{h\nu} 2Cl$$

Consequences of global warming

The available records of the average global temperature suggest that there has been a warming of atmosphere by about 0.5 °C over the last 100 years. Model calculations suggest even a higher temperature rise between 0.6 and 2.4 °C for an equilibrium surface warming. Global warming will have an effect on the sea level due to two processes, both of which contributing to a rise in the ocean water table. One is the thermal expansion of the surface layer of sea water and the other is the increased melting of glaziers in the temperate region. A sea level rise of about 1-2 cm has been noticed in Tokyo and New York during 1940-1980 period. The sea level rise will inundate low lying areas and fertile deltas rendering them uninhabitable and making certain types of flora and fauna extinct. Other probable climatic changes include variations in rainfall and wind pattern. For instance, a large inter annual variability which is believed to be above normal has been observed in the Indian sub continent, leading to widespread droughts and floods. Another study indicates that the frequency of storm situation over the North Sea has increased since 1950.

The altered climate will also seriously affect the agriculture and forestry. Increased CO_2 will affect the photosynthesis and increased temperature will cause heat stress and evapo-transpiration in crops. Escalation of pest growth, changing soil moisture levels and intensified spoilage of stored agro products by enhanced microbial activity are some of the indirect effects. Shift in productive area and reduced yield could also result. In off shore, growth of phytoplanktons, fish yield and their migratory patterns etc., could get affected. The incidence of vector borne diseases such as malaria and filariasis could increase. Sea level rise could also increase the salinity of fresh waterbodies such as rivers, affecting quality of drinking water supplies to urban population, in particular.

Abatement of global warming

The abatement of global warming depends on how much of greenhouse gases released by various anthropogenic sources can be curtailed. Realizing the need for controlling infra red absorbing gases, a global effort is continuing to come to consensus among all countries as to how and when each country should cut down its emissions and by how much it should be. Already developed countries have agreed to reduce their greenhouse gas emissions down to 1990 level by the year 2000. Developing countries have been given a longer time frame for this task. Meanwhile, all the countries have agreed to develop methodology and to formulate regulation for promoting low greenhouse gas emanating technologies, for sustainable management of ecosystems and for introducing adaptation strategies.

Research is already underway to develop alternative agricultural and industrial technologies to mitigate greenhouse gas emissions. It has been already agreed for a complete global phase out of the production of CFCs by the year 2000. These will be replaced by recently developed HFCs and HCFCs which show much shorter lifetimes (1-50 years) in the atmosphere. Methods for controlling methane in ruminant animals (e.g. type of diet), in rice cultivation (e.g. effect of rice varieties, fertlizer and water regime) and in landfills are currently investigated. In the energy sector, development of more efficient fuel combustion techniques and alternative environment friendly technologies (e.g. solar power, wind power) as well as optimization of available power generating processes are under study. Extensive biomass burning in highly inefficient stoves and open-hearths is a major source of greenhouse gases in the developing countries. Improved methods are required for the abetment of gas emission in this sector. Extensive reforestation programmes are essential to minimize fast depletion of the forest which is a natural sink of CO_2. The awareness among the public is also of utmost importance as far as mitigation of greenhouse gases are concerned.