38
Green House Effect and Its Control

38.1. INTRODUCTION

The pollution caused by thermal power plants and nuclear power plants to the earth atmosphere was considered seriously for last four decades and handled very effectively by providing many advanced methods to remove and control poisonous gases and particulates from the exhaust. The effect of CO_2 was never considered so seriously as thought during the current decade as it has no harmful effect on the human health or biological life. Otherway, the presence of CO_2 was considered essential for the O_2 balance on the earth.

Even though, CO_2 has no ill-effects on human or biological health of the earth, its present trend of increase in atmosphere has created a great threat to the human being for his survival as its major impact on the earth is the commonly known as Green House Effect (Increasing the temperature of the earth surface slowly).

The present time is also the most appropriate time for correcting the most serious mistake made during 20th century which has posed a serious threat to some of the most cherished values of humankind and in some cases to the very survival of most forms of life on the earth.

Rapid industrialisation world-wide has adversely affected the atmosphere with the CO_2 concentration, arising mainly from combustion of fossil fuels, increasing steadily over the past four decades. We have understood now, the damage which we have made to our living atmosphere for our more and more comfort and now we have reached to a stage to consider the measures to be taken immediately to stop further damage.

The earth has entered a period of climatic change that is likely to cause widespread economic social and environmental dislocation over the next century if emissions of heat trapping gases are not reduced. The undesirable global climate change is indeed in progress and that at least some of the warming is due to human action, specifically by burning coal, oil and wood for power generation, transport and cooking.

Without any doubt, the 20th century has been catastrophic from the point of view of environment. For the first time in the earth history, planet level threats have emerged as a result of man's own actions. Two major threats are Global Warming and Depletion of Ozone (O_3) layer. Of these, the second one is much easier to tackle as it involves only a few specific gases to be controlled whereas in meeting the first threat, drastic reduction in overall energy consumption (which is responsible for CO_2 emission in atmosphere) is inmediately required.

*The effects of CFCs on the depletion of O_3 layer and its effects on global warming is detected and effective measures are already taken to phase out CFCs by safe group of refrigerants by the year 2010 partly and by the year 2050 fully.

The scientists suggest that by doubling the green house gases (CO_2 and CFCs) can increase the earth temperature by 0.5 to 5°C by trapping global heat. It is also concluded that industrial nations will do little to stop CO_2 from increasing because stabilising CO_2 concentration even at double of today's level (350 ppm) over the next 100 years can be attained only if emissions eventually drop substantially below the 1990 level (335 ppm). This is partly because, these gases remain in the atmosphere for many, many years. CO_2 accounts for 70% of all so called green house effects. And if increase in CO_2 in atmosphere is continued, it could cause the earth to warm up a few degrees (5°C) which is enough to cause serious climate and social problems. The water level may go up by 3 m in Newyork, Losangles, Bombay and Bangladesh and will have difficult time in coming future.

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*There is separate chapter on this topic in the book "Refrigeration and Air-conditioning" by the same author and interested readers are advised to refer that book for further details.

Increasing trend of CO_2 in the atmosphere has definitely posed some serious problems before the environmental scientists :

(*i*) The first question is, how much CO_2 will be added to the atmosphere in future years and at what rate by burning the fossil fuels and clearing the forests ? These human activities have already increased CO_2 in atmosphere by 1.5%.

(*ii*) Second question is, whether the increase in CO_2 will cause an important global rise in average temperature and other changes in the world climate ?

(*iii*) The third question is, whether the possible climate changes due to increase in CO_2 in the atmosphere would have major consequences on human life ?

The answer to all three questions is yes and therefore, it has become essential to take steps to curb the CO_2 increase in atmosphere to maintain the comfortable human life on the earth.

The environment is now one of the fastest growing areas in terms of career opportunities, albeit for all the wrong reasons—the growing importance of an environmental engineer, pollution control specialist or an environmental lawyer is quite comparable to that of a doctor in the midst of an epidemic. Growing levels of industrial effluents, stricter pollution control laws and increasing industrial activity, are now making environmental professionals indispensable in the manufacturing sector.

At the industrial level, environmental engineering is one of the more lucrative areas. An environmental engineer works at preventive as well as curative levels on pollution control. Depending on the raw materials and production process, the residuals of a manufacturing activity, in the form of processed wastewater, atmospheric waste, unutilised materials, emissions, sludge and solid waste at various stages, need to be handled and minimised. The environmental engineer's job profile involves assessing the environmental impact of a particular manufacturing activity, devising system packages for industrial clients, manufacture and maintenance of pollution control equipment, evolving 'low or no waste technologies' and modification of the manufacturing system itself, with the view to optimise resource use and minimise waste and ecological damage. He ensures that a plant meets standards set by the central and state pollution control boards, ISO standards and environmental laws. Consultancy firms, conducting studies on environmental impact assessment, pollution level analysis, and air, soil and water quality, also employ environmental engineers.

Another related area is energy engineering, which among other things involves developing energy-efficient technologies, and non-conventional energy sources, nuclear reactor engineering, Bio-mass energy, wind power and solar energy systems, power generation and system planning, as alternatives to conventional electrical power.

38.2. CO_2 AND ITS ROLE IN THE BIOLOGICAL LIFE

Atmosphere is made of N_2 and O_2 with small percentages of other gases as CO_2, NO_x, CH_4, O_3 and man-made gases as chlorofluoro carbons (CFCs). Very small percentages of these gases determine to a large extent the effects on own planet. However, they all are presently undergoing rapid changes in their atmospheric concentrations as a result of human activities. The two problems created by their changes are Green House Effect (responsible for the increase in global temperature) and statospheric O_3 depletion which has created a life threatening by exposing the earth to ultraviolet radiations.

CO_2 is not considered a toxic gas. It is not even considered a pollutant but its presence in atmosphere is considered essential for photosynthesis and production of O_2 which is most essential requirement of human life. However, higher concentration of CO_2 produces respiratory problems, and carboxyhimoglobin in blood and deprives brain from O_2.

CO_2 is colourless and odourless gas that does not support combustion but it is one of the most important ingredients of the planets' biosphere. Exchanged between plants and animals, air and sea, at a rate of hundreds of billions of tons per year CO_2 arises from and helps to sustain the life on Earth. Carbon, one of the components, is the very essence of life. It comprises the backbone of all organic molecules, of which all living things are made. It combines with O_2 which provides animals with the energy needed to drive their

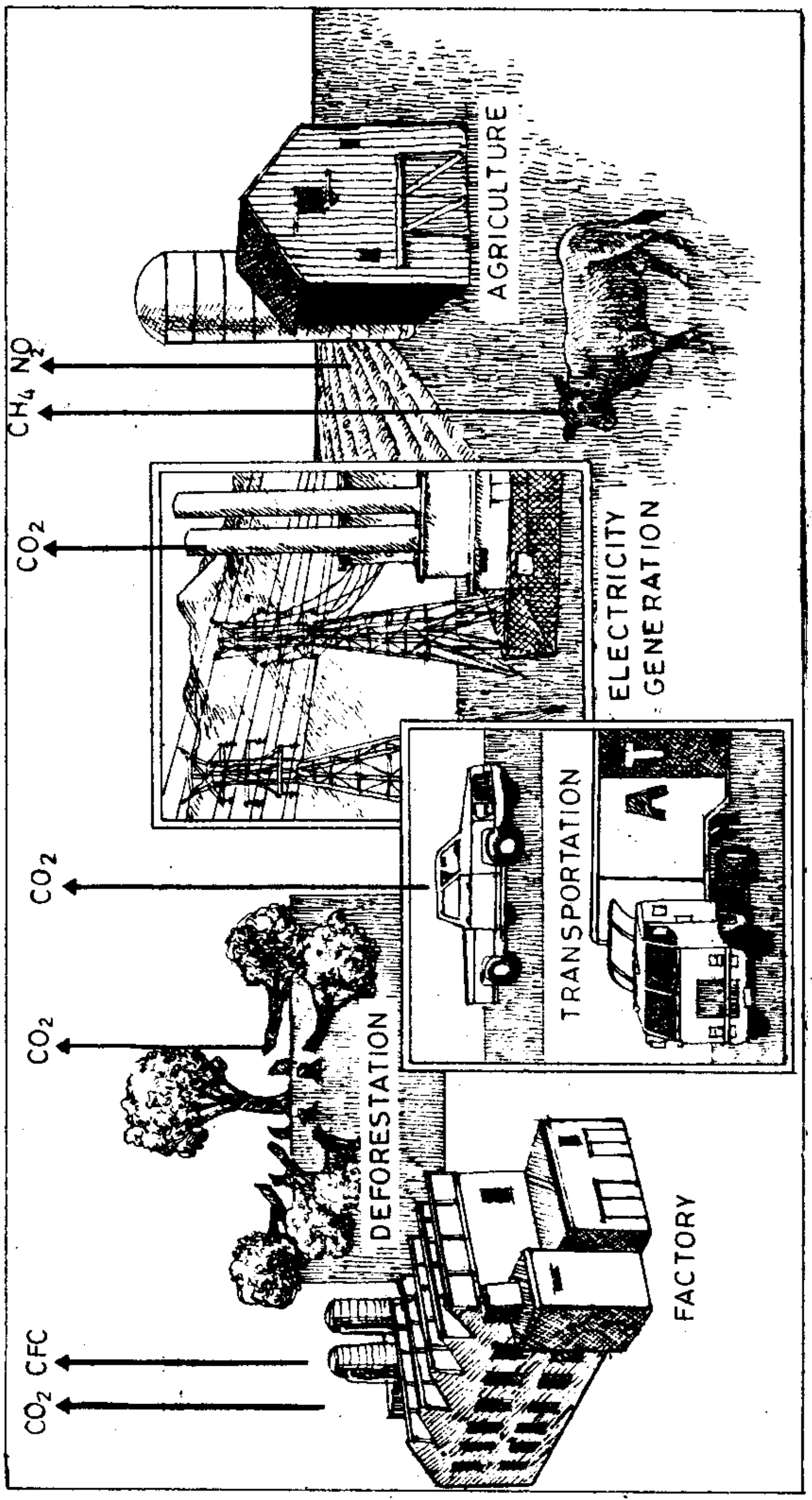


Fig. 38.1. CO_2-emission from man made sources.

biological processees. The gas itself is exhaled into the atmosphere and in turn is taken in by plants, which use the molecules, plus H_2 from water, to take carbohydrates for building new tissue.

CO_2 is only 0.03% of the atmosphere by volume (or 2.25 trillion tons). Its heat trapping quality is partly responsible for the climate that has been so hospitable to life on earth.

The quantity of CO_2 emitted naturally and by manmade causes are listed below.

Natural causes	*Amount tons/year*	*Manmade causes*	*Amount (tons/year)*
Organic decay	2×10^{12}	Combustion (power plants)	2×10^{10}
Volcanoes	1×10^{12}	Industry	2×10^{6}
Respiration	1×10^{12}		

Total $(A + B)$ steady state = 3×10^{12} tons/year (325 ppm)

The man-made causes of increasing CO_2 in air are shown in Fig. 38.1.

It is obvious that CO_2 contribution is mainly by natural causes, even then, the power plant and transport combustion also contribute significantly. Therefore, the CO_2 is continuously increasing in the atmosphere as it was 312 ppm in 1940, 318 ppm in 1960 and expected to be 350 ppm by 2000.

The level of CO_2 in the atmosphere is maintained steady state by photosynthesis which reduces CO_2 and increases O_2 in the atmospheric air. The photosynthesis is a process which is carried out by the green plants by absorbing CO_2 and moisture in the air and convert them in O_2 and organic matter in the presence of sunlight.

There must be sufficient green plants to absorb generated CO_2 and convert into O_2 but when the CO_2 emitted rate is higher and number of green plants is decreased, then the CO_2 steady state condition is achieved at higher concentration in the air and this is what is happening because of increasing demand of power worldwide and large cut-outs of forest trees because of increased rural population who use wood as basic fuel for them.

The present CO_2 emission into atmosphere is 5700 crore of tons per year from man-made causes and forest area only in India is shrinking at a rate of 1.5 lac hectors per year (the major dams construction is responsible for only 12% and remaining is 88% by other causes). This scene is very panic as both are equally responsible to increase CO_2 percentage in air. Therefore, there is demand to reduce the power requirement and increase the forest area by artificial plantation. Many measures are already in process throughout the world to reduce CO_2 by different methods which will be discussed at the end of this chapter.

38.3. WHAT IS GREEN HOUSE EFFECT

In many countries, where sun energy is not easily available, for the cultivation of fruits and vegetables, is made available for their growth through green house effect. The term *Green House* was first brought into use by Swedish Scientist Swante Arhensum in 1896.

A green house, as shown in Fig. 38.2 (*a*) is a house made of complete glass where the vegetables are cultivated. In this house, the solar energy at shortwave radiation enters inside through the glass as glass is almost (80-90%) transparent to short wave radiations. This shortwave radiation when strikes the inner earth surface of the green house, converts into heat-longwave radiation. This longwave radiation is again reflected back into atmosphere from the inside surfaces but it cannot go out as the glass restricts the longwave radiation going out and traps the heat. This trapped heat (which should not have happened without glass) contributes to the warming of glass house and provides energy for the growth of plants. This trapped energy essential for the growth of plants keeps the plants green. Therefore, this effect is known as Green House effect. The earth surrounding atmosphere behaves just like glass and keeps the earth green. Therefore, this effect is also popularly known as Green House effect.

Warming of the atmosphere and subsequently the earth surface warming takes place because of green house effect. The atmosphere contains radiatively active substances like CO_2, water vapour and other trace gases that contribute towards the warming up.

In bodies without an atmosphere, like moon, the sun facing side is unbearably hot because the radiation from the sun strikes it directly and heats its surface. The dark side is bitterly cold because, the heat it catehes during the "*day*" is lost in "*night*". But on earth, the thick blanket of atmosphere (nearly 200 km) prevents heat from escaping to space. Actually, the atmosphere is almost transparent to shortwave radiation and therefore all short wave solar energy (95% lies in between 0.4 to 8μ wavelength) reaches the earth. This radiation is converted into heat-longwave radiation which is then re-radiated. These longwave radiations cannot get through the atmosphere as easily as shortwave radiation. It remains trapped by the air and this trapped heat which contributes to the general warming of the earth and creates temperature conditions conductive to the human and biological life. The earth green house effect is shown in Fig. 38.2 (*b*).

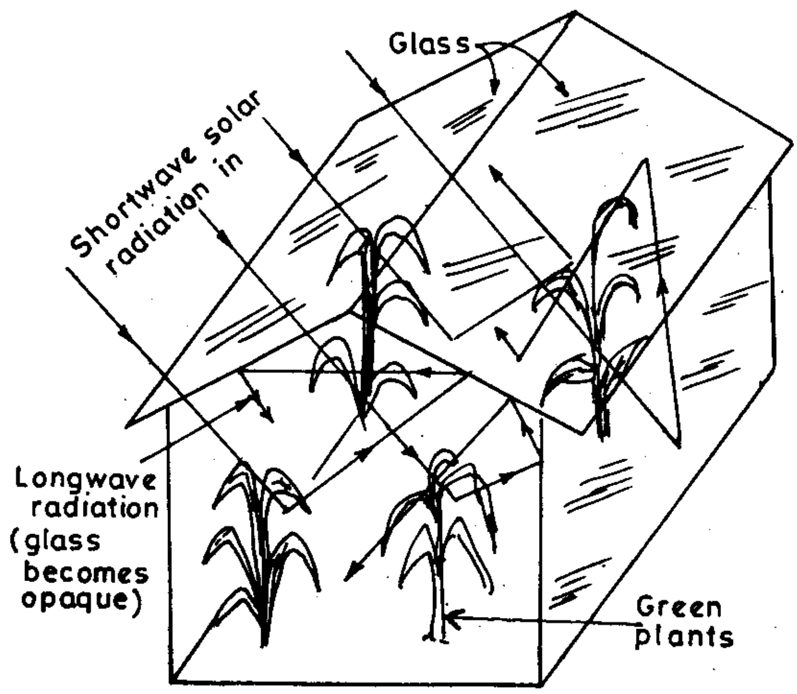


Fig. 38.2 (*a*) Green House.

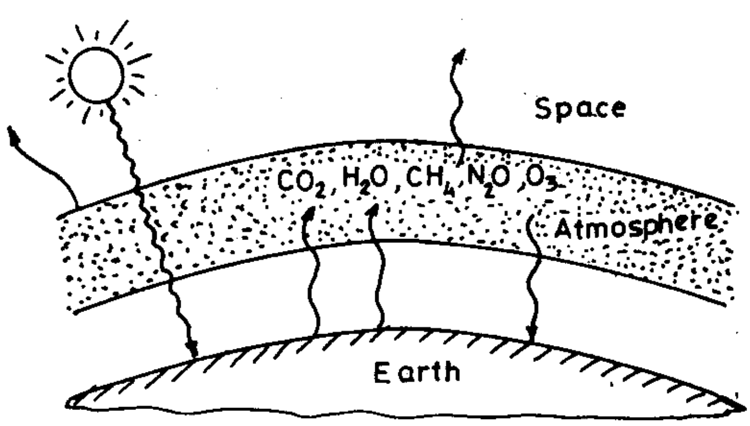


Fig. 38.2. (*b*) Greenhouse gases trap long wavelength energy from the earth's surface, heating the atmosphere, which, in turn, heats the earth.
(Earth as a greenhouse)

In the process of green house effect, the visible light comes in as it would have, if there was no atmosphere. But, the atmospheric gases transparent in the visible part of the solar spectrum tend to be opaque in the longer infrared part of the spectrum. The thermal radiation in the infrared is impeded from getting out, resulting in the blanketing of the earth in the infrared spectrum but not in the visible part of the spectrum.

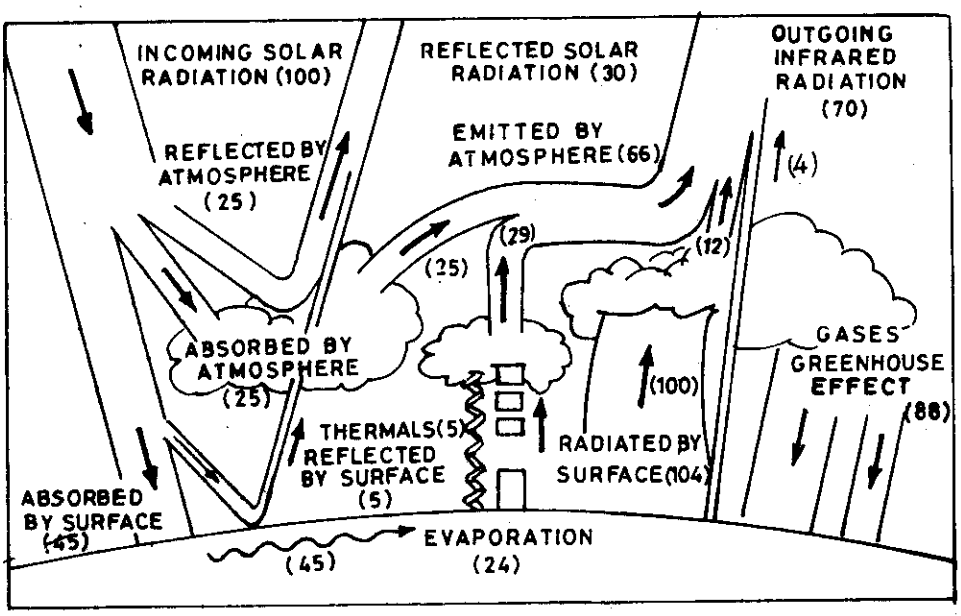


Fig. 38.3. Solar radiation and greenhouse effect.

As a result, the earth surface temperature has to go up until the radiation which is leaking out in the infrared just balances the visible radiation that is coming in. Fig. 38.3 explains the greenhouse effect in terms of various radiation components. The numbers in the brakets are in terms of the percentage, each arrow represents relative to earth-average solar constant of 340 W/m^2.

However, if too much heat is held back, life can be endangered. Such a runaway "Green House Effect" occurs on venus which has an extremely dense CO_2 rich atmosphere. The surface temperature of the venus is 477°C. It is not because it is close to the sun, but it is because of the dense surrounding layer of CO_2 in its atmosphere.

If no green house effect existed on earth, the average temperature would be – 19°C well below the freezing point of water and hence, incompatible with any form of life as we know it. Most of the heat entered from sun into earth atmosphere is re-radiated but in the process, a delicate balance is maintained which keeps the earth surface at an average temperature of 15°C. It is obvious to understand how crucial the green house effect is in keeping us warm and comfortable. But too much of good thing can have the opposite effect, like on venus.

This green house effect has been working from the very birth of the earth. It has helped in the development of the environment over the earth. The animals, birds and vegetation all are tied up with each other as an ecosystem which has a self-ecological balance like human health. The excessive rise in population, excessive cutting of the forest and unlimited rise in power generation causes an imbalance of the ecosystem, naturally, such a significant imbalance rarely occurs. This kind of disturbance in the ecocycle is predicted like eruption of volcanos and floods. The nature has proved to be competent enough to restore back the fine ecological balance ***but upto limited range.***

The CO_2 gas in the atmosphere is solely responsible for green house effect on the earth as it is transparent to short wavelength and *opaque* to long wave radiations. Its percentage in atmospheric air will definitely decides how much energy will be trapped into the surrounding atmosphere which is responsible for earth surface temperature. Higher % of CO_2 will trap more and increase the earth surface temperature slowly. Its immediate effect on increase in temperature may be slow as hardly 5°C within coming 100 years but its long term effects are serious and destructive and therefore, it is necessary to take due care before the atmosphere is so much damaged by the human activities.

CO_2 alters the earth's heat balance by acting one way screen as it is transparent to shortwave solar radiation and stops the back flow of heat from long wave radiations emitted from earth surface. This increases the earth surface temperature and this phenomenon is known as **Green House Effect.**

38.4. O_3 (OZONE) AS A GREEN HOUSE GAS

The economic and industrical progress of human being in the long run shows to have caused more harm to the nature and to himself than any good.

Progressive molestation of the nature under the name of development has left not a single sector of nature unpolluted. The most significant and dangerous effect of this pollution has gone too far and demands urgent attention and measures to curb it, is the earth's protective case—the O_3 layer. Ozone has protected the life on earth from the harmful ultra-violet rays since long. Today, it's thinning endangers the life on earth.

The main culprit for this is the increasing use of CFCs which are used on very large scale in refrigeration and air-conditioning industries.

Harm done is irrecoverable though late, recently steps have been taken to prevent future depletion of O_3 layer. In Montreal Protocol, all countries have agreed to bear the costs of switching over to CFCs substitutes to save O_3 layer. India has also signed the protocol in 1992. Accordingly USA has agreed to provide economical assistance of \$ 1.75×10^6 to India to phase out the use of ozone depleting CFCs.

The effect of O_3 in the outer atmosphere of earth has similar effect like CO_2 but the nature of effect is in different form and more serious. The most intensively studied Green House Gas (GHG) is CO_2 and the potential impact of an increase in its concentration has been widely discussed. However, other gases like chlorofluoro carbons (R-11 and R-12) can also significantly amplify the green house effect of CO_2.

The other important gases which are responsible for green house effect are R-11 and R-12, they are popular refrigerant used in refrigeration and air-conditioning industry. Their leakages in the atmosphere act with the O_3 layer and destroys the O_3 molecules.

The solar energy in the range of ultraviolet radiation wave length (which is highly injurious to the human and biological life) is retarted by the O_3 layer and prevents its entry through the atmosphere to the earth. With an extensive study, it has been established that the reactions between R-11, R-12 and O_3 destroys O_3 layer and it has already detected ozone-holes in the upper atmosphere of the earth as shown in Fig. 38.4 (*a*). Therefore, the ultraviolate wavelength energy directly enters into the atmosphere (just like flowing water through a hole on the surface of a pot). This effect of pouring energy through these holes compared with the percolation of energy through CO_2 layer is more serious. These gases (R-11 and R-12) have greater growth rates, stay longer in atmosphere (hundreds of years) and so have greater green house effects than CO_2. For example, on molecular basis, the release of one CFC molecule has the same surface heating effect as the addition of 10,000 CO_2 molecules. The effect of CFCs is more serious than CO_2 but the total effect of CFCs on green house effect compared with CO_2 is (percentage wise) considerably less. Even then, enough care has been taken to wipe-out CFC's from the refrigeration industry by the end of 2020 by replacing the safe refrigerants. The purpose of this chapter is not to discuss the effect of CFCs on green house effect but devote more concerning CO_2 effect as the emission of CO_2 cannot be stopped but it can be reduced by adopting different methods.

The likely concentration trends of other GHGs (green house gases), and their effects are approximated in terms of an equivalent amount of CO_2 because they are radiatively similar to it. At present, the effect of other GHGs is approximately equivalent to an increase of 40 to 50 ppm of CO_2. During the next 50 years, the other GHGs will increase their effects relative to CO_2 through their greater growth rates, longer residence times, and their higher efficiencies. This would result in a green house situation equivalent to CO_2 doubling well before 2050. Therefore, preventive measures must also include controlling the emission of both CO_2 as well as other GHGs.

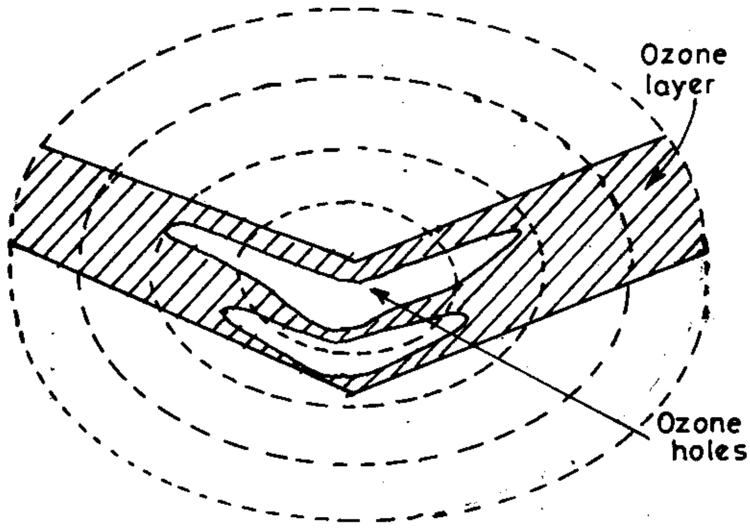
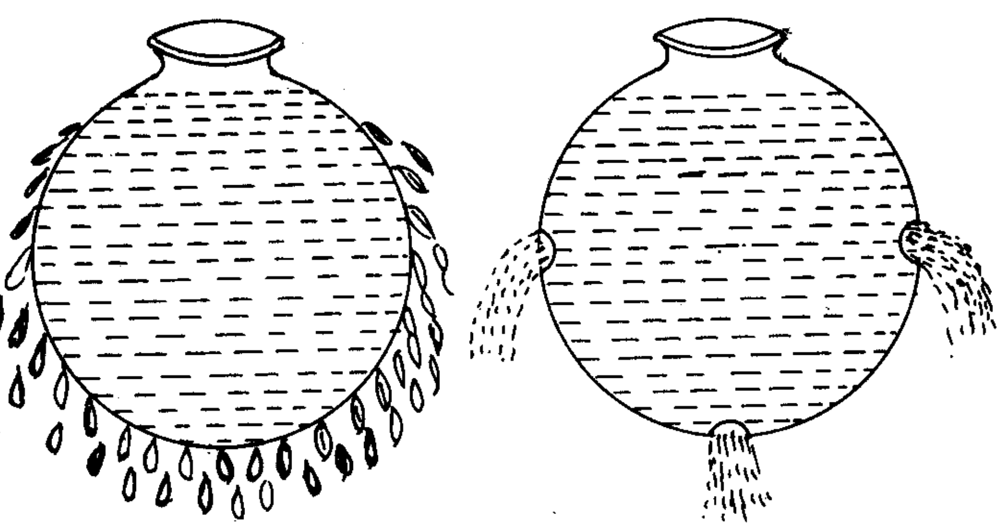


Fig. 38.4 (*a*) The Antarcnc Ozone Hole. The dramatic reduction discovered is shown here.



(*i*) Effect is similar to CO_2 (*ii*) Effect is similar to O_3

Fig. 38.4. (*b*)

The present percentage contribution to green house effect by different gases is shown in Fig. 38.5 and it is obvious that CO_2 contributes maximum to the global warming.

CFCs and CFC Substitutes and their effects on O_3-Depletion and Green House Effect

Substances	*Chemical Formula*	*O_3 Depletion Potential*	*Green House Strength*
CFC – 12	CCl_2F_2	0.90	1.00
HCFC – 22	$CHClF_2$	0.05	0.07
HCFC – 123	$CHCl_2CF_3$	0.15	0.10
HCFC – 124	$CHClFCF_3$	0.50	0.10
HFC – 125	CHF_2CF_3	0.00	0.20
HFC – 134 (*a*)	CFC_3HEF	0.00	0.10
HCFC – 141 (*b*)	CH_3CCl_2F	0.05	0.20
HFC – 152 (*a*)	CH_3CHF_2	0.00	0.10

Table I – Relative share of greenhouse gases responsible for global warming

Greenhouse gas	*Share in additional global warming (per cent)*
CO_2	50 (40 energy related, 10 other factors)
CFC	22
CH_4	13 (partly from fossil fuel exploitation)
O_3	7 (related to NO_x and CO emissions)
N_2O	5
H_2O	3 (stratospheric water vapour)

Table II – Greenhouse Gases in Earth's Atmosphere

Greenhouse gas	*Major sources*	*Total emissions per year (Millions of tons)*	*Average residence time in atmosphere*	*Approximate current concentration (PPB)*
Carbon dioxide (CO_2)	Fossil fuel combustion, deforestation	5,500	100 years	350,000
Methane (CH_4)	Rice fields, cattle, landfills, fossil fuel production	550	10 years	1,700
Nitrous oxide (N_2O)	Nitrogenous fertilizers, deforestation, biomass burning	25	170 years	310
Chlorofluora carbons	Aerosol sprays, refrigerants, foams	1	60 to 100 years	About 3 (Chlorine atoms)

The other gases listed in Table I are chemically far more efficient in absorbing infrared radiation than carbon dioxide. The combined warming effect of these trace gases will soon equal or exceed the effect from carbon dioxide alone [6-7].

There is a large group of natural ozone-cracking substances produced by algae, bacteria and plants. Methyl chloride and methyl bromide are the biggies together accounting for 20% of O_3-depletion. A whopping amount of methyl is generated by natural processes including biochemistry of salt-marsh plants, coastal ecosystems and breakdown of organic matter in soil.

Salt marshes are top producers, even though they constitute less than 0.1% of the global surface area, produces 10% of total atmospheric load of methyl chloride and methyl bromide.

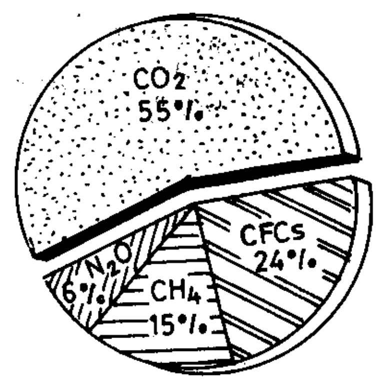


Fig. 38.5. Contribution to Green House Effect by different gases.

Ozone Hole

An ozone layer outside the atmosphere protects the earth from ultra violet rays radiated by the sun as it has high absorption capacity for these rays. Due to large use of CFCs during the last two centuries, the O_3 layer is becoming thinner and thiner as CFCs destroy the O_3 very rapidly. When this was detected by the scientists, the restriction has imposed on its use in 1987 as per Montreal Protocol and plan is adopted to phase out CFCs by 2010.

The O_3 from the atmosphere is eaten out by CFCs and creates a hole and such a hole was detected in 1985 over Antartic. The hole recently detected over South Pole covers nearly 1750 lacs of square kilometer which is three times the area of America. This hole has covered complete Antartica zone and also reached to South America. Such a huge hole was detected in 1998 which covered 1680 lacs of square kilometers. Such hole is expected everyyear but it takes very long time (15—20 years) to fill it up as production of O_3 is a very slow process.

The development of the hole which could extend from the Arctic to the British Midlands, follows a period of usually low temperatures combined with high levels of pollutants in the atmosphere—the ideal formula for O_3-destruction.

The effect of this is minimum over India but there is an Ozone dip.

38.5. THE OTHER GREEN HOUSE GASES (GHGs)

The water vapour and CO_2 are the main GHGs responsible for greenhouse effect. Any gas that absorbs in the infrared will help to reduce the loss of terrestrial radiation to outer space. However, absorption by water vapour and CO_2 is so strong that other gases will contribute little unless they absorb radiation in the range of 8 μm to 12 μm (the atmospheric window) where absorption by CO_2 and water is weak.

The most important trace gases that contribute significantly to the trapping of terrestrial radiation are CH_4, NO_x and CFCs (F-11 and F-12). Methane concentrations are only about 0.5% of CO_2 but it is 21 times as effective as CO_2, while CFCs are only one millionth of CO_2 but 15000 times more effective compared with CO_2.

Methane, currently at 1750 ppb is increasing by 1% annually and is expected to double in about 70 years. The sources of CH_4 emissions are rice paddies, waste disposal and oil recovery operations. Doubling methane would have about 15% of the warming effect of doubling CO_2.

NO_x, currently at 300 ppb is increasing at the rate of 0.25% per year. The main source is combustion. It is estimated that likely increase is about 20% by 2060 and will contribute about 4% to the total greenhouse warming.

The present concentrations of CFCs (F-11, 0.06 ppt and F-12, 0.14 ppt) contributes to global warming to about 0.2 W/m^2 or 12% of total. The trace gases combined now contribute to 50% of total green house effect. Even CFCs emissions are reduced, the green house effect may rise as F-11 have 80 years and F-12 have 1400 years lifetime. If the Montreal Agreement to reduce emissions to 80% of 1986 level from 1993 and to 50% from 1998 is fully implemented, CFCs are likely to contribute about 10% to greenhouse warming in 2060.

The percentage of GHGs and their effects towards greenhouse effect are listed in the table III below.

Table III – Major Greenhouse Gases and their Characteristics

Gas	*Atmospheric concentration (ppm)*	*Annual concentration increase (%)*	*Relative greenhouse efficiency (CO_2 = 1)*	*Current greenhouse contribution (%)*	*Principal sources of gas*
Carbon dioxide	351	0.4	1	57	Fossil fuels, deforestation
CFCs	0.00225	1	15,000	25	Foams, aerosols, refrigerants, solvents
Methane	1.675	1	25	12	Wetlands, rice, livestock, fossil fuels
Nitrous oxide	0.31	0.2	230	6	Fuels, fertilizer, deforestation

The different refrigerants green house effect (O_3 depletion potential) relative to F-11 is shown in Fig. 38.6.

The present refrigerants (F-11 and F-12) are going to be replaced by F-134 *a* and F-143 *a* which have very less warming effects compared with conventional refrigerants as shown in Fig. 38.6.

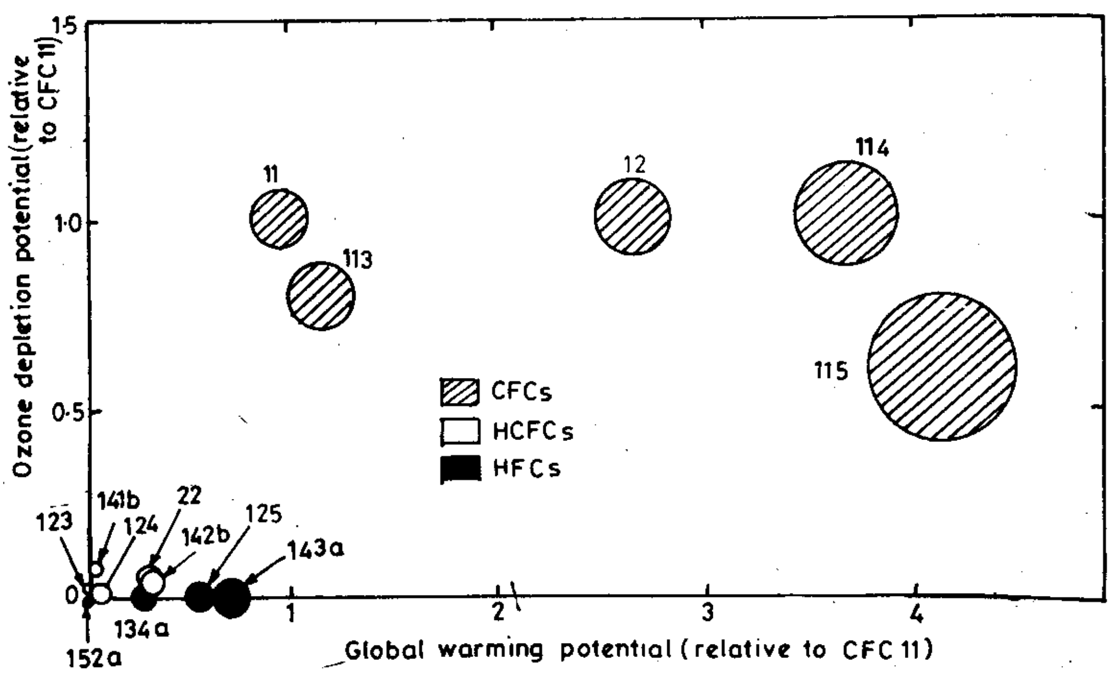


Fig. 38.6. Global warming potential and ozone-depletion potential for fully halogenated (CFCs), hydrochlorofluorocarbons (HCFCs), and hydrofluorocarbons (HFCs) measured relative to F-11 of the circles is proportional to atmospheric lifetimes.

38.6. TREND OF CO_2 INCREASE IN ATMOSPHERE

An assessment of the evolving greenhouse climate requires an estimation of the future trends in concentration of CO_2 and other GHCs. This is a hazardous undertaking because such trends depend on

Table IV – Overview of a selection of greenhouse gases influencing climate

Constituent	Principal anthropogenic sources	Principal sinks and removal processes	Atmospheric residence time	Global average mixing ratio in 1980	Possible increase from 1980-2030 (uncertainty range in 2030)	Potential influence or climate and surface temperature change
Carbon dioxide (CO_2)	Fossil fuels, deforestation, soil destruction	Ocean biosphere	6-10 Yr.	339 ppmv	339-450 ppmv (380-550 ppmv)	Warming in T. Cooling in S. $2 \times CO_2 \rightarrow 3 \pm 1.5°C$ global, 2 to 3 times greater at poles
Methane (CH_4)	Rice paddies, cattle raising, biomass burning, gas leakage, fossil fuels	Photochemical reaction with OH and NO_x. Soils in semi-arid climates, net CH_4-flux from T. to S. Reactions with OH and $O(^1D)$ in S.	9-10 Yr.	1.65 ppmv	1.65-2.34 ppmv (1.85-3.30 ppmv)	Direct and indirect greenhouse effect in T ; influence on chemistry in S. (source of H_2O, reaction with Cl and HCl-formation) $2 \times CH_4 \rightarrow 0.3°C$
Ozone (O_3)	Indirectly produced through photochemical reactions with other substances	Through oxidation of CO and NO under the influence of NO ; catalytic reactions with *e.g.* NO_x, Cl_x, HO_x in S.	30-90 dy(T.) 2 Yr. (S.)	0.02-0.3 ppmv (T.) 5-10 ppmv (S.) (at 30 km)	12.5 per cent increase in tropospheric O_3	O_3-production in T. leads to warming : $2 \times O_3 \rightarrow 0.9°C$
Nitrous oxide (N_2O)	Biomass burning, fossil fuels, artificial fertilizers	No major sink in T., photolysis and reaction with $O(^1D)$ to form NO in S.	165-185 Yr.	300 ppbv	300-375 ppbv (350-450 ppbv)	Greenhouse effect in T. impact on O_3-budget in S. $2 \times N_2O \rightarrow 0.3\text{-}0.4°C$
Chlorofluorocarbons ($CFCl_3$) (CF_2Cl_2)	Propellants, coolants, solvents	No known sink in T., sink in S. through photolysis	65 Yr. 110 Yr.	0.18 ppbv 0.98 ppbv	0.18-1.10 (0.5-2.0 ppbv) 0.28-1.80 (0.9-3.5 ppbv)	increase from 0.1 ppbv. $CFCl_3 \rightarrow 0.13°C$ $Cf_2Cl_2 \rightarrow 0.15°C$
T = Troposphere S = Stratosphere		ppmv = parts per million ppbv = parts per billion		2 × = doubling of concentration		

population, economic and industrial developments, as well as on the sources, sinks, lifetimes of green house gases and chemical reactions of the trace gases which are all quite uncertain.

Global Budget of CO_2

In order to estimate the future concentration of atmospheric CO_2, it will be necessary to study and understand the complete carbon-cycle. The total atmospheric reservoir of CO_2 is equivalent to 743 GtC (gigatons of carbon, 1 giga = 10^9) which is considerably less than 1760 GtC for the terrestrial biosphere, of which about 560 GtC is stored in trees and plants and it is tiny compared with 39000 GtC in the oceans. Therefore, the atmospheric concentration of CO_2 is susceptible to small changes in the fluxes between these reservoirs. The current emission rate of CO_2 from burning of fossil fuels is 5.4 GtC/year while the emissions due to deforestation and changes in land use are estimated at 1.6 GtC/year. These are very small compared with the fluxes exchanged between the atmosphere and the earth's surface which exceeds 200 GtC/year. The atmosphere retains about 3.4 GtC (50% of emission) leaving 3 GtC to be taken up by the oceans. The net fixation of CO_2 by photosynthesis is about 100 GtC/year. Most of this is released by respiration and returns to the atmosphere but some is dissolved in the ocean and some is converted into inorganic carbon and falls to the ocean floor. Earth CO_2 balance is shown in Fig. 38.7.

The present study suggests that ocean uptake can accept about 1.8 GtC/year and then there is an imbalance of 1.6 GtC/year. This is a measure of the uncertainty in current understanding of the global budget of atmospheric CO_2. This is because of some unknown mechanism for removing CO_2 from atmosphere or the amount of CO_2 released by deforestation is overestimated. Relatively minor adjustment in the world ocean circulation and chemistry are likely to affect significantly the amount of CO_2 added each year to the atmosphere, even if emissions are stabilized. Little ocean warming is likely to decrease the net uptake of CO_2 by sea water. And until, this problem is resolved, prediction of CO_2 emissions to atmosphere in future is uncertain. Many models are developed to predict CO_2 emissions in future considering all the points mentioned above.

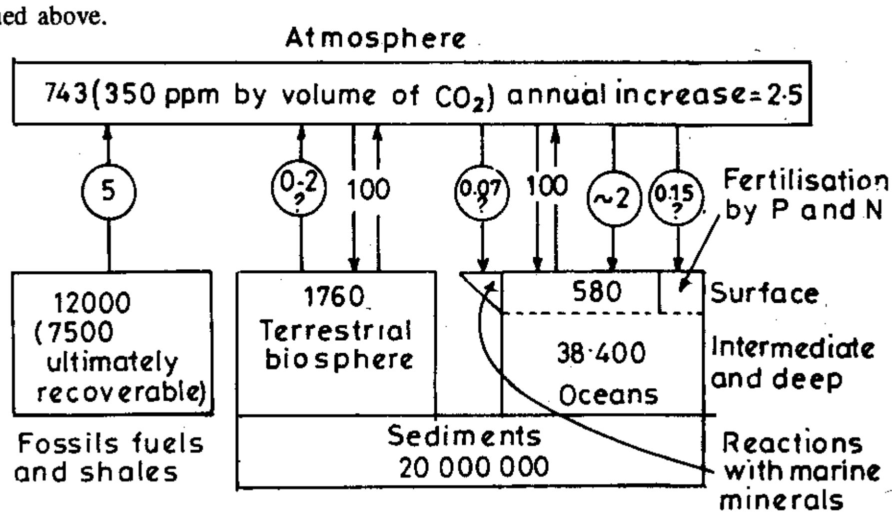


Fig. 38.7. Global carbon reservoirs and present natural and anthropogenic fluxes between reservoirs. Reservoir size in GtC (1GtC = 1 thousand million (10^9) tonnes of carbon). Fluxes between reservoirs in GtC per year. Anthropogenic fluxes are circled.

The annual emission of CO_2 (C-emission) from fossil fuel combustion gas flaring increased from about 0.1 GtC (gigatons of carbon) in 1860 to about 5 GtC in 1980 (an average growth rate of 3.4% per year).

The future emission estimates for 2020 are shown in Fig. 38.8 (*a*), Fig. 38.8 (*b*) and Fig. 38.8 (*c*). Some present estimates show that the future C-emission could be quite low if new technology is used to improve the efficiency (as fluidized bed and combined cycle) and greater use of non-conventional energy sources.

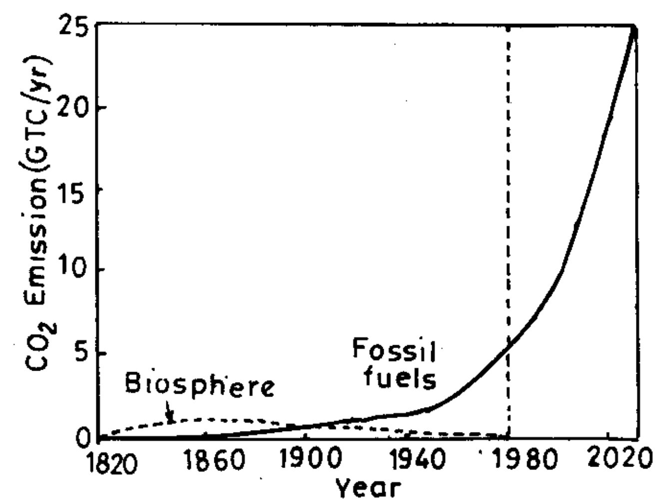


Fig. 38.8. (*a*) Simulation of carbon dioxide emission.

Estimates of pre-industrial atmospheric CO_2 levels show a range between 250 to 290 ppm. The first precise measurements, made on Mauna Loa on Hawaii, showed an increase from 315 ppm in 1958 to 345 ppm in 1984 with a mean growth rate of 1.6 ppm per year. However, future CO_2 levels depend not only on the assumed emission scenarios but also on the transfer processes between the najor CO_2 reserviors (ocean) and the terrestrial ecosystems (with land use changes and forest destruction).

Concerning the effect of other GHGs gases, it is common practice to approximate their effects in terms of an equivalent amount of CO_2. Presently, their effect is equivalent to 40 to 50 ppm of CO_2 and during the next 50 years, their effect is going to increase because of greater growth rates, longer residence times and their higher efficiencies. Preventive measures are already taken to curb their effects.

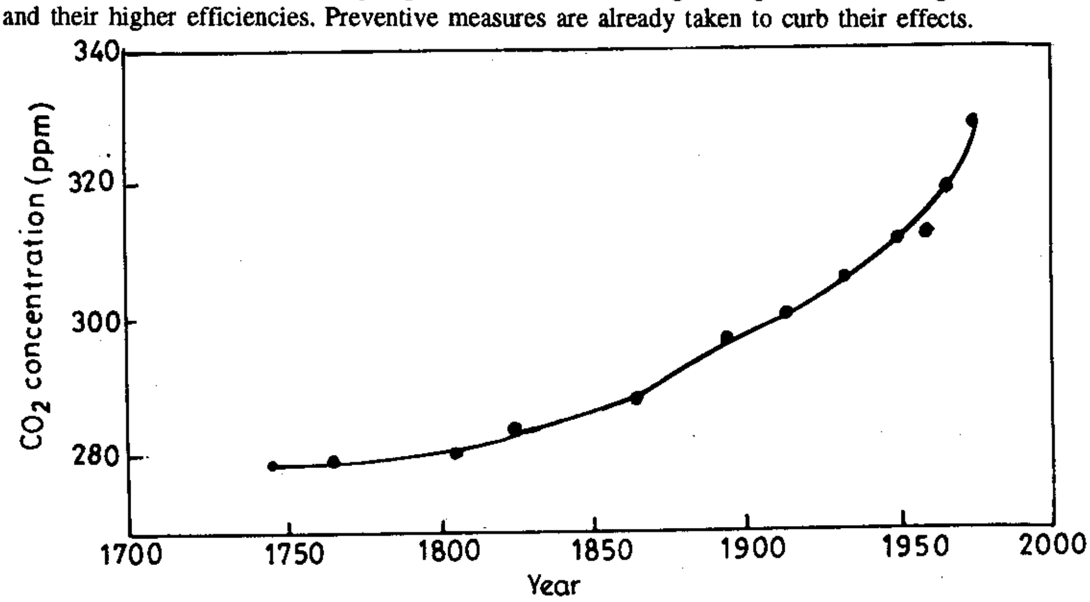


Fig. 38.8. (*b*) Atmospheric CO_2 concentration (measured).

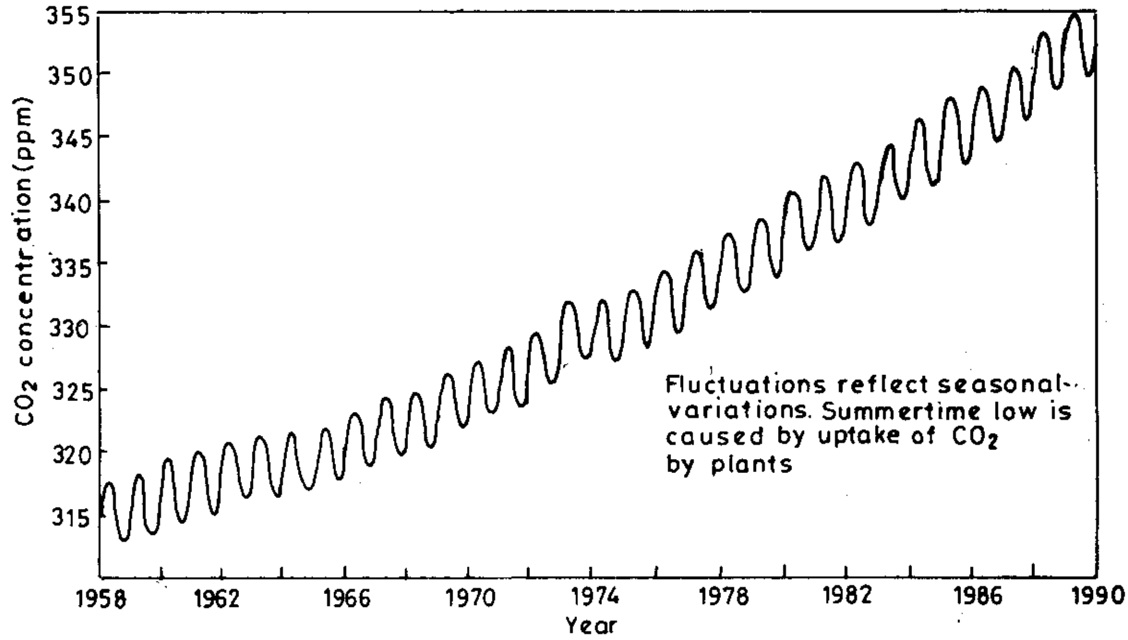


Fig. 38.8. (*c*) Concentration of atmospheric carbon dioxide at Mauna Loa Observatory, Hawaii.

It can be seen from the Fig. 38.9, the major sources which provide energy to the world are coal, oil and gas and they are responsible for CO_2 emission. The total carbon release during 1860 to 1980 is shown in Fig. 38.10 which shows increasing trend. The U.S. is responsible for more than 20% of the world emissions of CO_2 having 5% of the world population.

The contribution to CO_2 by different countries in tons and tons per capita are shown in Fig. 38.11 (*a*) and Fig. 38.11 (*b*). The contribution by different regions of the world is shown in Fig. 38.11 (*c*).

The contribution to green house effect by different gases in U.S. is shown in Fig. 38.12. As U.S. is more responsible for green house effect, than the rest of the world, therefore, it is necessary on the part of U.S. to take immediate steps to bring down the emissions of different gases in coming future.

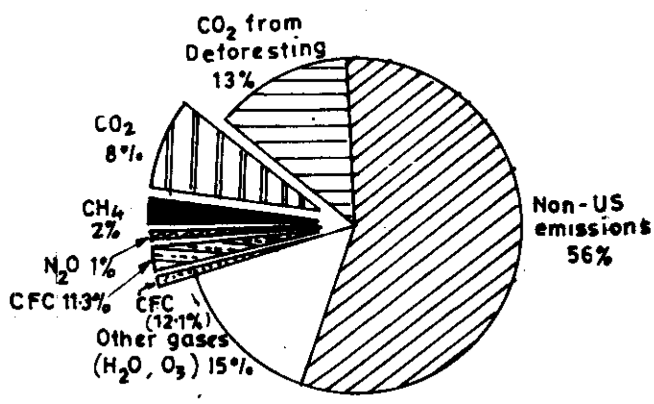


Fig. 38.9. World energy use in 1988.

The effect of GHGs on the temperature variation is shown in Fig. 38.13 (*a*). To cut down this effect, U.S. Govt. has already taken the steps to stabilize the total emissions as shown in Fig. 38.13 (*b*) till 2020.

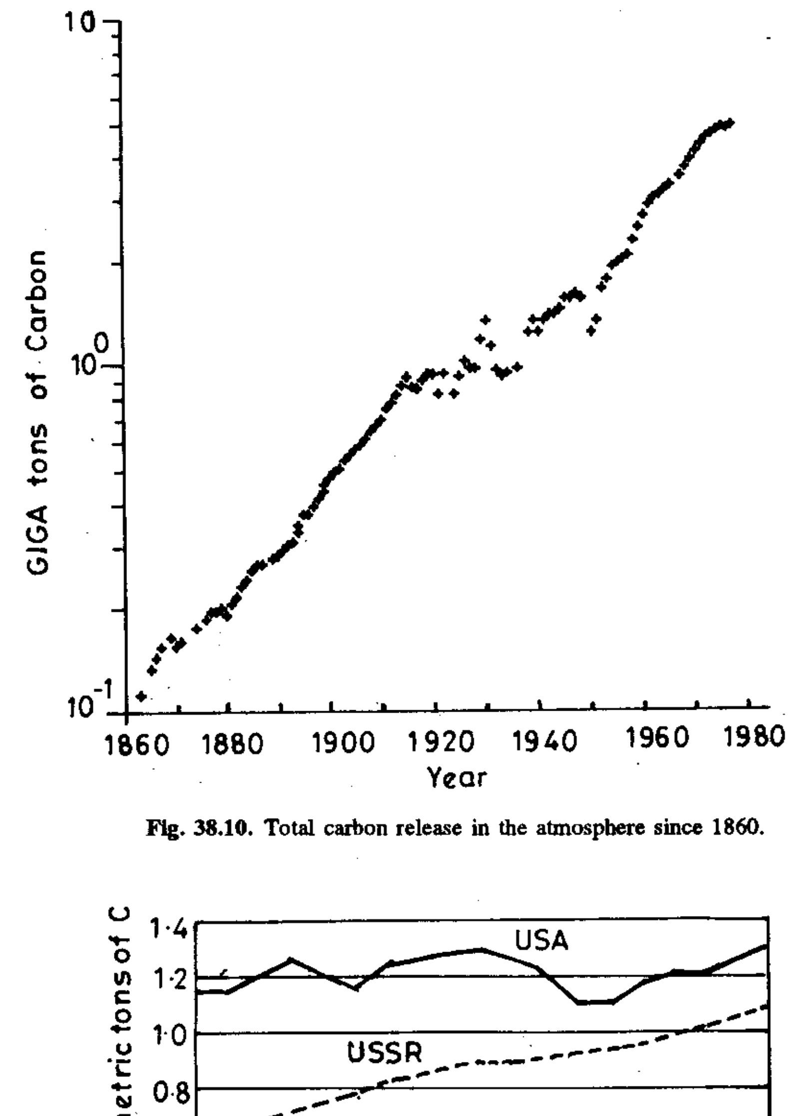
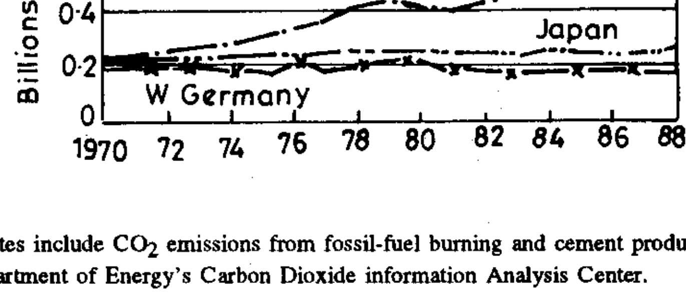


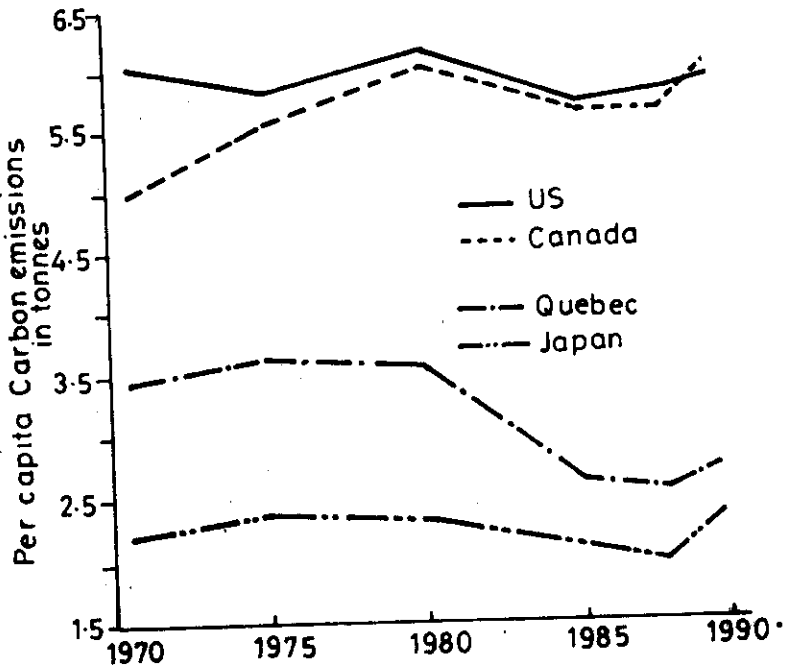
Fig. 38.10. Total carbon release in the atmosphere since 1860.



Note : Estimates include CO_2 emissions from fossil-fuel burning and cement production.

Source : Department of Energy's Carbon Dioxide information Analysis Center.

Fig. 38.11. (*a*)



Sources : O.C.D.E. and Ministere de Penerie et des resources du Quebt.

Fig. 38.11. (*b*)

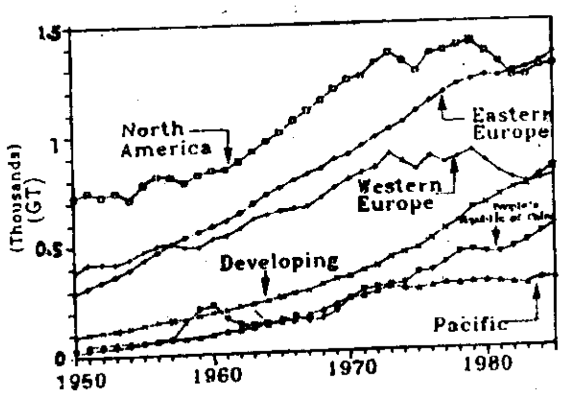


Fig. 38.11. (*c*) Fossil fuel CO_2 emissions by world regions.

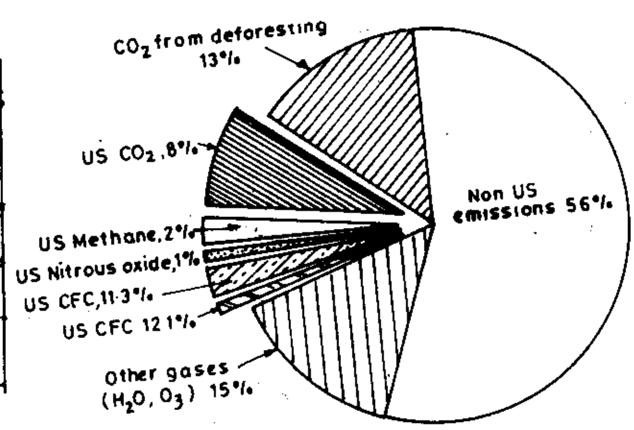


Fig. 38.12. U.S. greenhouse gas emission and its contributions to global warming.

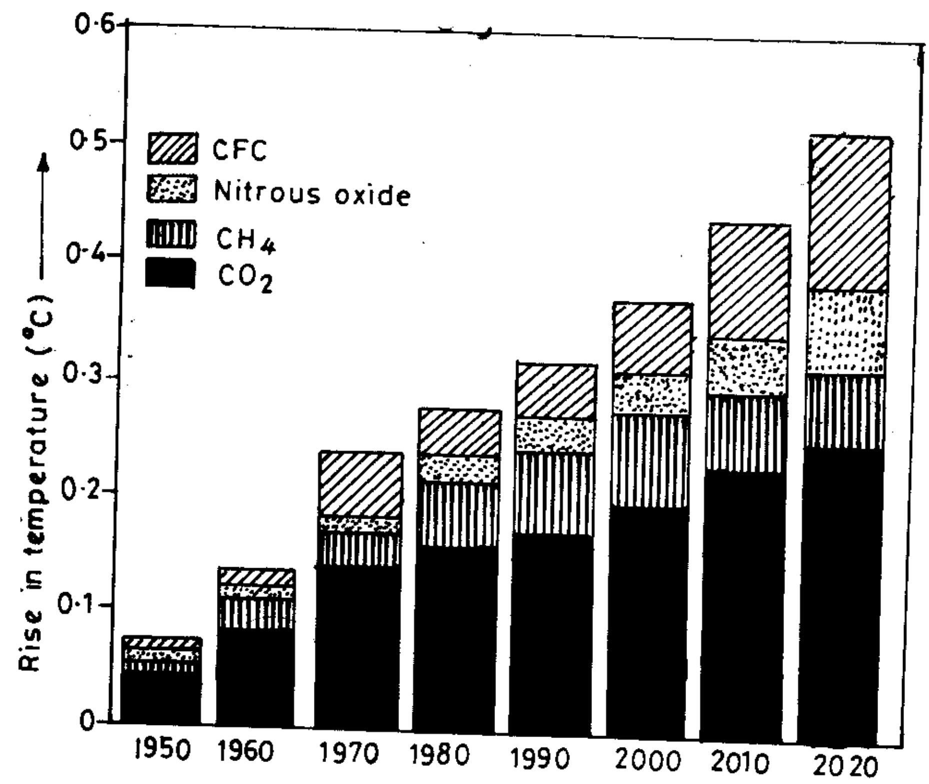


Fig. 38.13. (*a*) The contribution of different gases towards green house effect (in terms of temperature) during 1950 to 2020.

38.7. EFFECTS OF GREENHOUSE ON THE EARTH

The greenhouse effect is accelerated during last decade because of increased use of fossil fuels, rapid deforestation and uses of trace gases (F-11 and F-12).

Inter-governmental Panel on climate changes (IPCC), a group of several hundred scientists from 25 countries, has predicted that earth average temperature will increase by 0.3°C per decade warming roughly 3°C by 2100, unless action is not taken to reduce emission over the period. The impact of global warming will generally be negative, causing frequent natural disasters such as, storms, floods and typhoons, a rise in sea water level and therefore problems with shore protection, salinity intrusion and submergence of low-lying areas and changes in agricultural production capabilities.

A continuing rise in greenhouse effect will increase earth surface temperature and it will melt snow and ice which will increase global sea level by 50 cm at the end of 2100. And the effect of this, most of the beaches on the east cost of the U.S.A. would disappear

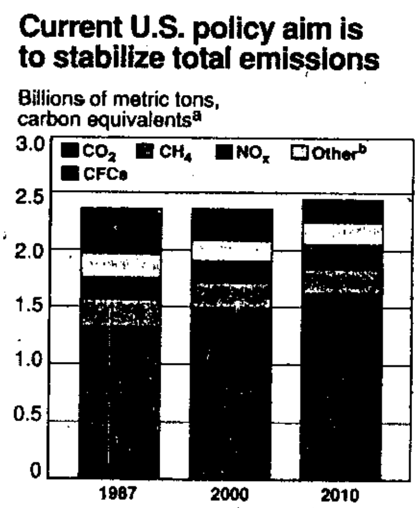


Fig. 38.13. (*b*) Emissions of gases other than CO_2 are given as the equivalent amount of CO_2 calculated from the gases relative global warming potentials includes nitrous oxide (N_2O), carbon monoxide, and volatile organic compounds.

within coming 25-years. They are already disappearing at an average rate of 20 to 80 cm a year. It is also predicted that there may be draughts in some regions like the current one in north-eastern U.S.A. and heat waves like the one in Chicago in last summer. Melting mountain glaciers around the world, may increase water resources in some regions and streams could be diminished in the summer.

The major greenhouse effects are listed below.

(1) Agriculture. It is predicted that, due to greenhouse effect, U.S. corn and wheat belts might become warmer and drier and would reduce 26% corn and 10% wheat production. It is also anticipated that crop margins will shift polewards by 100 km per degree of warming. Increased CO_2 level would stimulate plant growth but this may be counteracted by increasing levels of pollutants such as O_3, SO_2, NO_x and acid rains. The developed countries may face this situation by technological developments but it will be difficult for the developing countries in the light of increasing population stress.

(2) Water resources. Reduced rainfall and increased evaporation in warmer world would drastically reduce run-off in some areas, thereby significantly decreasing the availability of water resources for corp irrigation, hydro-power generation and for industrial and transport uses in one part of the world and flood danger in the other part.

(3) Sea-level rise. In a warmer climate, the sea level could rise either because of the expansion of ocean water or because of melting ice with warming by 5°C by 2050, the sea level could rise between 20 cm to 150 cm. A rise in the upper part of this range could have disastrous effects on low lying coastal areas, this includes coastal erosion, increased frequency of storm, flooding and salt water infiltration causing pollution of irrigation and drinking water.

Such rises in sea water level

(*i*) will cost tens of billion dollars for beach and coastal erosion.

(*ii*) causes vast changes in low land protection, break waters locks, bridges, docking facilities and land use.

(*iii*) leads to more severe storm flooding with consequent loss of life, property and farmland particularly in South Asia.

(*iv*) inundates wetland areas with associated harm to fishing.

(*v*) brings extensive damage to water management systems, drainage, irrigation, salt water intrusion and ground water.

Drowning Island

The exhaustive use of fuels has lead to a multitude of ill-effects over the biosphere. Increasing content of CO_2 and other gases have lead to formation of holes in the protective ozone layer of the earth. Constantly increasing temperature of earth has lead to excessive melting of the glaciers at both the poles resulting in a significant increase in the water content of the oceans. This increase has predicted the drowning of the shore areas of the land in the future.

The most affected due to this predicted hazard are the Islands of Maldives whose future has been cut down to a mege 350 years approximately from now.

Maldives has about 1200 Islands set close together with a population of about 2.25 lac. It is only about 3.5 metres above the sea level, hence even a yearly rise of 10 mm in the sea level endangers its existence and demands urgent consideration and a concrete plan of action.

The president of Maldives Mr. Gayyum had already urged the scientists to look into this problem and chalk out a plan of action to save the Islands. He also raised the problem in the general meeting of international organisation. In 1989 the authorities of the Islands which are endangered by increasing level of the oceans had a meet in the capital of Maldives, "Mal" and stated that they were going to suffer due to over-industrialization of the advanced nations.

(4) Forests. In a warmer world, the hardwoods and conifers of temperature latitudes could migrate further north and replace some of the boreal forest. However, by the time, the warming becomes effective enough to cause forests to move polewards, the rapidly proceeding forest dieback mid-latitudes may leave little forest for such migration. Similarly, a warmer and moister climate anticipated for tropical areas could favour the expansion of tropical rain forests at the expense of subtropical moist forests. At any rate, the destruction of forests would feedback on the climate by changing the heat and water budgets.

The fast developing telecommunication technology creates two major problems to the global environment, the greenhouse effect and depletion of O_3 layer and destroys the global environment.

The publication of telephone directory destroys the environment as one set of directory causes the loss of a tree. Now in India, there are six million telephone links and Department of Telecommunication has planned to have 20 million new connections in the next 8 years. In the world, the number of telelinks is beyond the calculation. The substantial loss of trees causes gases like CH_4, CO_2 and water vapour. These gases damage the atmosphere and increases the earth temperature.

To prevent the loss of forest, foreign countries have started to provide its subscribers with PC and data base information compact disc. The subscribers can retrieve in the PC whatever details they want. Non-subscribers can obtain information from directory enquiry cell. This would lead to the gradual reduction of papers.

(5) Climate change. The studies concerning the effect of greenhouse emphasize that there is less confidence in predictions of regional climate change than in global change. For example, warmer aretic weather may melt the reflective ice, but this may be countered by increased cloudiness from greater evaporation.

As for demographic effects concerned, Northern Canada, Siberia and Scandinavia may become more attractive population, 15000 years ago with 5°C global temperature, we had an ince age with 60 m thick glacial ice in Canada and parts of USA. What would a rise of 5°C do (in 2100) ? May be northern forests would develop to help to reduce CO_2 emissions. May be agriculture would shift north.

38.8. CONTROL OF GREENHOUSE EFFECT

The greenhouse effect is overwhelming in scope and will specially impact on all of us dealing with energy. Humans are capable with a couple of lifetimes of grossly altering the climate and eliminate the freshness of air we breathe if necessary action is not taken well in advance.

With the present potential scenarios of global climatic change, the question arises, should we initiate relief measures and if so, when ? It is usual argument that countervailing measures would not be justified before the large existing uncertainties are reduced. This poses the question, how much certainty is required to warrant action ? This involves a difficult question which has to be viewed against the risk/benefits involved. But if we wait until we are certain that justify our action, it may be too late for any countervailing action. To be on the safe side, it is necessary to take action in the matter so the condition should not be out of control.

The following actions are suggested and adopted by many countries in the world to reduce CO_2 level to 1988 level by the year 2020 as the effect of green house is already experienced in the different parts of the world.

(1) Increased use of natural gas. CO_2 emission can be reduced by switching from high carbon coal to low carbon natural gas. It is also necessary to use combined cycle plants which provide overall high efficiency. For example, currently, 85% CO_2 emission in USA comes from 60 coal fired plants but it can be reduced to 65% by replacing conventional coal plants with high efficiency combined cycle gas turbine plants using natural gas as a fuel. Coal releases about 25 g of carbon pr 1000 kJ of energy whereas oil emits 20 g of carbon per 1000 kJ and natural gas about 15 g of carbon per 1000 kJ.

(2) Use of More-hydro-power. Hydro-power is considered as emission free power so it is essential to develop this source of energy throughout the world. Hydro-power provides safe, clean, renewable and cost effective source of energy. The reliance on hydro-power combined with energy conservation programme have led to a sharp decline in the consumption of petroleum products. Thanks to hydro-power, total CO_2 emission has declined by 17.5% in the last 20 years, despite population and economic growth in USA. The supply of hydropower to New-York and New-England states during 1978 to 1989 eliminated the need for 350 million barrels of oil.

(3) Use of alternative energy systems. This includes, solar thermal, solar photo voltaic, wind power, tidal power and OTEC systems. These systems are developed in many countries of the world wherever the potential is available. It is thought that these sources of energy will play vital role in the total energy supply to the world in the next century. These sources of energy are totally free from any emission or atmospheric pollution.

Gujarat Govt. has already requested to the Union Govt. to tap national and international funding resources for the development of a 900 MW tidal power project in the Gulf of Kutch. Solar photovoltaics and solar thermal ("power towers") will be an option for generating power in sunny areas which someday may well be transmitted coast to coast with low loss through superconducting cables.

(4) Use of nuclear power. Because of dangers created by the nuclear power waste, there was resistance by the people throughout the world for the growth of nuclear power. Therefore, the growth rate of this source was reduced during the last decade. But now there is no other alternative except to use nuclear power if the power is to be developed on bulk amount. The technology is developing safe waste disposal methods and this will be one of major alternatives as it has no greenhouse effects. The fusion development is also thought as it has no threat of waste disposal like fission reactors.

(5) Use of efficient equipments. Use of efficient automobiles, all electric equipments and other transportation system will reduce the emission CO_2 to the atmosphere. It is also proposed to use H_2 as an alternative fuel for air-crafts as they are one of the major consumers for the petroleum products.

(6) Removing CFCs from refrigeration industry. The USA Govt. has sanctioned a bill of \$ 10 million per year for finding alternative refrigerants. The fate of CFCs is already sealed. Their production is being phased out under the Montreal protocol on substances that deplete the O_3 layer and contribute to 30% of total greenhouse effect. There will be a complete phase out of CFCs by 2050 including even F-22 which has less greenhouse effect compared with F-11 and F-12.

(7) International reforestation and stopping of deforestation. The vegitation and forest in the world is one of the major source to absorb CO_2 and emitting O_2 which is life sustaining gas. There is large deforestation throughout the world because of rapid population growth which requires wood as basic source of energy. This should be stopped by providing alternative and efficient source of energy, particularly to rural population and strict rules should be emposed for deforestation. Reforestation programmes are already taken in India and abroad also.

(8) Carbon charges. Carbon charges are considered a favourite tool for reducing CO_2 emissions. Like energy tax, a carbon tax would encourage all consumers, whether individuals, businesses or Govt. to use less fossil fuels. Additional benefit from carbon charges, however, is that they would also promote fuel switching. Over the long term, carbon charges would provide an incentive for development of alternative renewable sources of energy.

(9) Other actions. Other actions are to include reduction of CH_4 and NO_x emissions and encouraging international cooperation to limit population growth as energy efficiency is linked with birth control.

(10) Increase in sink capacity. If the cost of CO_2 abatement is going to be high by using suggested methods, then the next solution is to increase CO_2 sink capacity to balance the increased emission. The sinks include forests and oceans. Trees in the forests and algae in the ocean take up CO_2 to "photosynthesise" as food.

One practical method suggested was to *fertilise* the forests and oceans with iron, phosphorous potassium and nitrogen which increase photosynthesis. Addition of small amounts of trace elements and iron results in binding of many tons of CO_2.

However, the environmental impact of such additions including long term studies of ocean fertilisation will be required before taking it up practically. Such studies for reducing CO_2 are already undertaken in Japan and Europe.

An advisory group on greenhouse gases (AGGHGs) has been set up jointly by international council of scientific unions, the world Meteorological Organization and United Nations Environment Programme in July 1986 to carry out the following :

(i) biennial review of global and regional studies on GHGs and

(ii) periodic evaluations of the rates of GHG increase and their effects.

Table V – National targets for reduction of CO_2 emissions

Country	*Stabilization by year*	*Reduction target (per cent)*	*Reference year*
Australia	2000	20 by 2005	1988
Austria	—	20 by 2000	1988
Canada	2000	—	1990
Denmark	—	20 by 2000 50 by 2050	1988
France	2000	—	1990
Germany	—	25 to 30 by 2005 80 by 2050	1987
Great Britain	2000	—	1990
Italy	2000	20 by 2005	1988
Japan	2000	—	1990
Netherlands	1995	3 to 5 by 2005	1988
New Zealand	—	20 by 2000	1990
Norway	2000	—	1990
Switzerland	2000	—	1990

38.9. COSTS OF CO_2 ABATEMENT

"We do not fully comprehend either costs of action or the cost of inaction" said Michael R. Deland (Chairman of the Council on Environmental Quality USA). "We have no clear measures of the cost effectiveness of competing options, we are unsure whether it would be cheaper to adopt to or prevent change".

But more and more scientists are trying to reduce these uncertainties. They are attempting to analyse what it would cost to slow down the rate of global climate change and what the price would be if society does not act to control greenhouse gas emissions.

The cost of CO_2 emission to society can be classified as follows :

(1) Damage costs. This cost is the cost to cope with or combat the various types of damages caused by the global warming. Little information is available regarding damage costs as different effects, their volume and regions of the world are not predictable accurately by any of the mathematical models developed so far because of many uncertanties. Shifts in climatic zones could make entire regions unfit for agricultural production, forest habitats and human settlement. Wide spread starvation, and settlement of affected population may be direct results. There is no doubt that repairing the damages is not the option and that damage cost would be far higher than CO_2 control in the long term.

(2) Control costs. The cost to reduce emitted CO_2 from the atmosphere per ton of CO_2 increases with the percentage by which it needs to be reduced. The first few percentage points can easily be achieved at a relatively low cost by enhancement of energy efficiency changing the fuels with lower carbon content and by avoidance of deforestation and promotion of afforestation.

Further steps become progressively more expensive and include energy use substitution such as increased use of nuclear, solar and wind energy. The next step would be to use bio-ethanol fuels for vehicles and promotion of H_2 as a fuel.

Several studies have attempted to quantify the cost of CO_2 abatement as listed below in Table VI.

Table VI

Nation	*The cost of CO_2 abatement in \$/ton*	*Method used*
Dutch	\$ 23 to 27	CO_2 reduction
German	\$ 53	CO_2 scrubbing
USA	\$ 13 to 48	Carbon saving target 5% to 20%
Swiss	\$ 60 to 90	CO_2 abatement in transportation section

Many countries have already fixed the reduction of CO_2 target by adopting different methods as listed below.

(3) Mitigation costs. A German study investigated the cost of recovering CO_2 from the exhaust of thermal power plants and disposing off in depleted natural gas reservoirs or into the deep sea. Costs ranged from \$ 22 to \$ 30 per ton. Injection of CO_2 into the ocean must be at depths and pressures sufficient to keep the CO_2 in liquid form and it would cost between \$ 90 to \$ 110 per ton of CO_2.

Carbon fixation and sequestration by reafforestation projects is a measure which could help to mitigate CO_2 emissions. After 30 to 70 years from now, newly planted forests would reach maturity and CO_2 absorption as a result of growth would be equivalent the release of CO_2.

During the total growth period, forests do sequester CO_2. The cost per ton of CO_2 fixed by forest vary widely, from \$ 5 (Guatemala), \$ 6 (Costa Rica) to \$ 12 to \$ 26 (USA). These costs seem low, but there are limits to the areas which can be afforested. For example, USA would have to increase present forest area by 7.5 times to absorb CO_2 it emits annually. This would require 1.5×10^9 ha of forest, which is 65% more than the total USA land area.

It is also not expected that afforestation projects will account for more than a few percent of global CO_2 emission reduction. Although, afforestation constitutes the least cost option, it should not be seen as the marginal cost of CO_2 abatement if the target is to reduce substantially the net emission of CO_2 on a large scale.

(4) Carbon tax. To finance CO_2 control programmes, several countries have introduced a carbon tax sometimes combined with an energy tax.

The first country to do so was Finland, has introduced in 1990 a CO_2 tax of \$ 6.9 per ton of CO_2 emitted. In the same year, Sweden has also introduced a carbon tax of \$ 14 per ton of CO_2 emitted. Norway also introduced this tax as \$ 50/ton to the companies.

The European community is also planning to introduce an energy cum CO_2 tax. Proposals are \$ 3.3 per ton of CO_2 in 1993 to \$ 11.1 per ton of CO_2 in 2000. In addition to this, there will be an energy tax for fossil fuels as \$ 0.25 per gigajoule in 1993 to \$ 0.83 per GJ in 2000.

Major sums of tax money will be collected even though the aforementioned tax level is below the marginal cost of CO_2 abatement measures. For example, twelve countries of European Community would emit about 3×10^9 tons of CO_2 and collect \$ 34 billion per year as carbon tax in the year 2000. This money should be spent to achieve the largest reduction possible in worldwide CO_2 emission.

38.10. CARBON FIXATION METHODS AND OCEAN DUMPING

If there were a CO_2 guzzling animal in existence, it would likely live in USA. The USA pours out nearly 20% of world's CO_2 in the atmosphere per capita basis. And this is one of the main reasons, it is so resistant to any legislation curbing CO_2 emissions. As scientific debate continues over the existence and effects of global warming and its link with CO_2 build-up in the atmosphere, most industrialized nations have already started projects to deal with CO_2 emissions.

Table VII

Country	France	Italy	Japan	U.K.	West Germany	Canada	USA	World
CO_2 release in tons per capita per year	2.0	2.0	2.3	2.9	3.1	5.2	5.9	1.2

The emitted CO_2 can be captured and used as a chemical feedstock in food processing, soda ash production and oil recovery systems. However, such uses will take care of only a small fraction of the total. Handling the balance in future may use the methods as biological fixation, using algae to fix CO_2 and use it in photosynthesis as well as injection in exhausted oil wells or aquifers and ocean dumping.

The capture and disposal of CO_2 from flue gas of thermal power plants is technically feasible but one has to think economical feasibility as it requires a significant fraction of the energy content of the fossil fuel and additional equipment with large capital expenditures. The process that requires least energy is air-separation flue gas recycling. In this process, about 30% of the total energy content of coal is consumed and thermal efficiency of the power plant is reduced from 35% to 25%. Excluding pipeline and deep water disposal costs, we estimate that electricity production costs will increase about 80%.

There are many methods to collect CO_2 from the power plant exhaust but a few of them which are economically feasible are discussed here.

CO_2 Capture Technology

Most of the methods proposed for the capture of CO_2 are based on the separation of CO_2 from the other components of flue gas. Since CO_2 typically constitutes only 15% by volume in flue gas, energy requirements are high for the separation. The following scheme is based on prior enrichment of CO_2 in the flue gases by burning coal in an atmosphere of O_2 and recycled flue gas instead of air.

(1) Air-separation/flue gas recycling. Air compression and separation of CO_2 is very common process used in industry today. A 500 MW plant requires 9000 tons of O_2 per day. The processes available for air-separation include membranes and cryogenic distillation which is commonly used for large scale air separation economically. The cryogenic process as shown in Fig. 38.14 consists mainly of heat exchangers and distillation columns. The O_2 produced from air-separation plant is mixed with recycle flue gas to approximate the combustion characteristics of air. In air, the N_2/O_2 ratio is about 3.65. A CO_2/O_2 ratio of 2.42 gives similar flame temperatures as well as similar ratios of radiant heat transfer to convective heat transfer. By using O_2 instead of air, it may be possible to redesign the boiler to take advantage of higher flame temperature and thereby improve the overall thermal cycle efficiency.

(2) Amine scrubbing method. The use of amines for removal of CO_2 was first patented by Bottoms in 1930. Triethanolamine (TEA) was first commerically available amine. Today, several amines are widely available as monoethanolamine (MEA) and diethanolamine (DEA). The MEA has high load carrying capacity (amount of CO_2 absorbed per unit volume of solvent). This means that less solvent circulation is required for a given system performance which leads to lower capital and operating costs.

The Dow Chemical Company has developed a new amine technology, called FT technology, specifically designed to remove large amounts of CO_2 from flue gases. This technology is based on a 30% MEA solution with additives to control corrosion and inhibit the oxidative degradation of amines.

The chemical reaction in this system is

$$C_2H_4OHNH_2 + H_2O + CO_2 = C_2H_4OHNH_3 + HCO_3$$

The general arrangement of the components of this process is shown in Fig. 38.15. Lower temperatures favour the forward reaction.

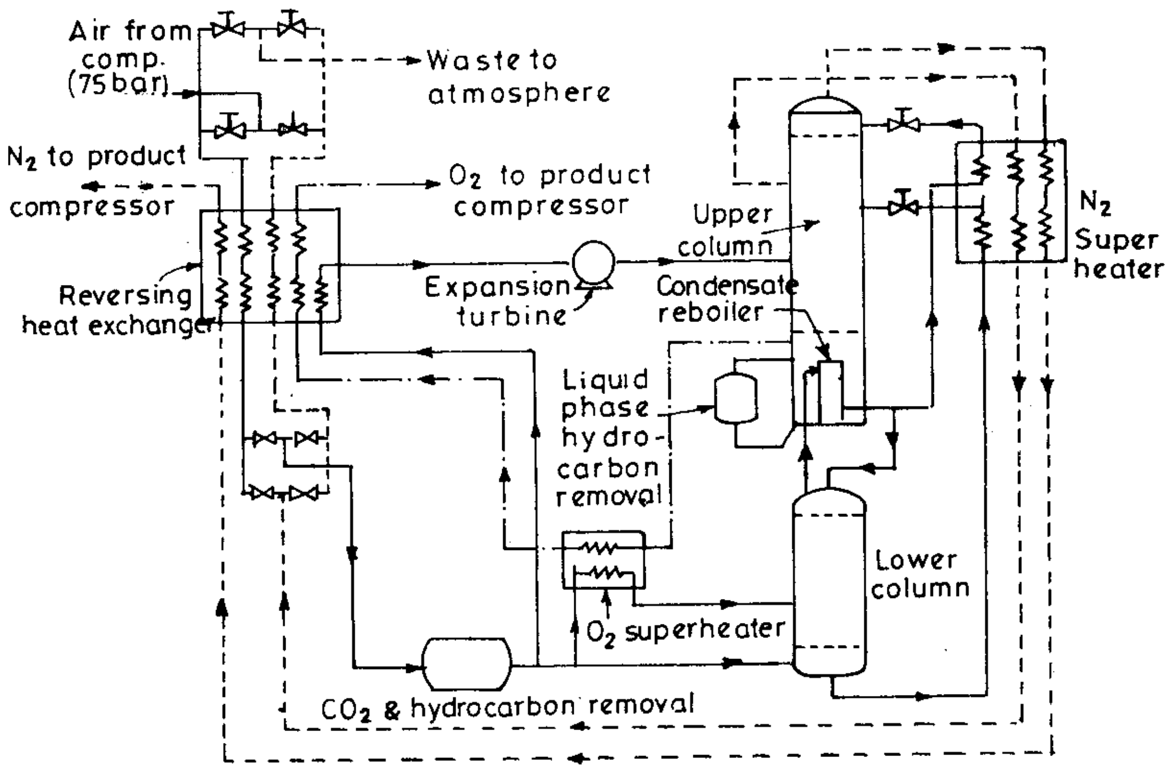


Fig. 38.14. Air separation/flue gas recycling.

The basic units of the process are the absorption tower, the regeneration tower and the lean/rich exchanger. An MEA recovery unit is also required to regenerate amine that reacts with SO_2 and NO_x.

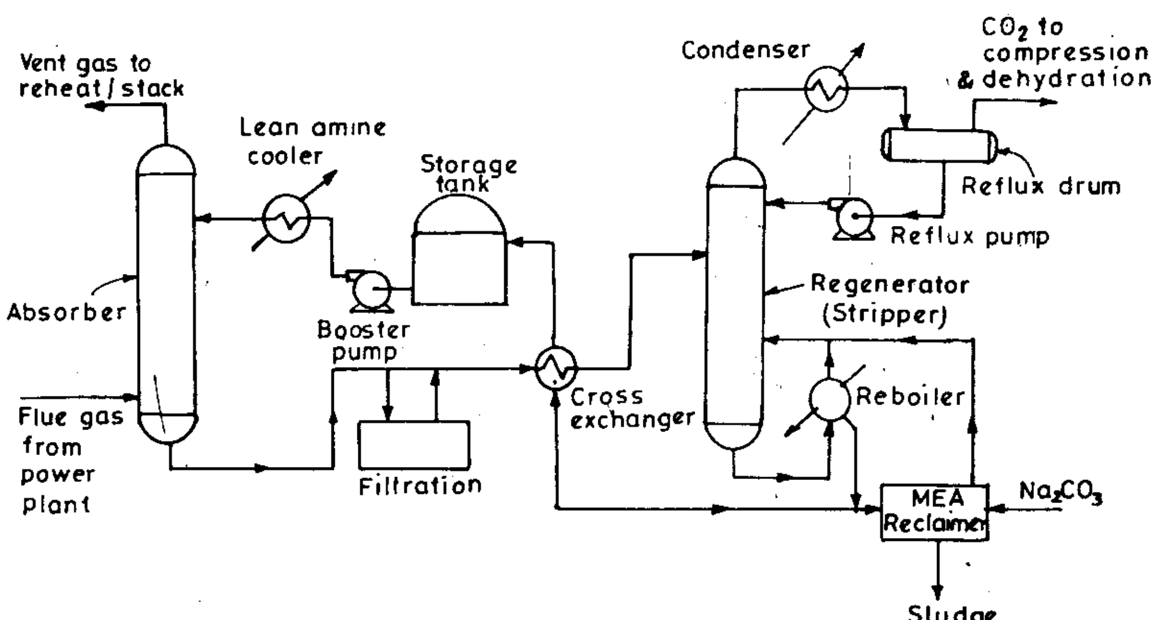


Fig. 38.15. Amine separation process.

In the absorption tower, CO_2-lean MEA solution absorbs CO_2 from the flue gas. The absorption tower consists of a packed section for absorption and a water wash at the top to reabsorb vaporised MEA. The tower operates at close to atmospheric pressure and at 40 – 50°C temperature. Therefore, it is necessary to quench flue gas before entering the absorber tower and vent gas is reheated to have the required buoyancy before being exhausted to atmosphere. Amine concentration is kept low (< 20%) to minimize corrosion problems.

Most SO_2 removal processes remove only 60 to 90% of SO_2. Therefore, an MEA reclaimer is required for flue gases containing significant SO_2. In the reclaimer, sodium carbonate (Na_2CO_3) is added to the amine to precipitate out salts containing SO_2 and NO_x. Daw has estimated that the solvent loss rate for its FT technology is 1-2 kg solvent per ton of CO_2 recovered.

The regeneration column operates at elevated temperature (100 – 120°C) to remove CO_2 from amine solution. The column overhead product contains CO_2 which is ready for compression, dehydration and pipeline transport. This system requires nearly 30 to 50% of coal energy.

(3) Sea water scrubbing. In this process, the flue gases are brought in contact with sea water either at atmospheric pressure or elevated pressure. The sea water absorbs CO_2 from flue gas. The pressure head required for the sea water to overcome the frictional losses in a pipe is given by

$$F = \frac{32\, fQ^2L}{\pi^2 g D^5}$$

where D and L are diameter and length of pipe and Q is the flow rate (m^3/sec) and $f = 0.0015$ and F is friction loss in term of energy per mass of flowing fluid.

The power required (P) to pump the sea water is given by

$$P = FQ \propto \frac{Q^3L}{D^5}$$

At atmospheric pressure and assuming inlet water contains no CO_2 and outlet water is saturated, 413,000 kg/sec of sea water is needed to absorb 90% of CO_2 from 500 MW power plant. To pipe this water 16 km in 4.6 m diameter pipe requires 3600 MW while 7.6 m diameter pipe requires only 300 MW. Therefore, it is so obvious that to reduce power requirement to an acceptable level requires a very large diameter pipe and increases capital cost dramatically.

The sea water flow of 413000 kg/sec is about 250 times the solvent flow rate in amine process and this factor may be 500 to 1000 if realistic CO_2 concentrations in the inlet and outlet sea water streams are considered. Therefore, the capital cost of the absorbers for sea water scrubbing will be 2 to 3 orders of magnitude greater than the amine scrubbing system.

By operating the absorber at elevated pressure, the solubility of CO_2 in the sea water is increased, thereby reducing the sea water flow rate. However, the saving in the capital costs due to reduced sea water flow rate will be offset by the higher capital costs of pressurization. In short, by increasing operating pressure, much of the benefit of the reduced sea water flow rate is offset by thick wall of the pipe and high pressure requirements. If the absorber pressure is 10 bar, the flow rate required is 41000 kg/sec (assuming CO_2 free inlet and saturated outlet), then the energy requirement is 45 to 55% of coal energy (including pipeline transport of 100 km). This energy requirement is nearly equal to the energy requirement of amine process, but still the pipeline diameter required is 5 m and sea water flow double the amine flow. Therefore, sea water scrubbing either at atmospheric or elevated pressure is not considered as viable option.

Dumping of CO_2 in Ocean

The nature of CO_2 sea water interaction depends on the release depth and the characteristics of the CO_2 stream. In equilibrium with sea water, CO_2 is in the gaseous phase down to a depth of about 500 m. At greater depths, liquid CO_2 remains in the stable phase. If CO_2 is released at ambient sea temperature, the density of CO_2 liquid is less than sea water to a depth of 3000 m and greater below that depth. Thus, the released liquid CO_2 will have a tendency to rise (because of buoyancing force) at all practical release depths.

Ocean disposal has a certain technical appeal because, if the site is deep enough, the CO_2 stabilizes as a solid hydrate (known as clathrate) with sea water CO_2—$6H_2O$ or CO_2—$8H_2O$, the hydrates are denser than CO_2 or sea water and thus may sink to the ocean bottom.

The amount of hydrate to be formed in the release cannot be estimated from the present available data.

In the following exercise, we are going to assume that all the released CO_2 remains in liquid form until fully dissolved in sea water.

For a given set of release conditions, the dynamics of liquid-liquid system depends on the rate at which CO_2 is injected :

(*i*) At low flow rates, bubbles form slowly and break off when buoyancy forces become greater than the restraining surface tension.

(*ii*) At moderate flow rates, fluid momentum becomes important and a jet forms at the release orifice. The jet lengthens with increasing flow to a point where instabilities become more important and disintegrate the jet into drops.

(*iii*) At very high flow rates, no jet is formed and stream automizes into tiny droplets at the orifice exit. (It is just like spray drying technique).

Generally CO_2 collected and injected from large power plants, the flow will be in either jetting or automization regime. In jetting, the drop size is roughly twice of orifice diameter and droplets are considerably smaller than release orifice.

The surface tension, viscous and buoyant forces tend to break up large drops. The largest drop radius is given

$$R = \sqrt{\frac{\sigma}{(\rho_w - \rho)\, g}}$$

where σ and ρ are surface tension and density of liquid CO_2 and ρ_w is the density of sea water. The value of R verses sea depth is shown in Fig. 38.16 taking ocean water temperature profile from literature.

At intermediate depths, stable drops are atmost 1 to 2 cm in radius. At these depths, the formed droplets are positively buoyant and will rise. Drag forces slow the drops and simultaneous mass transfer will tend to dissolve the drops into the surrounding unsaturated sea water. The purpose of disposal system is to dissolve the drops completely. The release depth is estimated such that by the time liquid CO_2 drop ascends to 500 m, they completely dissolve in sea water. They may flash into gaseous bubbles at some depth after ascend and still be dissolved before they ascend to the surface. Since ocean depths greater than 500 m are not available to many coastal power plants, then one has to consider optimal release depths, including regimes where some flash vaporization may occur.

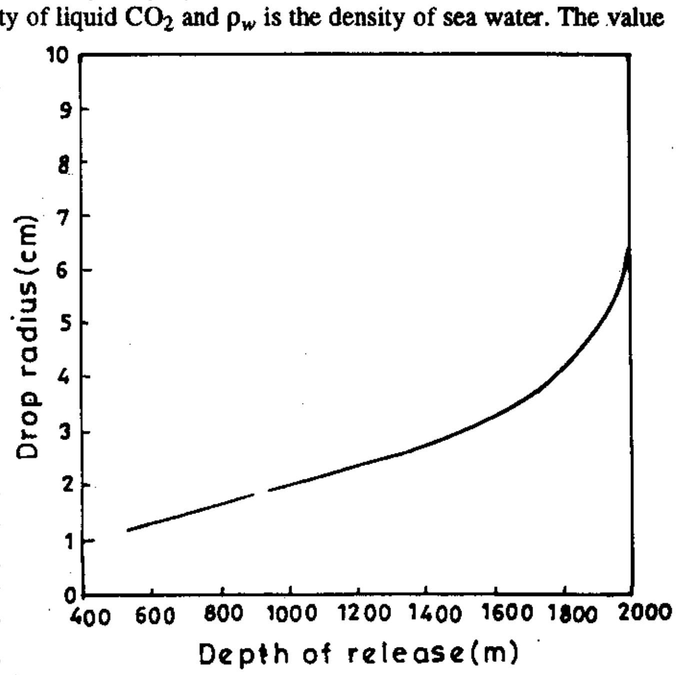


Fig. 38.16. Largest stable drop radius as a function of depth.

EXERCISES

38.1. What are the different sources of CO_2 emission and what do you understand by CO_2 balance ?

38.2. Explain the meaning of green house effect and how it is related with earth ?

38.3. Explain how CO_2 is responsible for greenhouse effect and why ?

38.4. The effect of CFCs is different in form compared with CO_2 even then it also helps to accelerate greenhouse effect. How ? What is their contribution to green house effect and why so large ?

38.5. What are the reasons (give quantitive figures) for increasing CO_2 in the atmosphere ?

38.6. Discuss the different effects of green house effect on earth in future.

38.7. What are the different methods presently adopted in the world to reduce the future effects of greenhouse effect ?

38.8. What are the different costs which are considered for CO_2 abatement ?

38.9. Explain different carbon fixation methods. What are the addvantages of MEA method ?

38.10. Dumping of CO_2 in ocean is a feasible and economical method for disposing CO_2. Discuss.

□□□

39
Major Electrical Equipments in Power Plants

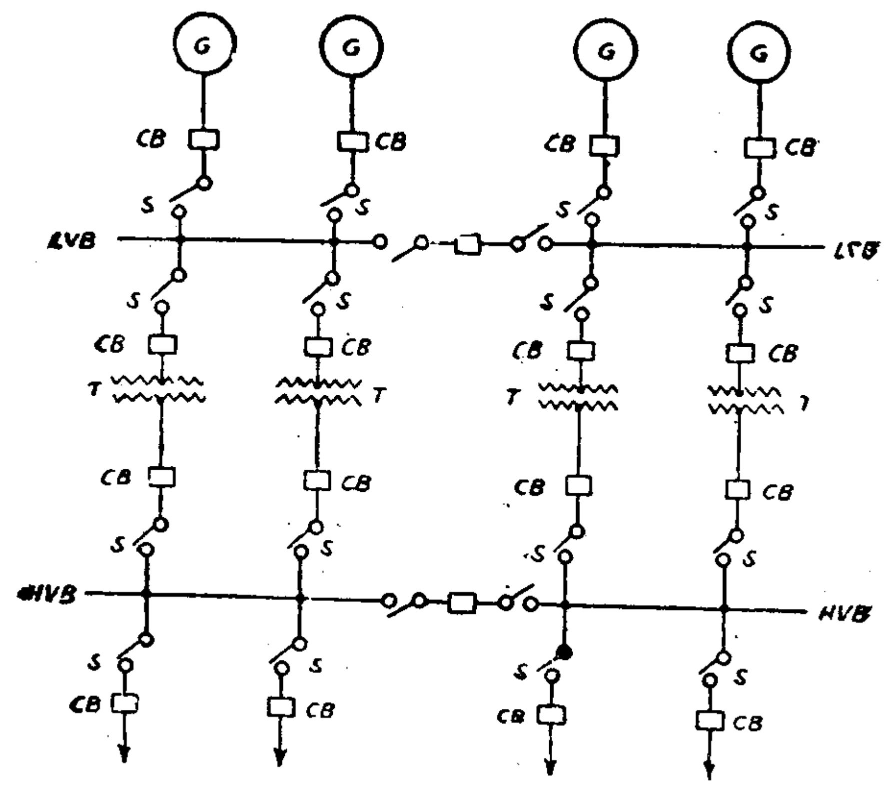
39.1. INTRODUCTION

In the last thirty-eight chapters, the different types of the power plants are discussed. The whole purpose of this text-book is to introduce the students to the different energies and methods to convert these energies into electrical energy. An emphasis is also given on economic analysis of generation. The authors have tried to discuss all the phases of power generation in last thirty-eight chapters except the electrical equipments. The authors strongly feel that it will not be proper end of the book without including the electrical equipments used in power plants. It is impossible to discuss the principles of generation, transmission and distribution of electrical energy in this text-book and it is not necessary as specialised books on these topics are already available.

The purpose of this chapter is to introduce the students to the electrical equipments used in power plants.

39.2. LAYOUT OF ELECTRICAL EQUIPMENTS

The layout of the electrical equipments in the power plant consists of the arrangement of the busbars, circuit-breakers, transformers, and controlling switch-board.



To transmission lines

G = Generator, CB = Circuit breaker, S = Switch or Isolator
T = Step-up Transformer. LVB = Low voltage bus-bar,
HVB = High voltage bus-bar.

Fig. 39.1. Single bus-bar system sectionalized with a circuit-breaker.

The controlling switch-board consists of instruments to indicate the behaviour of the equipments at any time. Controlling instruments are used to control the operation of the whole station and different types of relays to protect the station equipments against abnormal faults.

(1) Single Bus-bar Arrangement. The arrangement is shown in Fig. 39.1. This arrangement can be used for a power station having number of generators and a single bus-bar arrangement. The advantage of this system is, a fault on one part of the bus-bar does not completely shut down the whole station.

The system shows a circuit-breaker and isolating switch between each generator and low voltage bus-bar, a circuit-breaker and isolating switch on both the low voltage side and high voltage side of the step-up transformer and a circuit-breaker and isolating switch to tie up the two bus-bar sections.

Nowadays, to use large number of circuit-breakers is out of date. In some modern power-plants, where the unit system is used, one generator and one transformer as a unit connected directly to the high-voltage bus-bars and there is only one set of high-voltage switchgear.

2. Duplicate Bus-bar System. The arrangement of the system is shown in Fig. 39.2. In this arrangement, both the low-voltage and high voltage bus-bars are duplicated. One of the two can be used as desired as a bus-bar-coupling switch is provided to transfer operation from one bus-bar to the other bus-bar.

The advantages of this arrangement are listed below :

1. It is possible to have one bus-bar alive and to carry out the repairs on the other when required without stopping the supply to the consumers.

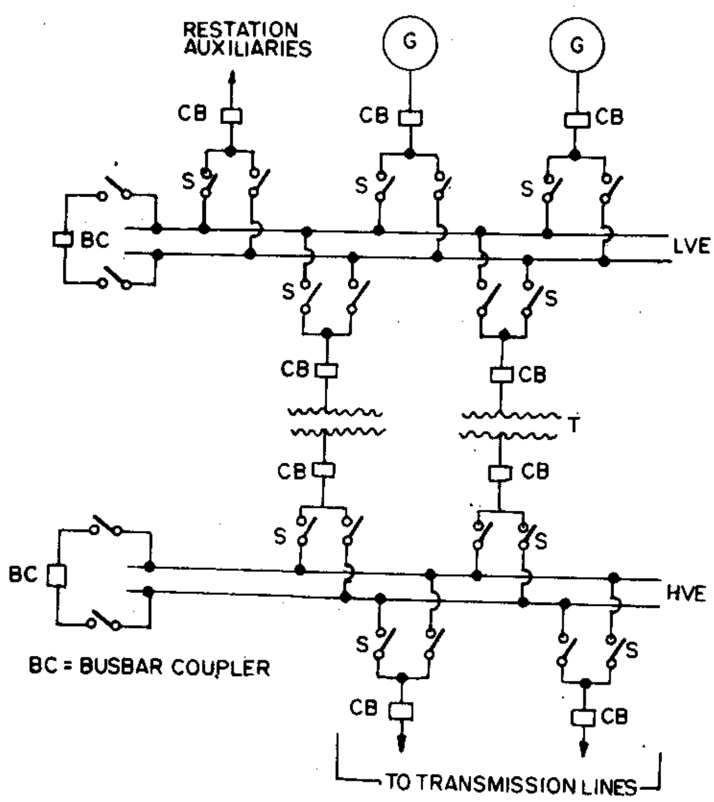


Fig. 39.2. Double bus-bar system.

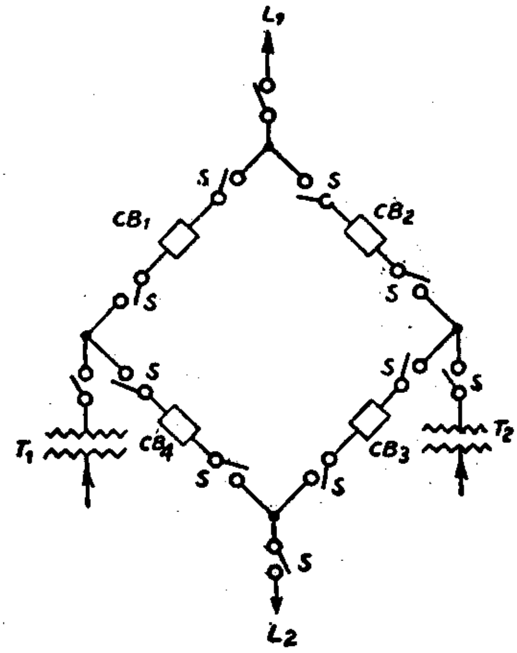
2. The repair of any bus-bar isolator is possible by switching out only that circuit in which it is used.

3. Quick restoration of operation of the installation is possible even after a short circuit has occurred on the working system of bus-bars.

4. The repair of circuit-breaker of any circuit without taking it out of service for an extended period is possible.

3. **Ring and Bridging Bus-bar Arrangement.** The arrangement of the system is shown in Fig. 39.3. In this arrangement, each line is served by two circuit-breakers, therefore, any one of the latter can thus be required without disconnection of the line. All the isolators are used for repair purposes only. Each line has its relay protection designed to trip both circuit-breakers simultaneously.

The ring bus-bar arrangement provides high reliability of supply with the aid of a comparatively small number of circuit-breakers as compared to a double bus-bar system. Further, the advantage of this layout is that there are always two parallel paths to the circuit and failure of one section does not interrupt the supply completely. Its shortcomings are the need to equip the circuits with a more involved relay protection and difficulty of making extensions (any increase in the number of circuits will require a considerable rearrangement of the switchgear). Owing to this drawback, this arrangement is mainly used where no further extension of the installation is foreseen.



L_1 and L_2 = Lines, T_1 and T_2 = Step-up transformers
S = Switch or isolator, CB = Circuit breakers.
Fig. 39.3. Ring type bus-bar arrangement.

The sub-stations of some hydro-electric power stations may be included in this group. The ring arrangement finds application for voltages of 110, 220 and 440 kV where two outgoing transmission lines are fed by two set-up transformers or auto-transformers.

The details of each equipment are discussed in the proceeding articles.

39.3. GENERATOR AND EXCITER

The electric generator is the most important part of the power station as all other units in the power stations are installed for the purpose of driving alternator.

The principle of electromagnetic induction is used for the generation of electric power with the help of generator. Fig. 39.4 shows the working principle of the alternator and a coil of wire. All modern types of alternating current generators (alternator) essentially consist of a fixed stator and revolving rotor. The stator core carries a 3-phase winding in which alternating e.m.f. is induced when the shaft of the rotor is revolved with the help of the prime-mover. The rotor is carrying field magnet and coils which provide the magnetic flux of the machine. The field is excited by a direct current brought into the field circuit by means of two rotor sliprings and set of brushes riding on them.

The magnitude of the induced voltage in the single phase of the stator winding depends upon the strength of the magnetic field, the speed of rotation and number of stator coils in series.

The winding of 3-phase generator may be connected either in delta or star arrangement, as shown in Fig. 39.5. With star arrangement two voltages can be obtained as line voltage V and phase voltage $V/\sqrt{3}$. The neutral point of the star arrangement can be connected to the earth and this helps the design of the protective system. In the event of a fault earthing one phase, the maximum voltage between two sound phases and earth is limited to phase voltage $(V/\sqrt{3})$ with delta system, an earth fault on one line, a voltage of $\sqrt{3}$ V volts will be applied between the earth and other two healthy phases. Therefore, in the event of a fault, the stress on insulation is greater in case of a delta circuit.

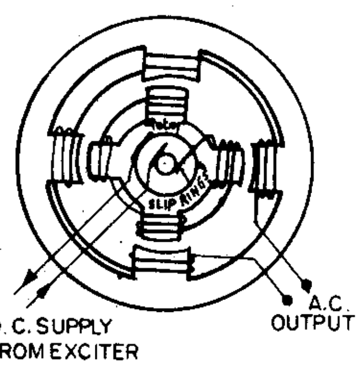


Fig. 39.4. The Alternator.

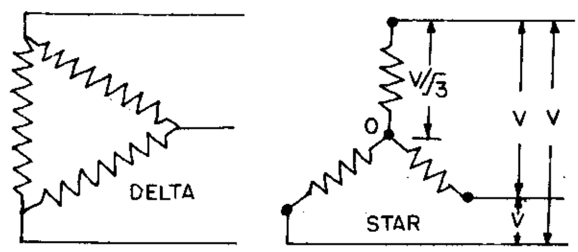


Fig. 39.5. Delta and Star Arrangement.

The main parts of the alternators are stator, rotor and exciter. The details of each are given below :

1. Stator. The stator mainly consists of three parts as stator frame, stator core and stator windings. The stator frame in circular is shape and is made of welded steel plate. The core is made of stampings of high permeability, low hysteresis and eddy-current losses. The eddy-current losses are reduced by coating the laminations on each side with an enamel. The radial ducts are provided at regular intervals through the length of the core for efficient cooling of the stator.

2. Rotor. The construction and design of the rotor of an alternator is most difficult as its weight is considerably high and rotates at a higher speed (3000 r.m.p.).

Large number of deep slots are machined in the rotor to accommodate the field windings which will carry field currents. The diameter of the rotor is limited to 100 to 110 cm. due to high weight of rotor rotating at high speed. The length between the two bearings is limited to 8 times the diameter of the rotor. The weight of the rotor of 120 MW alternator is about 30 to 40 tons.

It is also necessary to allow ample passage in the rotor through which cooling fluid can be circulated freely. Three different methods of providing ventilating slots are shown in Fig. 39.6. In the arrangment shown in Fig. 39.6 (*a*), normal slots are provided in the rotor teeth. In the arrangement shown in Fig. 39.6 (*b*), additional ventilating slots in the rotor are provided. The base slots are also provided as shown in Fig. 39.6 (*c*).

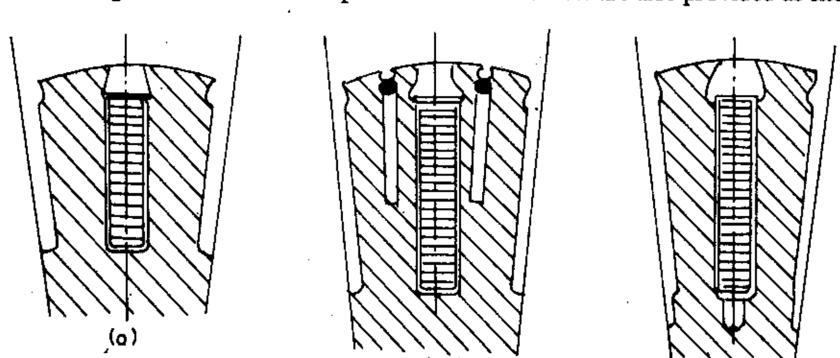


Fig. 39.6. Methods to provide slots for ventilating.

3. Excitation System. In all modern electric power stations, the rotor field of each synchronous generator is supplied by an individual D.C. generator known as exciter.

The exciter armature is either directly mounted on the generator shaft or is self-supported and directly coupled to the generator shaft.

Exciters are generally built as shunt wound D.C. machine. Its rating is 0.3 to 1% of the generator output. Exciters usually operate at a voltage between 115 and 400 volts.

A typical excitation circuit of a synchronous generator is shown in Fig. 39.7. Field rheostat is connected in circuit with exciter field winding for manual control of the generator excitation. By shifting the handle of rheostat, the resistance in field winding is changed to vary its current. This changes the voltage induced in exciter armature to alter the exciter terminal voltage so that the current in the generator field (rotor winding) can be adjusted to produce the required change in the e.m.f. induced in the stator winding for obtaining the given generator terminal voltage.

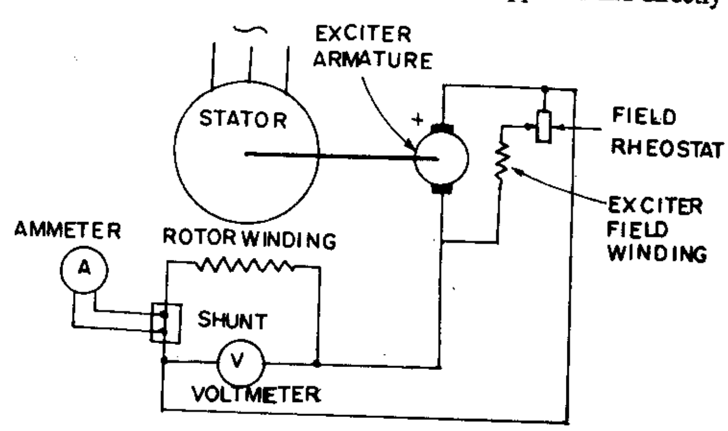


Fig. 39.7. Excitation circuit of a synchronous generator.

The armature shown in the circuit serves to monitor the value of the current fed into the generator rotor winding. This excitation current is usually so great that it is best measured with the help of shunt as shown in figure. The voltmeter in the circuit allows the exciter terminal voltage to be watched during start-up of the generator. Its other function is to permit calculation of the amount of power taken by the generator excitation circuit.

No fuses are inserted in the excitation circuit of a generator, because the exciter serves only for direct supply of its generator ; therefore, there is no possibility of a short circuit arising in the carefully made connections between the slipping brushes and the exciter.

Owing to the high speed of turbo-generators (1500 to 3000 r.p.m.), their exciters more or less frequently develop troubles during operation (especially the commutators). Therefore, generating stations with turbo-generators must have stand-by exciters in order to quickly switch the rotor winding over to supply from the stand-by unit without taking the turbo-generator off the line. A stand-by exciter unit generally consists of a D.C. generator coupled to a required cage drive motor.

In hydro-electric generating stations, where the water turbine-generators run at low speeds (62.5 to 125 r.p.m.), exciter troubles occur very rarely and no stand-by source of excitation is provided.

The recent trend—to excite turbo-generator and water turbine generators with rectified D.C. supplied from various kinds of A.C.—D.C. conversion equipment such as mercury-arc rectifiers : ignitrous and ionic excitation. Such type of excitation system offers many advantages as listed below over conventional excitation system especially when the output ratings reach high values.

1. Generator construction is simplified as there is no need for incorporating an exciter.

2. The possibility of more rapid changes in excitation voltage makes for greater stability of parallel operation when the fault occurs in the power system.

Ionic-type excitation system had been used for Kuibyshev Hydro-Electric Station in former U.S.S.R.

Design of Rotor of an Alternator. Generators coupled directly to the steam turbines are known as turbo-generators and those directly coupled to water turbines are known as water wheel generators. The dimensions and weight of the machine can be reduced if the speed of rotation is increased. This also results in number of economic advantages. This is the reason, the former Soviet engineering works manufactured mainly two-pole turbo-generators for 3000 r.p.m.

$$\left[n = \frac{120f}{p} = \frac{120 \times 50}{2} = 3000 \text{ r.p.m.} \right]$$

The turbogenerator rotors are built in cylindrical form and not over 100 to 110 cm in diameter. The reason for this is that the outer parts of the rotor have to travel at such a high peripheral speed that the centrifugal forces rise to values to extreme that it is unsafe to attach protruding poles and field coils to high speed rotors. On a forged round rotor of a turbo-generator, slots are milled out to insert and secure the conductors of the generator excitation winding. After the winding is put in, the slots are closed with metal wedges. Where the end windings leave the slots and extend beyond the rotor core, they are reinforced by high strength forged steel rings to prevent any deformation as a result of high centrifugal stresses.

In hydro-electric generating stations, the situation is different because the water turbines run between 60 and 750 r.p.m. which depends upon the factors as available water head, output rating and type of turbine used. Therefore, water-wheel generators suitable for such speeds must be designed with large number of poles. For example, the number of poles required for a system rotating at 62.5 r.p.m. and generating energy at 50 c/s

$$= \frac{50 \times 120}{62.5} = 96 \text{ poles.}$$

The water-wheel generators are built with salient (projecting) poles as they require a large number of poles and run at comparatively low speed. Therefore, water-wheel generator rotors are much greater in diameter than turbo generator rotors (8-10 metres or even more). When the output ratings are high, the rotors of water-wheel generators are made large in diameter to attain better cooling conditions in the machine.

The Kuibyshev-Hydro-Electric station in U.S.S.R. of 105 MW capacity running at 68.2 r.p.m. is an example of using 88 poles and 18 metre diameter of the stator.

The alternator of the diesel plant is of rotating field salient pole type. Its mechanical design requires special attention. This is necessary to avoid the possibility of torsional vibrations being set up by uneven turning moment of the engine. The coupling of the alternator and engine should be rigid to avoid torsional vibration of dangerous order.

Parallel Operation of Synchronous Generator. The electric power stations are erected for the operation of several generators designed to run in parallel with each other. The parallel operation of the generators ensures : (1) high reliability of supply to the consumers, (2) better economy in running of the power stations and their equipment and, (3) more stable frequency and voltage under conditions of varying load.

High reliability of supply to consumers is ensured because the load carried by any given generator running in parallel with several other machines can be immediately taken over by the other generators without any interruption in supply to the consumers when the given generators must be switched off the line on occurrence of some fault in it.

Parallel operation of the generators makes it possible to attain optimum economy of energy production by so distributing the system load that it is mainly carried by the units and stations which operate with the highest efficiency and produce the energy at the lowest possible cost.

Generator Cooling

Necessity of cooling the Generator. The efficiency of an alternator is the ratio of output to the total input. The useful output is the total input minus the losses. The losses in an alternator are classified as mechanical losses and electrical losses. The mechanical losses include the eddy current and hysteresis losses in the iron and the copper losses in the windings. The electrical losses convert into heat and raise the temperature of the insulation and machine part. If this converted heat is not removed, then the machine gets overheated and insulation is damaged.

In order to keep the temperature rise of the various parts of the generator and winding insulation from exceeding the respective maximum permissible value, every generator requires continuous cooling during its operation.

Methods of Cooling. The systems adopted for alternator cooling are mainly divided into two groups as closed system and open system.

(1) Open System Using Air. In open circuit cooling system, the cold air is taken in from the atmosphere with the help of the fan and passed through the machine and hot air coming out from the machine discharged either into the atmosphere or into the machine hall for station warming.

This system requires thorough removal of all dust particles from the air entering the machine. Otherwise any accumulation of dust in the ventilating channels and on the windings will soon hinder normal cooling and result in excessive rise in temperature of the various parts of the generator. The use of normal highly effective filter for cooling of air cannot, however, prevent a certain amount of dust from being deposited in the generators. Owing to this difficulty, they are never used and, if ever, only on low-capacity generators (up to 3 MW).

(2) Closed System Using Air. In a closed circuit cooling system, a given volume of air is circulated continuously through the generator. The hot air discharged from the generator in such a system is passed through water cooled heat exchangers where its temperature is reduced to the necessary value (40°C or 35°C) before it is again circulated through the generator. The air-cooler consists of a bank of tubes for the passage of the cooling water. The air is passed over the surfaces of these tubes for transfer of heat to the water.

During the frosty season of the year, the temperature of air entering the generator should not be allowed to drop below the value prescribed in station instructions. This is done to prevent any condensation of the moisture in the machine.

Advantages and Disadvantages of Closed System over Open System

Advantages : (1) It is best from the point of view of appearance both inside and outside the station.

(2) It makes the station quiet in operation.

(3) The possibility of dust and impurities deposition in the machine passages is less.

(4) It does not require any filter.

(5) It reduces the amount of moisture which might be passed through the alternator if open system is used in humid atmosphere.

(6) The absence of a supply of fresh air also makes it easier to combat a fire in a generator.

This system is mainly used for larger machines. Approximately 2.7 c.u.m. of air circulation per minute is required for each kW of loss in the alternator. This requires nearly 133 tons of air circulation per hour for a 60 MW generator running at 3000 r.p.m.

Disadvantages. The only disadvantage of the closed system over open system is the cost of the system. As it has many advantages, it is universally used for high capacity machines.

Hydrogen Cooling. Hydrogen is costly and not being naturally available like air. Hydrogen cooling system inevitably adopts closed system.

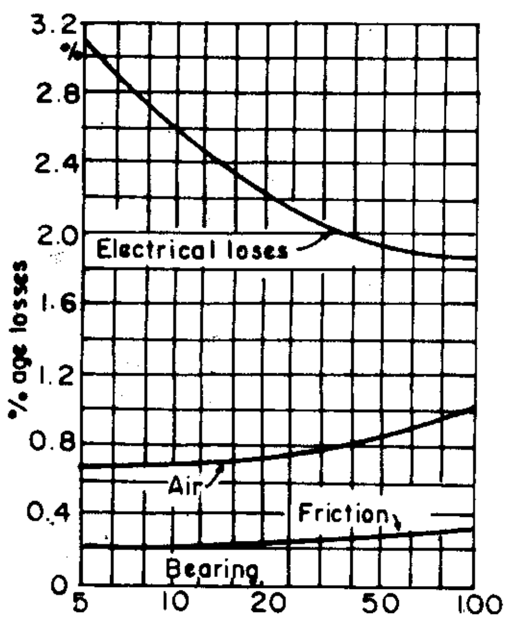
Air-cooling is successfully used for 100 MW generating units. If larger units were to be constructed, it would be necessary to reduce losses and improve the rate of heat transfer so as to obtain a better utilization of active materials.

The curve of losses with respect to the capacity of the generator is shown in Fig. 39.8 which shows that the windage losses are quite substantial and in fact increase with higher capacities. These losses further increase rapidly with speed as shown in Fig. 39.8. 20% increase in speed of air-cooled generator leads to 60% increase in windage losses.

This necessitates another cooling medium aside from air which would not only reduce the windage losses but would also transfer the heat generated at a rapid rate. The gaseous hydrogen was thought as a better cooling medium early in the 20th century and nowadays it is universally used in almost all thermal power plants up to 200 MW capacity generators.

The principle of H_2 cooling was first mooted and patented as early as 1915 by a German Scientist, Schuler. The first commercially operated H_2 cooled generator was a 25 MW unit in 1937 by General Electric Co., U.S.A. A 10 MW H_2 cooled experimental unit was constructed by Siemens in 1936. There was not much progress in the design till the end of Second World War. All H_2 cooled generators were developed after Second World War only.

Siemens being one of leading manufacturing Co. in this field, installed two H_2-cooled generators, 86 MW each at Tarazzano Power Stations in Italy. Siemens have supplied 4 H_2 cooled generators, 3 of 77 MW at Durgapur thermal power stations and one of 62 MW Bhusawal Power Station. Presently Siemens have constructed many such generators with capacities of over 200 MW and more.



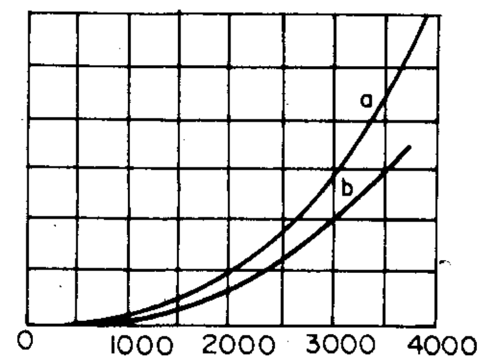


Fig. 39.8. Generator Capacity Vs different losses. **Fig. 39.9.**

H_2-cooled generators offer many advantages over air-cooled generators as listed below :

The two major advantages of H_2 as cooling medium are that its density is 1/14th of air and its thermal conductivity is 6.7 times that of air :

(1) Windage losses which are proportional to the density of cooling medium are drastically reduced, as 10 times lower as compared to air. Therefore, the efficiency of the machine is increased by 0.7 to 1%.

(2) The noise is considerably reduced due to lighter cooling medium and lower friction.

(3) The change-over from air to hydrogen cooling permits a machine of the same dimensions to have 20% greater output capacity or at a given output capacity, a hydrogen cooled generator will require 20% less active material (steel and copper) than an air-cooled machine. The reason for this is the rate of heat transfer is 1.35 times greater than air as thermal conductivity of hydrogen is 6.7 times greater than that of air.

(4) The cooling surface required for H_2 cooling is considerably smaller than that needed for air coolers due to high heat transfer rates.

(5) There is no possibility of fire hazard in a machine if the failure occurs in the winding insulation as H_2 does not support combustion. Therefore, there is no need to incorporate any means for fire control.

(6) The reliability of the insulation increases and its life span is prolonged. The absence of oxidation of the insulation and of accumulation of dust and moisture reduces the number and periods of shut-down for maintenance and repair.

(7) The corona effects on the conductors in the windings are less deleterious in H_2-atmosphere than in air. This also increases the life of winding.

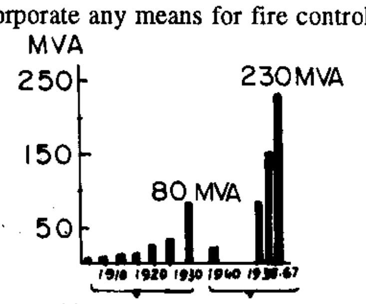


Fig. 39.10.

Due to the numerous advantages offered by H_2-cooling, it is universally accepted as a better cooling medium for high capacity (up to 200 MW) generator units. Fig. 39.10 illustrates how with the use of

H_2 as cooling medium, it became possible to construct individual units of larger capacities and at the same time to reduce the physical size and quantity of materials.

The fundamental difficulty to be overcome in using H_2-cooling is to ensure full safety against possibility of an explosion. This is because when H_2 is mixed with air in certain proportions, the mixture becomes explosive. To overcome this difficulty, the following precautions are taken :

(1) The frame of the machine is made gas-tight not only as regards the outer casing sheath, but also as regards all joints and seams through which air can penetrate into the machine.

(2) Where the shaft extensions of turbo-generators pass through the end shields, special shaft oil seals are provided.

(3) The H_2 pressure in the circuit is also maintained somewhat higher than the ambient atmospheric pressure (0.03 to 0.05 bar) to prevent the leakage of air into the system.

(4) Gas analyzers are included in the auxiliary equipment of each generator to monitor continuously and automatically the H_2-gas content in the cooling system of the machine during operation. As a rule, the H_2-content should not fall below 98% and O_2-content should not increase above 2%.

(5) To ensure that the machine is explosion-proof, its frame structure is designed to withstand a pressure up to 6 bar.

The maintenance of the purity of H_2 in the cooling circuit is essential as the properties H_2 (K, C_p and ρ) greatly deteriorate on adulteration with air. To maintain the purity of H_2 in the circuit and to obviate the risk of explosion, H_2 is maintained at 3 bar in most modern generators and effective sealing measures are provided.

Hydrogen Cooling Circuit. Hydrogen cooled generators are self-ventilated closed circuit type. Fig. 39.11 illustrates the cooling circuit.

The hydrogen is circulated in the generator through 3 cooling paths, after being picked up by the fans at each end of the rotor.

The first path is through the air gap. The gas in the air gap passes rapidly through the spaces between the stator packets and absorbs heat mainly in the end pasts of the stator core.

In the second circuit, the gas is conveyed through the stator end windings, through the cooling tubes welded into the stator frame and downwards through the stator core into the air in the inner sector. Here it reverses its direction and again passes through the stator axial spaces, in the centre portion, to the gas coolers.

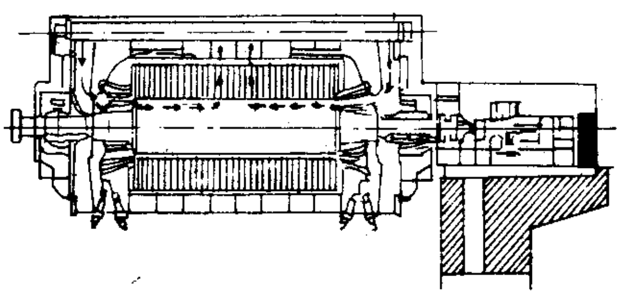


Fig. 39.11. Cooling Circuit of Hydrogen.

The third gas circuit is through the rotor end windings and the axial slots in the rotor teeth and out through the radial holes in the centre section of the rotor body into the stator axial spaces, and so to the coolers through which water is circulated.

The cooling chamber is so subdivided by baffles, that at the coolers, the gas from all parts of the generator is thoroughly mixed and flows away from the centre towards the ends where it is again picked up by the rotor fans and re-circulated.

Normally 2 or 4 coolers are provided depending on the size of the generator. The cooler tubes of Cupro-Nickel alloy are provided with fins to increase the area of cooling surface. The water cooler connections to the coolers are outside the sealed, explosion proof casing. A single thermometer is provided on the incoming bus and separate thermometers on the outlets of individual cooler to enable proper check and control of the cooling.

In this cooling system, normally the path of heat transfer is from the conductor, through the insulating material into the rotor/stator body and from these to the cooling gas.

In very large sizes of the generators, the direct cooling of the conductors is restored. In this cooling arrangement, the conductors are made hollow and the gas flows through the conductors.

Further intensification of cooling in machines has gone in the direction of increased hydrogen pressure. It has been found that a turbo-generator, for a given size, will have a rating of 30-50% higher than ordinary H_2-cooled generator if high-pressure H_2 is used for cooling. Better results are also attained with forced hydrogen cooling. These machines differ in that the rotor and stator windings are cooled by a stream of H_2 at a pressure of 4 to 4.5 bar.

As a result of more intense rate of cooling of the windings, it was found that a forced hydrogen cooled turbogenerator has twice the output of a machine of the same size having ordinary low pressure hydrogen—cooling. Only thanks to forced hydrogen-cooling which has been made possible, presently, to develop designs for machines with ratings reaching 300-500 MW and higher.

The present-day practice shows that hydrogen cooling is only economically justified when used in 3000 r.p.m. machine. In machines for 1500 r.p.m. and lower speeds, hydrogen cooling can only slightly improve the efficiency but this improvement does not repay the cost of incorporating H_2-cooling system in a machine. All water-wheel generators are only air-cooled as they run at a considerable low speed.

Filling of hydrogen. To avoid the risk of explosion, the generator casing is always flushed with CO_2 gas before filling H_2-gas in the circuit.

Liquid CO_2 is stored in bottles at a pressure of 60 bar expanded into the generator casing at a pressure of 0.5 to 0.8 bar. To prevent the freezing due to the latent heat of evaporation of CO_2, the gas is heated in a water bath at 95°C. The CO_2 gas is admitted into the generator causing at a rate of 0.5 to 0.75 m^3/hr.

The hydrogen is stored in bottles at a pressure between 150 to 200 bar and fed into the casing through a reducing valve and a silica gel breather at the rate of 1 to 1.5 m^3/hr. The hydrogen displaces the CO_2 which is led out into the atmosphere. For complete filling, the quantity of H_2 equivalent to 2 to 2.5 times the volume of the casing is required. When filled, the H_2 is maintained at 3 bar by keeping the reducing value always open between the H_2 bottle and generator casing.

Performance. The windage losses are nearly 25 to 30% of the total losses in the generator and their considerable reduction (90%) using H_2 as coolant enables H_2-cooled generators to attain better efficiency. In general, the efficiency of H_2 cooled generators is about 0.5% higher than air-cooled generators of equivalent size and at rated load.

At partial loads, the efficiency curve of H_2-cooled generated is flatter as shown in Fig. 39.12 as compared with air-cooled generator. The gain in efficiency at partial loads is even more pronounced than at rated load.

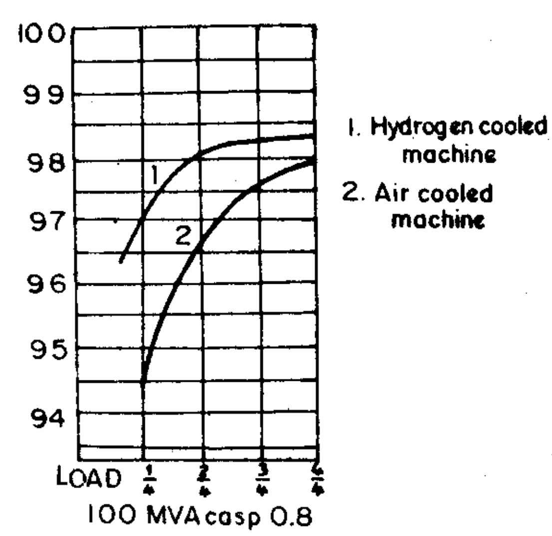


Fig. 39.12.

The initial costs of the H_2-cooled generators are high on account of the additional equipment required but the operating costs are lower on account of better efficiencies. With increasing size, the difference in initial costs decreases and that in operating costs increases. The economic limit after which H_2-cooled generators are recommended is around 50 MW.

High Capacity Turbogenerator Cooled by Hydrogen. A 1,200 MW turbogenerator had been built at the Electrosil plant in Leningrad in the former Soviet Union. This giant could produce enough energy to replace the efforts of 32 million workers.

It has long been known that the larger the machine, the lesser material per capacity unit is required to build it. Compared to a 300 MW turbogenerator, the cost of material in the 1,200 MW machines is only half as much. And the material accounts for about three-quarters of the machine's cost. Besides, it is simpler to make two large machines than eight small ones : it takes fewer workers and the machines, cranes and other equipment do not have to be exploited so intensively. And eight turbogenerators occupy twice as large an area as two bigger ones and require more service personnel to run them.

A 1,200 MW turbo-generator has an extremely high efficiency—almost 99 per cent. But even one per cent of loss equals 12 MW which continuously turns into heat inside the generator. Without forced cooling, the winding will immediately char, damaging the machine. But even a powerful air flow cannot remove the heat from the present-day super capacity machines.

Hydrogen's heat conductivity is seven times greater than that of air, employed instead of air, hydrogen yields an increase of current in the machine and hence an addition of 20-25 per cent to its capacity. Insulation deteriorates more slowly in hydrogen. Because, the rotor works in a gas which is 10 times less dense than air, the friction losses are reduced.

This is why hydrogen cooling has been suggested for the 1,200 MW turbogenerator. Under high pressure, hydrogen is forced directly through the inner cavities of the current conductors and from the stator winding the heat is removed by distilled water (ordinary water cannot be used because it conducts electricity). The hydrogen-water cooling system has proved very effective.

Of course, this type of cooling has complicated the turbo-generator design. The hydrogen inside the machine's body under enormous pressure strives to burst out. The air-hydrogen mixture forms detonating gas. To avoid an explosion, the stator is put into a gasproof body with reliable oil seals.

39.4. SHORT CIRCUITS IN ELECTRICAL INSTALLATIONS AND LIMITING METHODS

Any solid contact established between the different phases of an electrical installation or any bridging of them by a very low resistance is called short-circuit current. A short circuit current usually reaches values many times excess of normal rated current in the current carrying parts, circuit apparatus and even the generators.

One of the main causes of short circuits is a failure or break-down of the insulation between phases which allow the conductors to come into electrical contact with each other. Failures in the insulation in electrical equipment and installations occur because of defects in material, poor workmanship, natural ageing, mechanical injury and various other causes. In outdoor installations and on overhead power lines, short circuits may occur when a lighting surge or direct stroke breaks down the insulation.

Under normal operating conditions, the current drawn from a generator, according to Ohm's law, depends upon the value of the emf induced in the generator windings and the total impedance of the circuit. The total impedance consists of the impedance of the generator itself, the line impedance and impedance of the consumer load.

On occurrence of a short circuit current, as example, at a point SC_1 as shown in Fig. 39.13, the total circuit impedance comprises the impedance of the generator and the line circuit, while, if the short circuit occurs at point SC_2 on the stations buses, the impedance in the circuit is only that of the generator. In both cases, the total circuit impedance is significantly less than under normal operating conditions and, therefore, the short circuit current is proportionally greater than the normal load current. It thus follows that further the short circuit occurs from the generator, the greater the impedance of the circuit up to the point of fault and less the short circuit current.

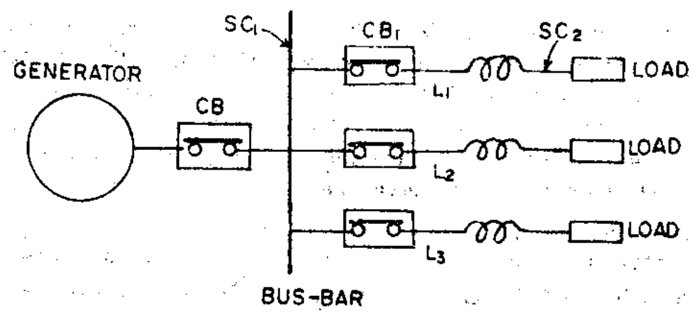


Fig. 39.13.

When several generators operate in parallel, the current flowing into the point of short circuit will be much larger than that from one generator because all the generators operating in parallel will contribute to the total circuit current flowing into the fault.

Effects of short circuits. (1) Since the short circuit current exceeds the normal load current of the current carrying parts by several times, the over-heating which it produces can be dangerous to the electrical equipments. To avoid harmful overheating of current conducting parts during short circuits, it is generally necessary to considerably increase their cross-sectional areas, in other words, install bus-bars, cables and wires of much greater size than required for carrying their normal load currents.

(2) The principal consequence of a short circuit is an interruption of supply to consumers.

The power supply is interrupted as a result of disconnection of the faulty section in the installation or in the circuit. For example, if the short circuit occurs at point SC_1 as shown in Fig. 39.13, where automatic tripping of generator circuit breaker *CB* cuts off supply to all the consumers of the station. If the several generators are operating in parallel in the station, a short circuit at point SC_1 on the station buses will cause all the generator circuit-breakers to be automatically tripped out at the same time.

A short circuit in line circuits, for instance, at point SC_1 on line L_1 will lead to automatic opening of its circuit breaker *CB* and interruption of supply to all its power consumers. In addition to this, the short circuit leads to a drop in voltage at the station buses and consequently, in the circuits connected to the buses of the station. This drop in voltage will continue until the faulty section has not been disconnected from the circuit by the respective circuit-breaker.

(3) The generator emf and the voltage in the stator winding drop due to considerable large short circuit current flow through the circuit. As a consequence of the drop in the generator emf, and also as a result of the considerable voltage drop in the stator winding due to the flow of large short-circuit current, every short circuit is found to cause a serious drop in voltage at the buses of the generating stations and in the power circuits.

(4) The shorter the distance between the place where the short circuit occurs and buses of the station, the less the residual voltage across the buses and hence, the less the voltage applied to the consumer circuits connected to the other unfaulted outgoing lines fed from the buses.

Any drop in voltage in the supply circuit means a disturbance in operation in the respective consumer circuits. It is a known fact that the torque of induction motor is proportional to the square of the voltage applied to them. At a significant decrease in voltage, the torque of motor may prove to be insufficient to operate the mechanism (machine tool), the motor must drive, and in case of an extended dip in voltage, it may lead to complete stalling of the motor. Therefore, it is necessary to switch off the faulty section of the circuit as quick as possible when a short circuit occurs in order to prevent the stalling of motors connected to the normal section of the circuit.

Limiting of short circuit currents. In large capacity installations, short circuit currents can attain such high values that unless certain means are used to limit them, the selection of electrical equipment capacity of withstanding them is very difficult.

This is accomplished by interposing auxiliary inductive reactances called reactors in each phase of the given installation.

A reactor is a large coil wound for high self-inductance and very low resistance. Its turns are insulated from one another and the entire coil is also insulated from earth. Each coil is built with a framework of insulating material to form a self-contained unit. At their ends, the coils are terminated for series connection in the circuit. In 3-phase installations, the reactors are assembled into units of three coils insulated from each other.

In a small power system, the inherent reactance of alternators, transformers, and lines may be sufficient to limit the short circuit current on any point to a value which can be dealt with by circuit-breakers. But when the system is extended by addition of more generating plants, lines and transformers in parallel, then a fault at the same location results in a much increased short circuit current. This means, the circuit breaker at a particular location will have to interrupt an increased current in the latter case. However, it should be clear that during normal operation, the current carried by circuit-breaker would suffice if the reactance of the system could be increased by the addition of reactors at suitable locations.

The short circuit current can be considerably reduced by the use of current limiting reactors and by their judicious placing. Thus the reactor helps in protecting the system. A reactor may be arranged in such a way that while there is no large voltage drop across it under normal operating conditions, it will prevent a large short circuit current being fed by the generators into the fault, thereby limiting the breaking currents of the circuit-breakers.

The suitable locations for the reactors in the circuit with corresponding advantages and disadvantages are discussed in the following paragraphs.

Location of Reactors

(*a*) **Generator Reactors.** Reactors may be used in series with generators as shown in Fig. 39.14 (*a*). The disadvantage of this arrangement is that, if the short circuit occurs on one feeder, the voltage at the common bus-bars drops to a low value and the synchronous machines connected to the other feeders may fall out of step. Another disadvantage is the voltage drop and constant I^2R loss in reactors under normal operating conditions (since full load current passes in the reactor as long as the alternator is connected to bus-bars). Modern alternators have large transient reactances to protect them in the event of a short circuit at alternator terminals. Generator reactors are used only with old machines which do not have enough reactance.

(*b*) **Feeder Reactors.** The reactors in series with feeders may be used as shown in Fig. 39.14 (*b*). In this arrangement when a short circuit fault occurs on a feeder, then the bus-bar voltage does not drop to a considerable extent (as was the case with generator reactor) but voltage drop and constant I^2R loss take place in the reactors during normal operation condition similar to generator reactors. Other disadvantages of this arrangement are no protection is provided against bus-bar faults and if number of generators are increased, the size of the feeder reactors will have to be increased in order to keep the short circuit current within the rating of the feeder circuit-breakers.

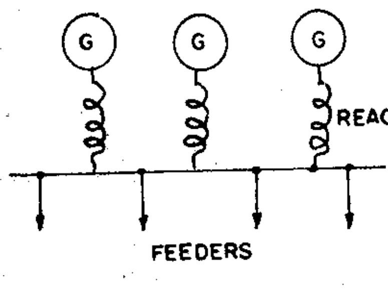


Fig. 39.14 (*a*) Generator Reactors.

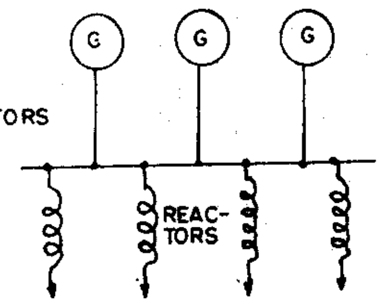


Fig. 39.14 (*b*) **Feeder Reactors.**

(*c*) **Bus-bar Reactors in Ring System.** The arrangement of the system is shown in Fig. 39.14 (*c*). With this arrangement of the reactors, the constant I^2R loss and voltage drop in the reactors are avoided. In this arrangement, each feeder is fed by one generator only and very little power being fed by the others through the reactors. The reactors can be made of high ohmic value. Under short-circuit condition, the faulty feeder is mainly fed by one generator. The other generators feed the faulty feeder only through the reactors which thus limit the fault current.

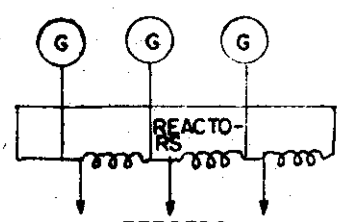


Fig. 39.14 (*c*). Bus-bar reactors in ring system.

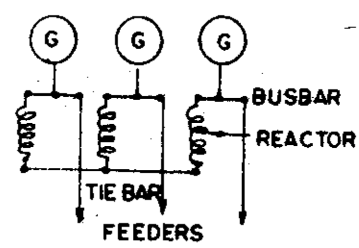


Fig. 39.14 (*d*). **Bus-bar reactors in tie-bar system.**

(*d*) **Bus-bar Reactors in Tie-Bar System.** The arrangement of the system is shown in Fig. 37.14 (*d*). This arrangement helps in reducing fault currents in the same way as the ring bus-bar reactor system, but in addition, it has the advantage of limiting the currents.

The tie-bar system has effectively two reactors in series between each section. Therefore, the reactors in this system need have half the reactance of those in a comparable ring system. Another advantage of this system is that additional generators may be connected to the system without requiring changes in the existing reactors.

The only disadvantage of tie-bar system of reactors is that it requires an additional bus-bar (tie-bar).

39.5. SWITCHGEAR INSTALLATIONS

The switchgear constitutes all parts or equipments of the power plant whose function is to receive and distribute electric power. It comprises assemblies of switching apparatus, protective and indicating metering devices, interconnecting bus-bar systems and relevant accessories.

The functions performed by the switchgear are listed below :

(1) The faults are localised and the faulty plant is automatically disconnected from system by the operation of protective equipments.

(2) To break short circuit without giving rise to dangerous conditions.

(3) To facilitate redistribution of loads, inspection and maintenance on the system.

The types of switchgears which are in common use are discussed below :

(1) Indoor Switchgear Installation. Indoor switchgears are preferred for small capacity stations and in the voltage range of 20 kV to 110 kV. It is adopted for 110 kV station when the atmosphere surrounding the substation site is highly contaminated by wastes from chemical, cement and similar works whose chimneys discharge dust, gases and vapours which are harmful for the electrical equipments. This is also applied to sites in regions with very low temperatures and those located near sea coasts.

The devices by which the circuits can be disconnected in such a switchboard consist of knife-type switches, air circuit-breakers and fuses.

Low voltage distribution switchboards find very wide applications. In small generating stations operated at voltage up to 1 kV, they comprise the main switchgear and are installed directly in the machine room. All operations involving the switch in and switch out of the generators and outgoing feeders are performed on these switchboards. The operating conditions of the station are also supervised by means of indicating instruments.

Where the voltages exceed 1000 V, the high voltage switchgear and bus-bars of each indoor installation are assembled in an isolated switch-room constructed so as to be fully reliable in service and ensure that the equipment can be operated with full safety.

The different methods of arrangement of the switchgear installation are used as per the type of circuit-breakers used. If the circuit-breaker is of the bulk oil type (60 kg and more oil) ; the switchgear structure will be designed with explosion-sectioning compartments which can open directly to the outdoor atmosphere. The open type compartment with approach from control, control is preferred when air-circuit breakers are used.

(2) Unit Type Switchgear Installation. A unit switchgear installation is a switchboard consisting of cabinet obtained from manufacturer fully assembled and ready for installation.

Each cabinet of unit type switchgear installation houses the electrical equipments required for one main connection. The latter is assembled of different kinds of units in accordance with the main connections layout of the given installation. Such units are constructed in the form of metal cabinets. Being sheathed in metal, they protect the operating personnel from coming into accidental contact with any of the live parts and also protect the equipments from dust.

Operation of unit-type switchgear installation has shown that they are highly reliable in service, safe to operate and that the electrical apparatus and current carrying parts are much less liable to gather deposits of dirt and dust than is the case in conventional on site assembled indoor substations.

By using unit type switchgear, substations can be erected more quickly, their buildings can be smaller and simpler in design. The future extensions and rearrangements are possible with this type of switchgears. Unit type substations have lower yearly costs than equivalent conventional design indoor substations.

The use of unit type switchgears has become widespread in recent years due to the advantages stated above.

(3) Outdoor Installation. The outdoor substations are preferred for the voltage range of 35 kV to 500 kV because they have the following main advantages over indoor installations within this range :

1. The volume of construction work is smaller and, therefore, the cost of switchgear installation is lower.
2. There is practically no danger of a fault which appears at one point being carried over to another point in the installation because the apparatus of the adjoining connections can be spaced liberally without any noticeable increase in costs.
3. The time needed for substation erection is shorter and a smaller amount of building materials is required.
4. All the equipments are within view and installation is comparatively easy to extend if need arises.

The disadvantages of outdoor installations as compared with indoor installations are listed below :

1. A much greater area is required by the substation.
2. Lesser convenience of operation, because the various switching operations with the isolators, as well as supervision and maintenance of the apparatus, must be performed in open air during all kinds of weather.
3. The effect of rapid fluctuations in ambient temperature and possibility of dust and dirt collection on the equipments of the installation requires special design of equipments which can be used for outdoor installations.

Notwithstanding the disadvantages, outdoor installations are very widely used in high capacity power plants.

The main structural elements in outdoor substations are the specially designed supports to which the insulators of an overhead conductor system are attached. The foundations used to support the outdoor installation apparatus are also important structural elements. The overhead conductor supports are constructed of reinforced concrete or steel.

39.6. CIRCUIT-BREAKERS

The function of circuit-breakers is to break the circuit when various abnormal conditions arise and create a danger for the electrical equipment in the installation. The heaviest duty, a circuit-breaker has to perform is to interrupt a short-circuit current which may reach a value of several tens of thousands and even more ($> 100 \times 10^3$ amps) in a large capacity power system. At the same time, in order to quickly eliminate the source of the fault, the circuit-breaker must open the circuit with least possible delay.

Principle of Circuit-Breaker. Circuit-breaking means rapid conversion of a predetermined section of circuit from a conductor to an insulator.

When the current carrying contacts are separated, an arc (which contains an ionized gas) is produced between them. This arc provides for the gradual change-over from current carrying to voltage isolating states of the contacts. Therefore, it plays an important part in circuit interruption process. The arc has to be carefully controlled because a good deal of energy in the form of heat is generated in it.

The produced arc is extinguished by the following two methods :

(1) High Resistance Methods. In this method, the arc resistance is made to increase rapidly by lengthening, cooling or splitting the arc so as to reduce the current to a value insufficient to maintain the arc. This method is used in D.C. circuit-breakers.

(2) Low Resistance Method. In this method, the resistance is maintained low and the arc is prevented from restriking after it has gone out at a zero current. This method is used in air-blast circuit-breakers and oil circuit-breakers and is applicable only for A.C. circuit-breakers.

The circuit-breakers which are commonly used are classified as air circuit-breakers and oil circuit-breakers.

(1) Simple Air Circuit-Breaker. Air circuit-breakers are a type of switching apparatus incorporating special devices for automatically breaking the circuits. They protect whenever an overload or a short circuit occurs. The air circuit-breakers finding the widest application are those fitted with overcurrent releases or trips to provide protection against short circuits and over-loads. A simpler type of a circuit is shown in Fig. 39.15 which has single pole and which can release the overcurrent instantaneously.

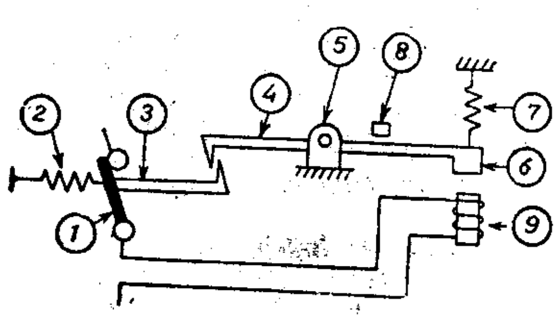


Fig. 39.15. Single-pole air circuit-breaker with instantaneous overcurrent release.

When it is in a closed position, it is prevented from opening by latch 4 because the latter is maintained in engagement with catch lever 3 by the upward pull of spring 7 on the latch arm. If the load current flowing through electromagnet 9 (coil of overcurrent release) exceeds the current setting, armature 6 is attracted by the electromagnet to overcome the pull of spring 7, turn the latch on pivot pin 5 and free the catch lever. Following this opening, spring 2 pulls circuit-breaker blade 1 out of contact. The position occupied by the latch when the circuit-breaker is open is fixed by stop 8. The circuit-breaker is closed by hand with operating handle 10.

The current at which the circuit-breaker will trip depends on the tension of adjusting spring 7 ; the greater the tension, the higher the tripping current and vice versa.

A fundamental shortcoming of the instantaneous release air circuit-breakers discussed above is that they have no trip free mechanism to open them automatically whenever their operating handle is held in closed position. Therefore, air circuit-breakers discussed above without trip free mechanism are unreliable and are unable to properly protect an installation. They are also undesirable from the point of safety because the operating handles are released with a force sufficient to cause injury to an operator standing in front of them. Trip free mechanisms in air circuit-breakers commonly take the form of a toggle link system.

These types of air circuit-breakers are used in A.C. installations for voltages up to 500 V but they can be used for higher voltage in D.C. installations.

(2) Over Current-Release, Air Circuit-Breakers for High Capacity. In overcurrent-release air circuit-breakers, the contact system normally comprises a set of load carrying and arcing contacts as shown in Fig. 39.16. The load carrying contacts 1 and 2 are designed to carry the load current continuously as long as the breaker is closed. They do not serve to interrupt the current when the breaker is opened. Main contacts should have as low a contact resistance as possible.

A moving main contact is of laminated brush type, assembled of a large number of flexible copper leaves. In the closed position, a spring presses brush 2 against flat fixed main contact 1 thereby providing a large number of points of intimate contact between them. The greater the number of points of close contact, the lower the contact resistance.

It should be pointed out that when such copper or brass parts are operated in air, their surface becomes oxidised. The result is a sharp rise in contact resistance and temperature of the contact. To avoid this, a coating of silver is applied. Silver does not oxide in air and becomes coated with a film of silver sulphide (Ag_3S) formed by decomposition of atmospheric hydrogen sulphide (H_2S) in the presence of oxygen. The conductivity of the sulphide film is almost equal to that of the silver ; that is why silver coated contacts retain their original properties.

The two arcing contacts 3 and 4 are connected in parallel with main contacts 1 and 2. When the breaker is in its closed position, only a part of the load current flows through them. The contact 4 is fixed, while contact 3 can move and is attached to a current-conducting plate 7. During the first moment of breaker opening, the main contacts separate just before the acting contacts can open. Since the arcing contacts shunt the main contacts, no arc will be drawn between the latter and the entire current to be interrupted must then flow through the arcing contacts.

When the gap between the main contacts reaches sufficient size, the arcing contacts begin to separate and an electric arc is set up between them. The arcing contacts, thus, by shunting the main contacts, protect the main contacts from the harmful effects of the electric arc. As the circuit-breaker closes, the contacts make the circuit in the reverse order.

The arcing contacts have to carry the entire load current for only a short period, this accounts for their small size. They are designed with detachable tips easily replaced when the contact faces become burned.

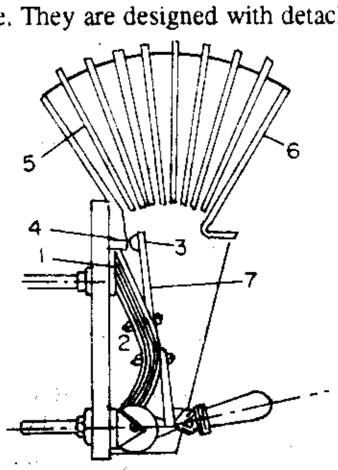


Fig. 39.16. Schematic representation of an air circuit-breaker fitted with an arc extinguishing chamber.

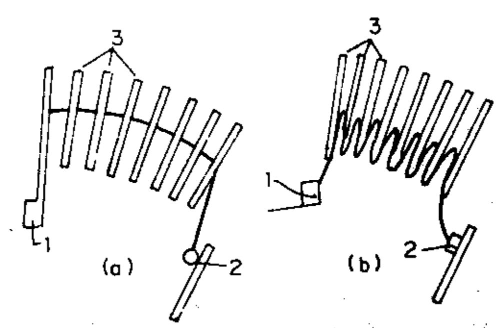


Fig. 39.17. Arrangement of arc extinguishing chamber ; *(a)* with grid of steel plates ; *(b)* with arc resistant plates of insulating material : 1-fixed contact ; 2-moving contact ; 3-grid plates.

To accelerate extinction of the arc and limit its size, air circuit-breakers are fitted with arc-extinguishing chambers. Fig. 39.16 represents one such type of arcing chamber having a set (or grid) of steel plates. In such a chamber, the arc drawn between the arcing contacts during an interruption of the current becomes extended and rises into the chamber 6 where it encounters a set of steel plates arranged perpendicularly to its path. The arc then splits up into a series of short hot arcs as shown in Fig. 39.17 (*a*).

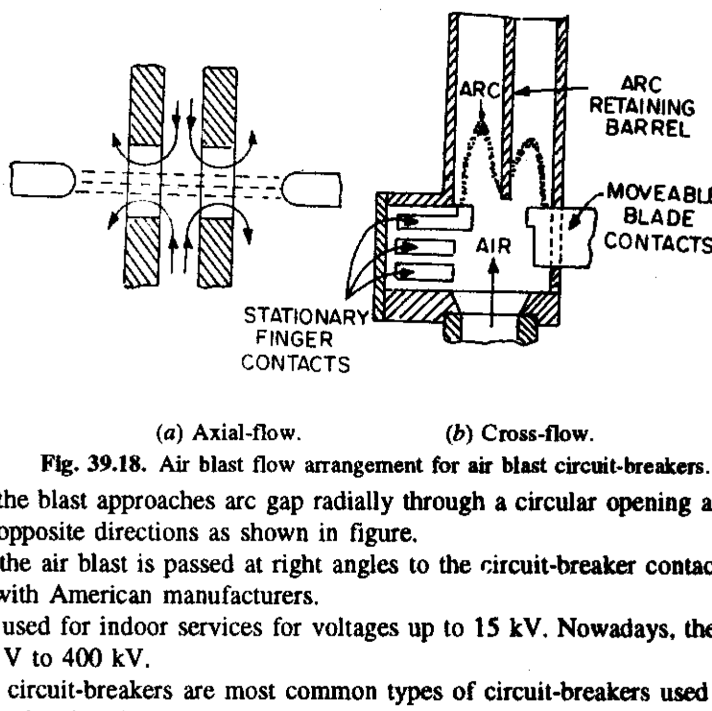
The arc rises into the arcing chamber grid plates because of the electrodynamic forces acting between the current flowing through the arc and that flowing in the current conducting parts of the circuit-breaker and also because the air heated by the arc also rises.

The short arcs which appear in the arcing chamber are intensely cooled by the steel plates, they are thus quickly extinguished before they can pass out of the chamber. Air circuit-breakers with such types of arcing chambers are capable of interrupting short-circuit currents reaching tens of thousands of amperes.

Some types of air circuit-breakers are designed with arcing chambers containing a set of arc-resistant plates of insulating materials. When an arc rises into such a chamber, it is forced between the plates as illustrated in Fig. 39.17 (*b*). The rapid extinction of the arc in this case is fostered by the considerable length to which the arc is stretched and its intimate contact with the surfaces of the dielectric. On being forced into a series of narrow gaps, the arc is extinguished more quickly than would be the case in an unconfined space.

When circuit-breakers must be tripped by remote control, they are furnished with trip coils serving to unlatch their free mechanism in the same way as the over-current releases. Such trip coil may be used where circuit-breakers must be opened automatically by a relay located at some other place in the given installation.

(3) Air Blast Circuit-Breakers. In such circuit-breakers, a blast of air at a very high velocity is used for extinguishing the arc. Compressed air stored in a tank at a pressure of 15 to 20 bar is passed through a nozzle to produce a high velocity jet of air. The high velocity jet of air coming out of nozzle provides axial blast or cross blast near the point of arc as shown in Fig. 39.18.



(*a*) Axial-flow. (*b*) Cross-flow.

Fig. 39.18. Air blast flow arrangement for air blast circuit-breakers.

In axial blast circuit-breakers, the blast approaches arc gap radially through a circular opening and escapes from the arc gap axially in opposite directions as shown in figure.

In cross-blast circuit-breakers, the air blast is passed at right angles to the circuit-breaker contacts. This arrangement is more common with American manufacturers.

Air blast circuit-breakers were used for indoor services for voltages up to 15 kV. Nowadays, these are used for system voltages of 220 V to 400 kV.

Oil Circuit-Breakers. The oil circuit-breakers are most common types of circuit-breakers used in power stations. The rating range of these breakers lies between 25 MVA at 2.5 kV and 5000 MVA at 250 kV. Plain tank type oil breakers operate satisfactorily when the current under interruption is neither too small nor too large. In modern power plants of high capacity, tank type oil breakers have arc-enclosing interrupting devices.

The use of oil in the circuit-breaker offers following advantages :

(1) It absorbs arc energy while decomposing.

(2) It has high dielectric strength.

(3) The gases formed during absorbing the arc have good cooling properties.

(4) Surrounding oil in close proximity to the arc presents a large cooling surface.

(5) It acts as an insulator between live part and earth.

The disadvantages of oil presence in circuit-breaker are listed below :

(1) It is easily inflammable.

(2) It can cause explosion by mixing with air.

(3) It requires maintenance and periodic replacement.

The type of oil circuit-breakers which are in common use are plain break oil circuit-breaker and self-blast oil circuit-breaker.

Plain Break Oil Circuit-Breaker. The arrangement of this breaker is shown in Fig. 39.19. The oil pressure in this breaker tank is solely due to the head of oil above the contacts which are enclosed in an earthed metal tank as shown in figure.

In this circuit-breaker, the gas bubbles generated set up enough turbulence in the oil and thereby help to eliminate ionized arc products and eliminate the arc earliest possible. The air over the oil surface acts as a cushion. The volume of the air cushion is 10 to 12% of the tank volume.

The liberated gases may diffuse into the air-cushion and form an explosive mixture. The large quantity of oil required and long and inconsistent arcing times are the main drawbacks of this circuit-breaker.

In view of these limitations, such circuit-breakers are suitable only for low current and low voltage operations, not exceeding 150 MVA at 11 kV.

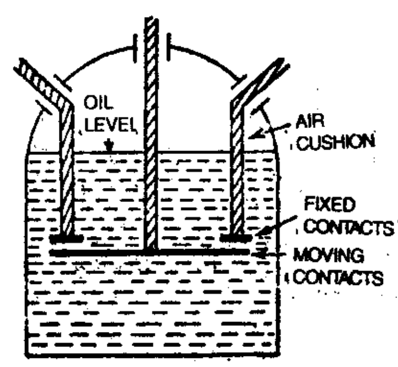


Fig. 39.19. Plain oil circuit-breaker.

Self Blast Oil Circuit-Breaker. In this circuit-breaker, the pressure of the gas bubbles set up in the oil by the arc is used to force fresh unionized oil into the arc path. For this purpose, the contacts are surrounded by a pot or pressure chamber. This arrangement increases the rate of rise of dielectric strength in the contact space which is an advantage. Therefore, this type of circuit-breaker has higher breaking capacity and reduces the arcing time.

The pressurised chambers which are commonly considered are of two types, plain pot, and jet pot.

(*a*) **Plain Explosion Pot.** The arrangement of this is shown in Fig. 39.20 (*a*). Both the fixed and moving contacts are enclosed in a closed cylinder as shown in figure. The shell is closed at the top and has a restricted opening at the bottom through which the moving contact passes. Therefore, the arc is established in a confined space, the products of the arc are expelled violently through the lower opening. The pressure generated in the pot during the arcing due to the formation of gas bubbles in oil creates turbulence in the oil and tends to cause arc extinction. The extinction of arc is not achieved while the moving contact is still within the pot but it occurs immediately after the moving contact leaves the pot due to axial high velocity blast of gas which is released through the restricted opening.

This oil breaker suffered from one serious disadvantage of increasing the arcing time when operating against currents considerably less than rated current (say 30% of rated). This was due to the low gas pressure compared with that generated at rated currents.

This drawback of plain explosion pot type breaker is removed by using explosion type oil pot.

Cross-jet Explosion Pot. The arrangement of this pot is shown in Fig. 39.20 (*b*). In this arrangement, as the moving contact is withdrawn, the gas generated by the arc exerts pressure on the oil in the back passage. As a result, when the moving contact uncovers the arc splitting jets and fresh oil is forced across the arc path, the arc is driven on to the insulating barriers which act as arc splitters. The arc length is increased due to the arc splitters and, therefore, the arc is weakened and finally interrupted. The movement of the oil is checked by the pressure of the arc itself as the pressure of the gas becomes very low at zero current.

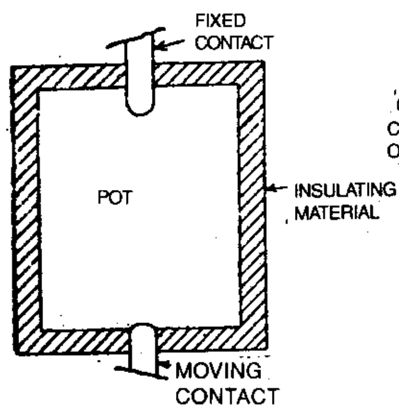


Fig. 39.20 (a) Plain Explosion pot.

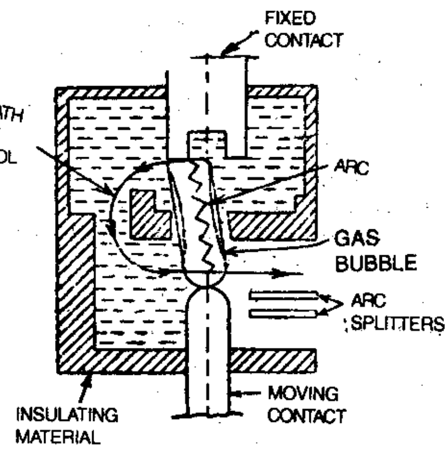


Fig. 39.20 (b) Cross-jet Explosion pot.

39.7. POWER TRANSFORMERS

The transformers are designed to convert alternating current of one voltage to alternating currents of some other desired voltage.

The different parts of the transformer are shown in Fig. 39.21.

The transformers are usually of oval shape and are fabricated from steel plates of 5 to 12 mm thick. The tank bottom and covers are made of still heavier steel plate. The tank covers are bolted to the tanks to provide a seated joint between them. The core and the windings arranged on it comprise an assembly which is placed within the tank.

The core serves as the magnetic circuit for the flux set up by the windings. To reduce the losses due to eddy currents, the core is assembled of laminations cut from special transformer steel sheets of 0.5 mm thick. Each lamination in the core is insulated from its neighbour in the stack by a thin coating of varnish or a sheet of thin paper. After assembly, the laminations are lightly pressed together by a series of clamping bolts to obtain a rigid core structure.

The transformers have windings of electrolytic grade copper wire of rectangular or round section. The wire is insulated with thin cable paper or cotton yarn. The cylinders of insulating materials insulate the windings from each other and from the core. Each winding has its ends brought up to porcelain terminal bushing 9 and 10 per lead-out through the tank cover.

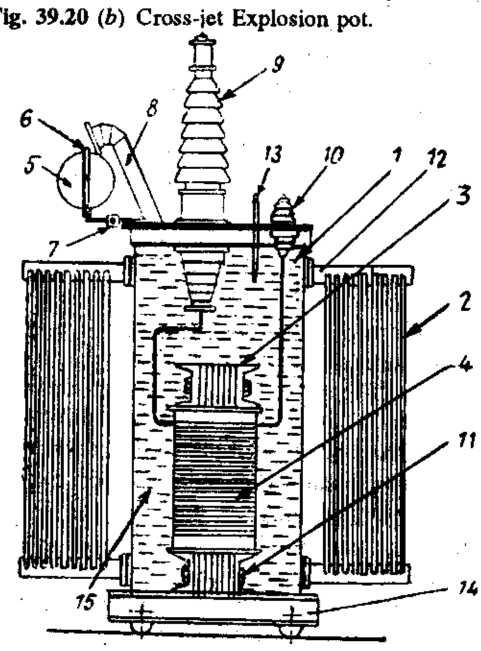


Fig. 39.21. Essential parts of a medium power transformer.

(1) Tank, (2) Radiators, (3) Magnetic circuit (core), (4) Windings, (5) Oil conservator, (6) Oil gauge, (7) Buchhlor relay, (8) Vent-pipe, (9) Terminal bush, (10) Terminal bush, (11) Clamping bolts, (12) Pipe connections of radiator, (13) Temperature indicating thermometer, (14) Tank underframe, (15) Transformer oil.

The tank serves to hold the transformer oil, a special grade of mineral oil (*Pr = 25000) produced from certain types of petroleum. The oil in the tank performs two functions, the first, it serves as a medium for transfer of heat generated in the windings and core steel to the air surrounding the transformer, and secondly,

* Prandtl Number.

to insulate the current carrying parts from each other and from one earthed tank. Radiators are fitted to the tank as shown in figure to increase the surface available for cooling of oil in transformer. The radiators are attached to the tank with a pipe connection 12 as shown in figure incorporating special type radiator valves.

During the operation of the transformer, the oil in transformer undergoes temperature changes and changes in volume. To take into account the change in the volume of oil during operation, it is essential to fill the tank partially leaving an air space under the cover free to communicate with the atmospheric air. This will oxidise the oil and form the sludge as the oil comes in contact with the air containing oxygen and moisture. This will result in deterioration of oil, mainly reduction of its dielectric strength. To avoid these harmful effects of oxidation and sludge formation, the majority of transformers are filled with an oil conservator 5 as shown in figure. The main functions of oil conservator are, firstly, to ensure that the transformer tank is always filled with oil and secondly to reduce the oil surface maintained in contact with the air. The top of the conservator is fitted with a breather opening to permit the air to be taken in or expelled out as the level of the oil in the conservator varies with changes in temperatures. The conservator is connected to the tank by a pipe of short length. A conservator usually has a volume amounting 8 – 10% of the volume of the oil in the transformer tank. To check the oil level, the conservator is fitted with oil gauge 6 as shown in figure in the form of gauge glass.

When a short circuit occurs in a transformer, it is generally accompanied by intense decomposition of the oil and the formation of a large amount of gases. The result is a sudden rise in pressure in the transformer which is dangerous for its tank. For this reason, transformers are fitted with explosion vent pipe 8 extending upward from the tank cover, the upper end is shut off with a thin glass disk. On occurrence of any sudden pressure surge in the transformer, the oil will be flung upward through the tube and rupture the glass disk. A portion of the oil is thus allowed to escape from the tank and thereby prevent an impermissible pressure rise in the tank. The thermometer 13 serves to measure the temperature of the oil in the transformer.

Buhholz relay 7 protects the transformer in the event of internal faults or flashovers which cause arcing that gives rise to gaseous products of decomposition of the insulating materials, wooden parts and oil.

The tank is supported by roller-mounted truck underframe 14 provided for moment of transformer during installation and removal in case of repair or overhaul.

Transformer Connections. The power transformers which are commonly used in power stations are either single phase transformer banks of three each or 3-phase transformer. 3-phase transformers can be used with advantage in place of blanks of three single-phase transformers. The connections most widely used in 2-winding 3-phase transformers are Delta-Star, Star-Delta and Delta-Delta. The merits and demerits of different types of connections are discussed below.

There is current and voltage symmetry with the delta (Δ) connection. The Δ connection is used for transformer windings when the voltage is small and currents to be handled are considerably large. This is because the phase voltage is same as live voltage and phase current is equal to line current/$\sqrt{3}$. A Delta-Delta connection is versatile because the failure of one single phase transformer out of three, leaves two transformers connected in open delta so that a 3-phase still can be obtained. The added advantage of this system is with two transformer units connected in open Delta initially supplying a certain load, it is possible to add a third unit and connect the bank in Delta to supply more load, as it grows in the system. Another advantage of this system of connection is, the division of load can be made to be in the same proportion as the rating of the transformers by proper proportioning of impedances.

The major disadvantage of Delta-Delta connection is the effect of difference in voltage ratios is marked in case of the Delta-Delta bank of transformers. Large currents flow in both high voltage and low voltage windings if all phases are not alike.

With Delta-Star transformer, the failure of one phase is more serious and it may involve discontinuity of supply. In Delta-Star arrangement, the division of current is entirely independent on the difference in the characteristics of individual transformer. The balanced 3-phase load is equally divided among the phase regardless of inequalities in impedance which is added advantage of the connection over Delta-Delta connection.

The Star-Star connections are not used normally as it is associated with number of disadvantages listed below :

(1) It introduces third harmonic current and voltage between live and neutral and has the possibilities of developing dangerous over-voltages.

(2) The instability of neutral exists because of differences between the magnetizing currents in different phases which arises owing to differences in the magnetic circuits caused by faults in construction and reason is, the neutral is shifted owing to the unbalanced load from live to neutral.

(3) In this system of connection, third harmonic magnetising currents cannot flow and this results in high flux densities and peak voltages induced are 50% greater than normal.

With the use of Delta-Star or Star-Delta, the presence of Delta eliminates the possibility of third harmonic voltages associated with Star-Star connections and stabilizes the neutral. The presence of star makes the division of load current among the phases independent of impedance.

The choice of Delta-Delta or Delta-Star in a particular power station is decided by the need for parallel operation with existing banks of transformers or the interconnection of network.

Selection of Transformer. The operating characteristic and capital cost should be considered for the selection of transformer to be used in power-station.

The following points should be taken into account for considering a choice between three single phase transformers and 3-phase transformers for a certain location.

1. It is possible to connect three-single phase transformers in Delta-Delta with full capacity and in open Delta on both sides for a smaller load.

2. In case of fault in one transformer, two single phase-transformers can be used to supply the load.

3. Single phase transformer occupies less space and weighs less than the corresponding 3-phase transformer. This is a factor to be considered particularly for underground power station, because the space carries lot of importance and handling of heavy weights would be difficult.

It is always preferable to use 3-phase transformer instead of 3-single phase transformers for ground surface power stations as it is cheaper, weighs less, occupies less space and is more compact.

The losses in the transformer are also an important criterion for their selection. A 3-phase transformer is preferable compared with a bank of three single-phase transformers as the core loss is 20% less in 3-phase transformer.

The impedance of transformers is another consideration for their selection as it plays important role in its operation. The transformer must have some percentage impedance voltage for their efficient working when operated in parallel. The impedance of a transformer increases with the insulation level and method of cooling used. Forced-cooled transformers are better for system requiring high impedance. The cost of the transformer increases rapidly if they are required with lower impedances than their normal standard values.

In selecting a power transformer for large capacity station, the factors which are to be considered in deciding the suitability of particular type of transformer for particular application are, initial cost, losses, method of cooling, insulation, percentage impedance voltage, regulation of voltage, floor area, weight, continuity of service and load factors.

The system engineer has full liberty to decide the emphasis to be given to each of the above points depending on particular application.

39.8. METHODS OF EARTHING A POWER SYSTEM

It is absolutely necessary to earth a power system at a suitable point by a suitable method as it offers many advantages as listed below :

1. It reduces the maintenance expenditure.
2. It improves the service reliability.
3. It provides better safety.

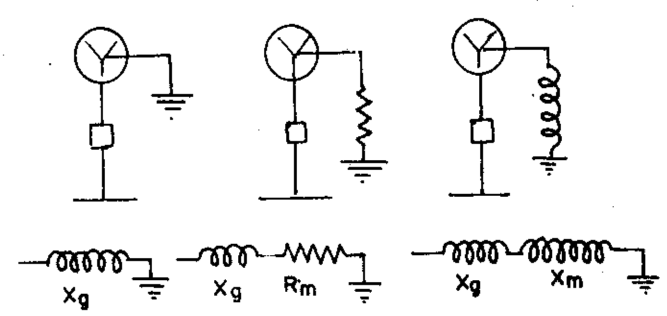
4. It provides safety to the electrical equipments against over-current.
5. It provides improved lighting protection.

The different types of systems used for earthing the power system are discussed below :

(A) Solidly Earthed. When the neutral of a generator or power transformer is connected direct to the earth, as shown in Fig. 39.22 (*a*), the system is said to be solidly earthed. The solid earthing does not make a zero-impedance circuit as the generator or transformer would have its own reactance in series with the neutral circuit. The direct earthing of a generator without external impedance causes earth-fault current from the generator to exceed the maximum 3-phase fault current if the impedance of the generator is too low. This may also exceed the short circuit current for which the windings are braced. For this system of earthing, it is necessary that the earth-fault current shall be in the range of 25% to 100% of the 3-phase fault current to prevent the development of high transit overvoltage.

(B) Resistance Earthed. The neutral of the generator is connected to the earth through a resistor as shown in Fig. 39.22 (*b*). The advantages of this earthing are listed below :

1. It reduces the effect of burning of faulted electrical equipments.
2. It reduces the mechanical stresses in the circuit carrying fault currents.
3. It reduces electric shock hazards to the persons, caused by stay-earth fault currents in the earth return path.



(*a*) Solidly Earthed. (*b*) Resistance Earthed. (*c*) Reactance Earthed.

Fig. 39.22. Methods of Earthing a Power System.

4. It also reduces the line voltage dip caused by the occurrence of the earth fault.

The magnitude of the resistance to be used should be such that it should limit the earth fault current to a value which will reduce minimum damage at the point of fault.

(C) Reactance Earthed. A reactor is connected between the neutral of the machine and earth as shown in Fig. 39.22 (*c*). Sometimes a low reactance is connected in series with the neutral of the machine to limit the earth fault current through the generator. This current should not be greater than the 3-phase fault current of the generator. The earth-fault-current of this earthed system should not be less than 25% of the 3-phase fault current in order to minimise the transient voltages.

39.9. PROTECTIVE DEVICES AND CONTROL SYSTEM USED IN POWER PLANT

Introduction. The power-station consists of generators, transformers, bus-bars, circuit-breakers and circuit going out of station. The purpose of circuit-breakers is to make the circuit connection when required and to trip or disconnect the circuits under faulty or abnormal conditions. Therefore, it is necessary to ensure the correct operation of the circuit-breaker by means of protective relays to enable a circuit to be isolated from the system under faulty conditions.

Different Types of Relays. The function of the relay in the power supply system is to recognize a short circuit and to initiate the operation of devices to isolate the defective element with the minimum disturbance to the normal power supply system. The protective relays avoid damage to equipments, or if there is damage, they minimize the cost of repairs.

The protective relays must operate at required speed with required reliability. Because, the speed with which relays and circuit-breakers operate has a direct bearing on the quality of service to the consumers, the stability of the system and amount of power transmitted without exceeding the stability limit.

Requirements of Relay

(1) Definite Operation with Accuracy. Whenever the specific condition occurs, the relay must operate and hold its operating contact closed until the required movements outside the relay have been established. The travel of relay must be very fast for an instantaneous type and for definite time type, the operation must accord with the type. All relays should give consistent performance whenever their operating conditions are required.

(2) Selective Operation. The same type of relay may be used to protect a number of parallel tie lines or one relay may be installed for differential protection of two parallel tie lines. In such application, the relay must trip out the circuit-breaker on the line carrying the greatest fault current if a fault occurs. The selection of the relay is made on the basis of the time grading of the system, the various relays being given appropriate time settings.

(3) Sensitivity. The relay has to operate in case of heavy overloads, short-circuits, reversals and such abnormal occurrences. It should be able to operate reliably when required under the actual conditions which produce the least operating tendency.

(4) Flexibility. The individual relays and plan of relay protection for the system must provide sufficient flexibility to meet all the ordinary methods of system operation and to permit extending the system without the necessity of radical change in protective plan.

The working of different types of relays which are commonly used in power plants are discussed below :

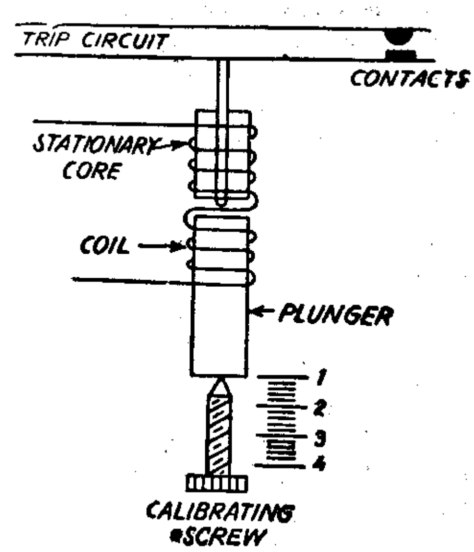


Fig. 39.23. Electromagnetic attraction type relay.

1. Electromagnetic Attraction Type Relay. In this type of relay, a plunger is drawn into a solenoid or an armature is attracted to the poles of electromagnet. Fig. 39.23 shows the arrangement of this type of relay. Energizing the coil creates a magnetic effect which causes the movable plunger to be attracted to the stationary core. This movement closes the contacts. Current magnitude required to raise the plunger depends upon its initial position with respect to the stationary core. This initial position is adjustable by the calibrating screw and the pick-up current.

The tripping time is very less than one cycle for heavy current through the operating coil, therefore, the relay operates at high speed. The major disadvantage of this relay is that it takes very little current in the coil to hold the movable core in raised position and, therefore, ratio between pick-up and drop-out currents is large.

2. The Over-current (Induction Type) Relay. Fig. 39.24 (*a*) shows the arrangement of different components of an over-current relay. The relay has two electromagnets (upper and lower) between which there is metal disc. The current enters into a line to be projected through a tapped primary and current transformer. The turns of tapped primary can be varied by a plug as shown in figure. This arrangement enables various current settings for the relay to be obtained. The secondary is a closed winding and is wound on upper and lower magnets.

When the primary winding carries current, voltage is induced in the secondary being a closed winding and current flows in the secondary. The fluxes are produced due to currents flowing in these windings. These fluxes are separated in phase and space as in shaded pole induction motor and, therefore, produces a driving torque on the disc depending upon the magnitude of the current. The disc spindle carries a movable contact which bridges a pair of fixed contacts when moved through a certain angle which can be adjusted for a particular setting, thus completing the circuit through the relay trip coil.

Fig. 39.24 (*b*) shows a reverse power relay. This relay is similar to over-current relay described above except that winding on middle limb of the upper magnet is operated by voltage and there is separate winding on the two limbs of the lower magnet operated by the current with tappings. When the power flows in the normal direction, the fluxes due to currents in both the windings tend to turn the disc in a direction away from closing the trip circuit. When there is reversal of power, the torque on the disc is produced in a direction to close the trip contact.

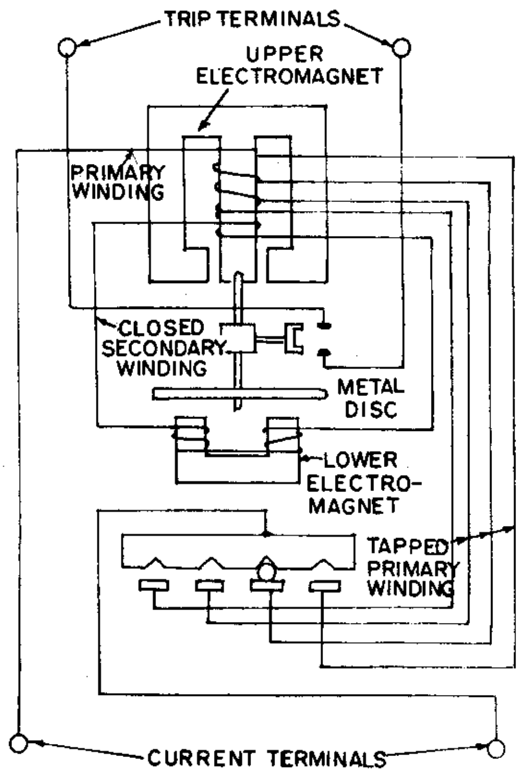


Fig. 39.24 (*a*) Induction type over-current relay.

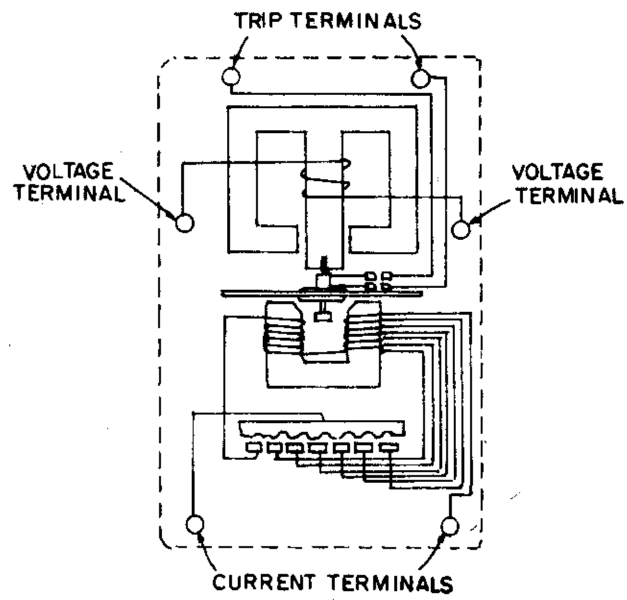


Fig. 39.24 (*b*) Induction type reverse power relay.

3. Directional Over-current Relay (Induction Type). The directional over-current relay is a combination of simple over-current relay and reserve power relay. Fig. 39.25 shows the arrangement of this type of relay.

The reverse power element rotates only when a reversal of power takes place. The disc of the relay then completes the circuit and provides the directional feature. When the contacts in the tower element are closed, the upper element comes into action, as explained earlier, to make the relay effective. The contacts of directional (reverse power) element are connected in series with over-current element so that the trip circuit is not energized unless both operate.

The directional relay may be used in combination with over-current relay to prevent operation except in one predetermined direction of power flow. If the directional relay is connected in series with over-current relay, then only the relays at two ends of the faulty section will operate and isolate the faulty section without disturbing the other lines.

4. Differential Relay. This type of relay compares current entering and leaving the protected apparatus and operates when they are not equal. Induction type of relay is used for the purpose. Fig. 39.26 (*a*) shows the principle of its operation as applied to one phase of an alternator winding. The operating coil of the differential relay is shown in figure. As long as there is no (earth) fault in the alternator winding, I_1 and I_2 are equal and so are i_1 and i_2 also. As a result, there is no current flowing in the operating coil. But when I_1 and I_2 become unequal due to the fault in the alternator winding, the difference current $(i_1 - i_2)$ flows through the relay coil. With this relay, a sensitive setting cannot be obtained.

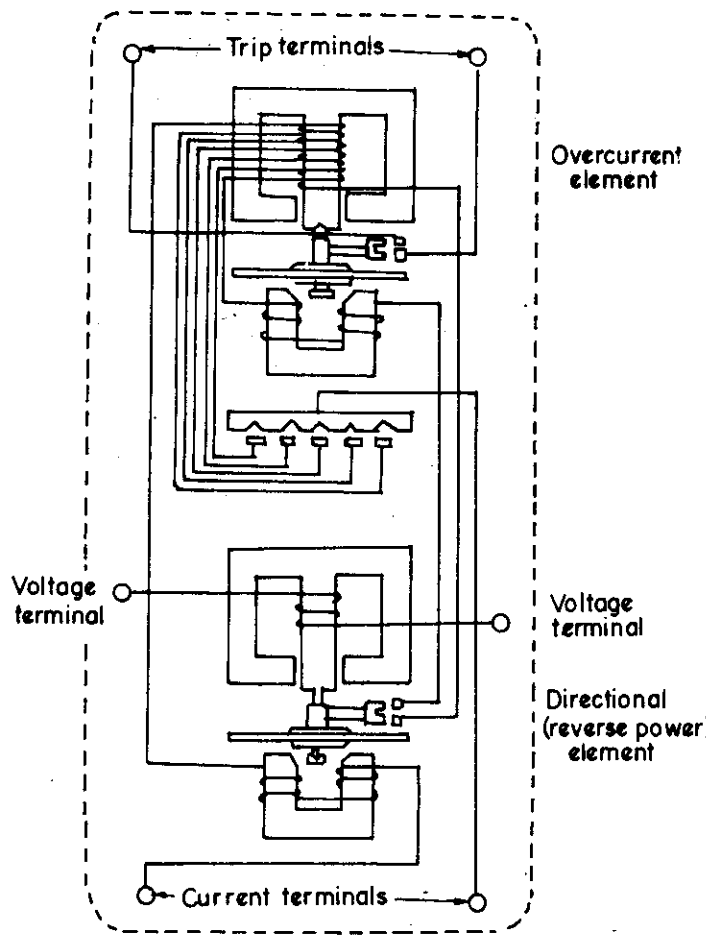


Fig. 39.25. Induction type directional over-current relay.

For getting the sensitive setting, a percentage differential relay as shown in Fig. 39.26 (*b*) is used.

This relay enables sensitive detection without danger of tripping on short circuits of the protected equipments. A comparison of Fig. 39.26 (*b*) with Fig. 39.26 (*a*) shows, there is an additional coil known as restraining coil which carries the sum of two circulating currents $(i_1 + i_2)$. Thus, if the currents are large, there is a large restraining force which cannot be overcome by an error in the current transformers. Therefore, the relay operates only when the ratio I_1/I_2 differs from unity by more than a certain amount which is adjustable by varying the number of turns of the restraining coil.

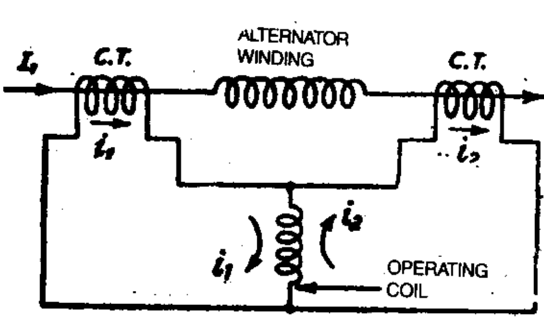


Fig. 39.26 (*a*) Differential relay.

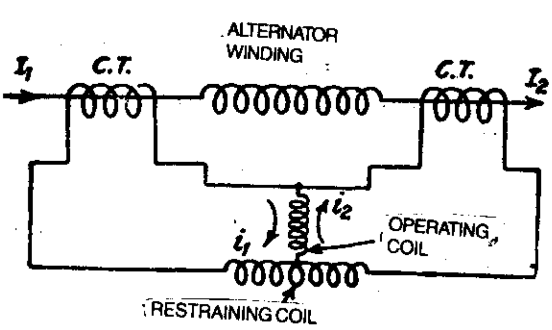


Fig. 39.26 (*b*) Percentage differential relay.

This relay is designed for the differential protection of generators and transformers.

5. Current Balance Relay. This type of relay operates by comparing the magnitude of two currents and trips out the line stopping the current. The arrangement of operating currents is shown in Fig. 39.27. When the current I_a is greater than I_b, the armature moves and closes the contact to trip out ('*a*').

This relay is primarily designed for the short circuit and ground protection of parallel transmission lines. Being dependent upon the balance in two lines, naturally this type of relay does not protect when one of the lines is out of service or when both circuits of a double circuit line are in trouble.

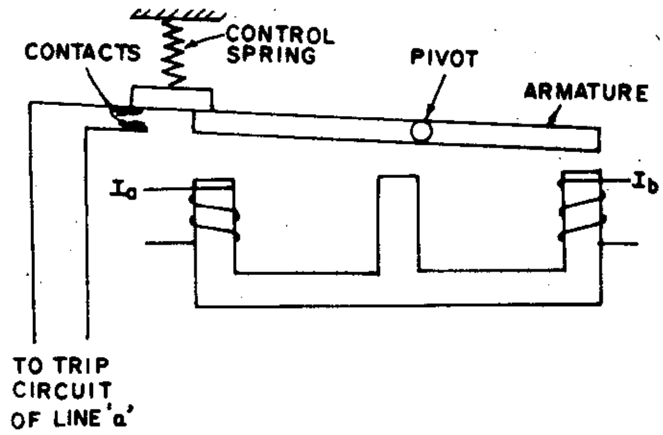


Fig. 39.27. Electromagnetic current balance relay.

39.9. VOLTAGE REGULATION

Power systems particularly never carry a constant load, whether during a full day or during any given season of a year, therefore, the supply circuits have to carry variable current accordingly. In consequence of this, the voltage drop in the circuit will also vary and change the voltages at the step-down bus-bars and at the terminals of the consumer equipment.

Power receivers require an invariable voltage of rated value at their terminals. Therefore, whenever the supply voltage fails to stay within the permissible limits, it must be adjusted to return it to its normal value.

The methods used to control the voltage at the consumer terminals irrespective of load on power plant are voltage control by change in ratio of transformation in the transformers and by changing the flow of reactive kilovolt-ampere power (kVA) in the circuits.

(1) Voltage Regulation by change in Ratio of Transformation in the Transformer. If the voltage applied to a step-down transformer rises, it will be necessary to increase the number of active turns in the primary winding to maintain the voltage across the secondary winding terminals to its original value ; in order to raise the voltage across the terminals of the secondary following a drop in the voltage applied to the primary, the number of turns switched into the primary must be decreased.

Control of Voltage on Load. When transformers are applied with on-load tap-changing equipment, the shift from one position to another is accomplished without any break in the circuit fed by the transformer. The tap changer by which this is done constitutes a built-in constructional element of the given transformer. Fig. 39.28 gives an outline of a circuit arrangement (one phase) used for changing.

The arrangement consists of moving contacts *a* and *b*, contactors C_1 and C_2 and reactor *R* the middle turn of which is connected to one of the halves of the given transformer windings. In normal operating conditions, both moving contacts *a* and *b* make circuit with one of the gap changer fixed contacts, and contactors C_1 and C_2 are closed. The total

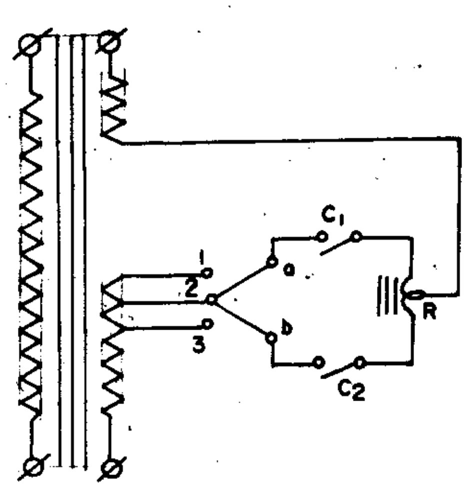


Fig. 39.28. Switching circuit on-load tap changing of transformer.

current flows through both moving contacts, both contactors and both halves of the reactor coil. In changeover, say from position 2 to 3, contactor C_2 is switched open and moving contact b is tuned to the fixed contact of tap 3. After this contactor C_2 is closed and shorts the section of the winding between taps 2 and 3 across the reactor. The latter must, then, in addition to the load current, carry the circulating current caused to flow by the difference in voltage across taps 2 and 3. Reactor R is selected so that its reactance will be sufficient to keep the circulating current at a suitable low level.

As soon as contactor C_2 is switched open, moving contact 'a' is tuned to make the circuit with fixed contact '3', and then contactor C_1 is reclosed. The last operation completes the change-over from tap position 2 to tap position 3.

Tap-changers of this type are furnished with operating mechanisms powered by an *a-c* or *d-c* electric motor. The operating mechanisms in all three phases are actuated simultaneously by remote control from the control board.

Transformers with on-load tap-changers are widely used in electric power stations and power system substations. Built-in tap changers have one fundamental shortcoming, that is, they increase the cost of the transformers.

(2) Voltage Regulation by changing the flow of reactive kVA power ($\sqrt{3}$ VI sin ϕ) in the circuit. All other conditions being equal, the drop in voltage of a circuit will be higher if greater reactive kVAs flow through it. This states that the voltage drop in the circuit can be changed by varying the reactive kVA flow through it, *i.e.*, the voltage of the circuit can be regulated.

In order to change the amount of reactive kVAs fed into the circuit, use is made of synchronous condensers.

A synchronous condenser is a synchronous motor which is operated without load. In order to change the reactive kVA power output, its excitation is varied. As in any synchronous generator, excitation is supplied by a D.C. generator.

When operated with over-excitation, a synchronous condenser will return reactive kVA to the circuit. If under-excited, it will draw reactive kVA from the circuit. In this way by regulating the exciting current in the synchronous condenser, it can be made to vary the amount of reactive kVA it will supply or take.

Fig. 39.29 illustrates how a synchronous condenser operates in conjunction with a given circuit. Fig. 39.29 (*a*) shows the situation when generator *G* fully meets the load demand for active power P_a and reactive power P_r. When synchronous condenser *C* is installed near the consumer as shown in Fig. 39.29 (*b*) and is operated over-excited, part of the reactive power P_c needed by the consumer load will be supplied by the synchronous condenser. In this case, a lesser flow of reactive power $(P_r - P_c)$ will have to be transmitted by the power line and transformers and, therefore, power transmission will be achieved with a smaller drop in voltage at the receiving end.

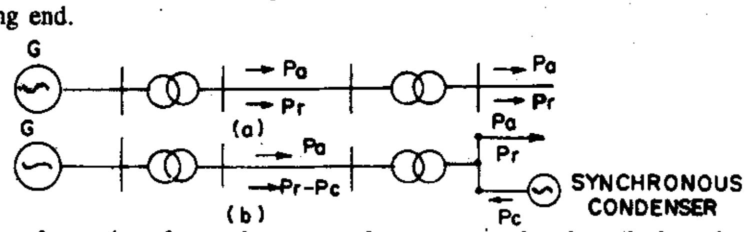


Fig. 39.29. Illustration of operation of a synchronous condenser connected at the end of supply circuit.

39.10. CONTROL ROOM

The control room is the nerve-centre of a power station. All the controls, protective devices and indicators are housed in it.

The control equipments include voltage regulators, frequency stabilizers and load distributors.

The protective devices include circuit-breakers, relay and emergency trippers.

The indicating devices include instruments for indicating the load, voltage, frequency, power factor and winding temperatures.

The equipments housed in the control room are synchronising equipments, integrating metres and suitable indicating equipments to show the open and closed position of circuit-breakers and many others.

The location of the control room in the power plant is very important. The following points should be kept in mind for selecting the location of control room.

1. It should be located away from the sources of noise.
2. It should be near the switch house to reduce the lengths of connecting cables.
3. It should be well ventilated, well lighted and free from draughts.
4. There should be access from the control room to the turbine house.

EXERCISES

39.1. What is the function of bus bar ? Draw different types of bus bar arrangements and discuss their relative merits and demerits.

39.2. Why excitation is necessary for synchronous generator ? Draw a neat line diagram used for excitation and explain its working.

39.3. Why generator cooling is necessary ? Explain the advantages and disadvantages of open system when air is used as coolant.

39.4. Why Hydrogen cooling is universally used in modern power plants ? List out its advantages over air-cooling system.

39.5. What do you understand by short circuit ? What are its effects on supply system ?

39.6. Explain the different methods used to limit short circuit currents.

39.7. What are the different types of switch gear installations ? Discuss their relative merits and demerits.

39.8. What is circuit-breaker ? What is its function in the supply system ?

39.9. Explain the working of air circuit-breaker with a neat sketch and list out its limitations.

39.10. What are the different types of air circuit-breakers ? Discuss their relative merits and demerits.

39.11. Draw a line diagram of cross-jet explosion pot type oil circuit-breaker and explain its working. What are the advantages of oil circuit-breaker over air circuit-breaker ?

39.12. Draw a line diagram of a power transformer and explain its working.

39.13. Describe the different methods used for earthing a power system. Discuss their relative merits and demerits.

39.14. What do you understand by a relay ? What is its function ? What are the basic requirements of a good relay ?

39.15. Draw a line diagram of Induction type relay and explain its working.

39.16. What is differential relay ? Discuss its merits over other types.

39.17. What are the basic requirements of a control room ? Draw a neat diagram of a control room used in modern thermal power plant showing all important components.

□□□

40
Energy Conservation and Management

40.1. Introduction. 40.2. Energy Requirements in Future. 40.3. Distribution of Energy Consumption. 40.4. Need for Energy Conservation. 40.5. Methods of Energy Conservation. 40.6. What is Energy Management ? 40.7. Energy Management Techniques.

40.1. INTRODUCTION

In a country with growing demand for energy, increased efficiency is the only way to meet the shortfall.

Power requirement in India has grown substantially with a peak shortage of 11-18 per cent and average shortage of 7-11 per cent. The ninth plan envisages a capacity addition of 40,000 MW and it is estimated that a capacity of 6500 MW should be added every year to meet the shortfall. This would require around Rs. 6500 crore per year.

For a developing country like India, setting up new plants to meet growing requirements is not possible financially and it is environmentally feasible. The solution lies in increasing the efficient use of available resources by removing inefficiencies and bottlenecks in generation, transmission, distribution and utilisation of energy.

Energy resources in India are numerous. They comprise human and cattle power, animal dung, forest fuel, coal and lignite, crude oil and its many derivatives, water and geothermal energy, hydel and thermal power, nuclear power and the nascent solar, wind and tidal power.

The problem that we face as energy users is both, a long term and a short term one as are clearly visualized in many publications. The long term problem is that energy based on fossil fuels is finite in India and in every other country in the world. We consumed power at a rate equivalent to 19 billion tonnes of coal per century till 1850 which went to 190 billion tonnes in the following 100 years till 1950 and is now proceeding at the rate of 380 billion tonnes projected for the remaining years of the century against a resource stock estimated at 3800 billion tons. Our fossil stock will last upto 2050 AD only at the current rate of consumption and provided the world do not increase further the per capita energy consumption and our population explosion is contained. The short term problem is that the escalation of crude prices has made that form of energy uneconomical. Our hopes of an early nuclear energy break through have not been realized and we are still grouping around with regard to renewable energy sources as solar, wind and tides. How then are we to meet the growing energy demand on which the projected 8 to 10% rate of industrial growth and 4% rate of agricultural growth are based ?

Power sector today is at a critical stage. Through the VIII plan power programme envisages a generation capacity addition of 36645 MW requiring an outlay of about Rs. 127000 crore, considering the present critical economic situation through which the country is passing, the available funds are upto 90,000 crore and only 29000 MW are added during VIII plan period. The present power shortage is around 10% and peak demand shortage is 21%. For revitalisation of the national economy, power sector has to play a vital role. Power shortage of this magnitude is not desirable and therefore, power sector has to explore various avenues to bridge the gap between power demand and supply.

One answer to this problem of limited supply of energy sources is energy conservation. By energy conservation is understood :

(*i*) Increased exploitation of our energy sources other than fossil fuels ;

(*ii*) Economy in their use ; and

(*iii*) An optimal pattern for using and replenishing the country's energy sources.

We, in India, are lucky to have a slow moving economy which is 3% compound rate of growth over the last 3 decades of planning. If we had attained our targetted 5% growth rate over the last 10 years, leaving alone experiencing the kind of economic miracle of a 7 – 10% growth rate which Germany, Japan and Korea have experienced over the past five to ten years, we would have been in disarray over our energy resources.

This would have resulted in even higher energy prices than now and we would have faced such acute shortages that we could not have obtained any form of energy even at much higher prices.

Energy conservation and improvement in operational efficiency of existing installations through proper energy management are most important thrust areas which if given greater attention could yield encouraging results through implementation of time bound action plans and help in reducing the anticipated power shortages. The capital investments involved in implementation of such action plan will not be much as compared to the expected benefits and in any case, will be much less than the capital investments involved in new generation capacity additions.

40.2. ENERGY REQUIREMENTS IN FUTURE

Development of modern society is totally energy based. Energy consumption is likely to increase with the future developments. USA is a country which has 8% world population and uses 30% of the total world energy consumption. The total world energy consumption is likely to increase to more than 11.5 GTOE (Giga tonnes of oil equivalent) by 2000 AD which was 8.2 GTOE in 1990 and 6.8 GTOE in 1978.

The energy consumption in India is also increasing at a much rapid rate than in many parts of the world. Major portion of this energy is obtained from commercial energy sources, *i.e.* coal, oil and electricity. Use of non-commercial energy sources such as solar, biomass and wind energy is also increasing. The following table indicates the forecast of energy demand in India :

Energy source	*Year*			
	1982 – 83	*1987 – 88*	*1992 – 93*	*2000 – 2001*
Coal (MT)	96.8	131.5	186.6	308.0
Oil (MT)	25.4	33.5	44.5	74.2
Electricity (TWh)	128.3	191.2	282.0	471.0
Non-commercial fuel (MTCE)	204.1	202.8	195.0	163.0

1 TWh = 10^9 kWh, MTCE = Million tons of coal equivalent

Notes : (*i*) Quantities of coal and oil does not include power for generation.

(*ii*) Quantities of non-commerical fuels is only for domestic use.

India has made enough progress in the energy sector. Power production was 1300 MW in 1947 has gone to 76000 MW in 1995. The coal production was 35 million tons in 1951 has gone to 200 million tons in 1995. The oil production was 63 million m^3 in 1966 has gone to 542 million m^3 in 1987. But the rate of increase in demand is more. At present there is 37% gap between indigenous production and demand for petroleum products. It is estimated that the import bill for oil will touch to Rs. 25000 crore by 2000 AD.

India may not be in position to afford huge capital needed for installation of new power plants and development of coal mines. In the present global scenario, the energy cost is rising rapidly and India's situation on energy front is alarming.

The trend in the world is also similar to India and because of better life requirement and increase in population, the power requirement is continuously increasing as shown in Fig. 40.1 (*a*), Fig. 40.1 (*b*) and Fig. 40.1 (*c*).

The energy sources used are limited in magnitude and those will be exhausted by the end of 21st century even if the present rate of demand is continued. These energy resources can be used for a longer time if proper conservation methods are used and available resources are properly managed.

In general, energy can be conserved by avoiding (*i*) the waste, (*ii*) decrease in demand and (*iii*) improvement in technology.

World Energy Consumption 1983-2000

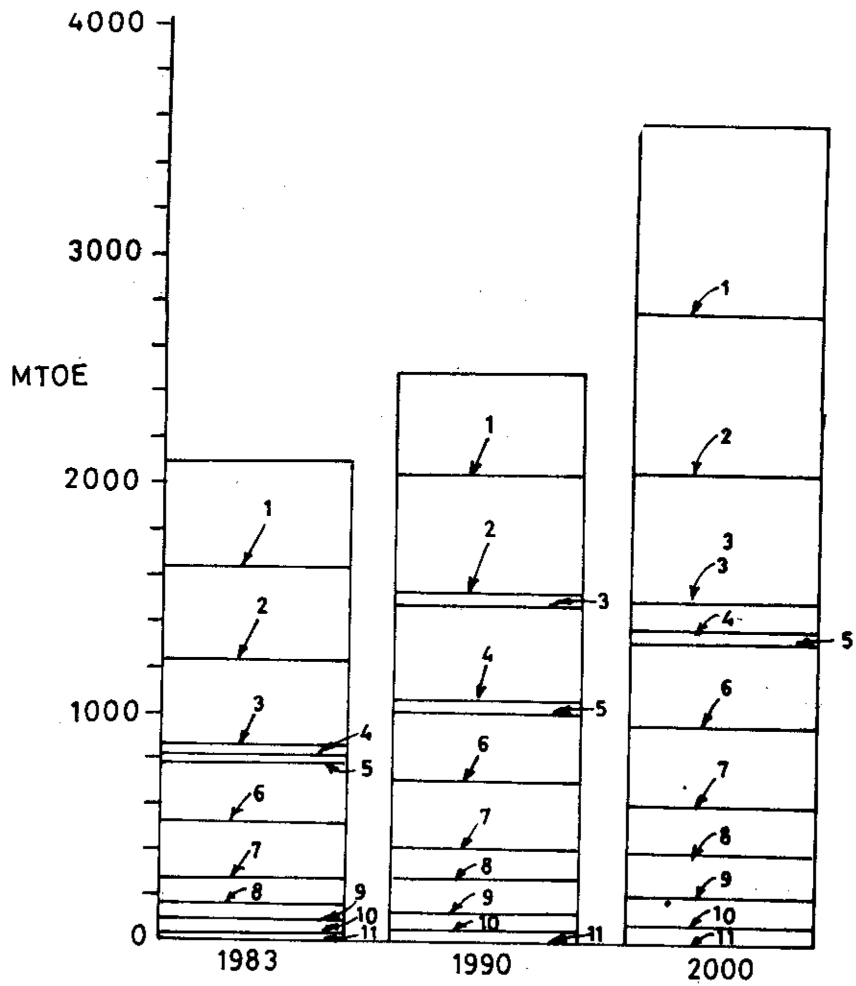


Fig. 40.1. (*a*) World Energy Consumption from 1983-2000. MTOE (Million tons of oil equivalent).

World Coal Consumption 1983-2000

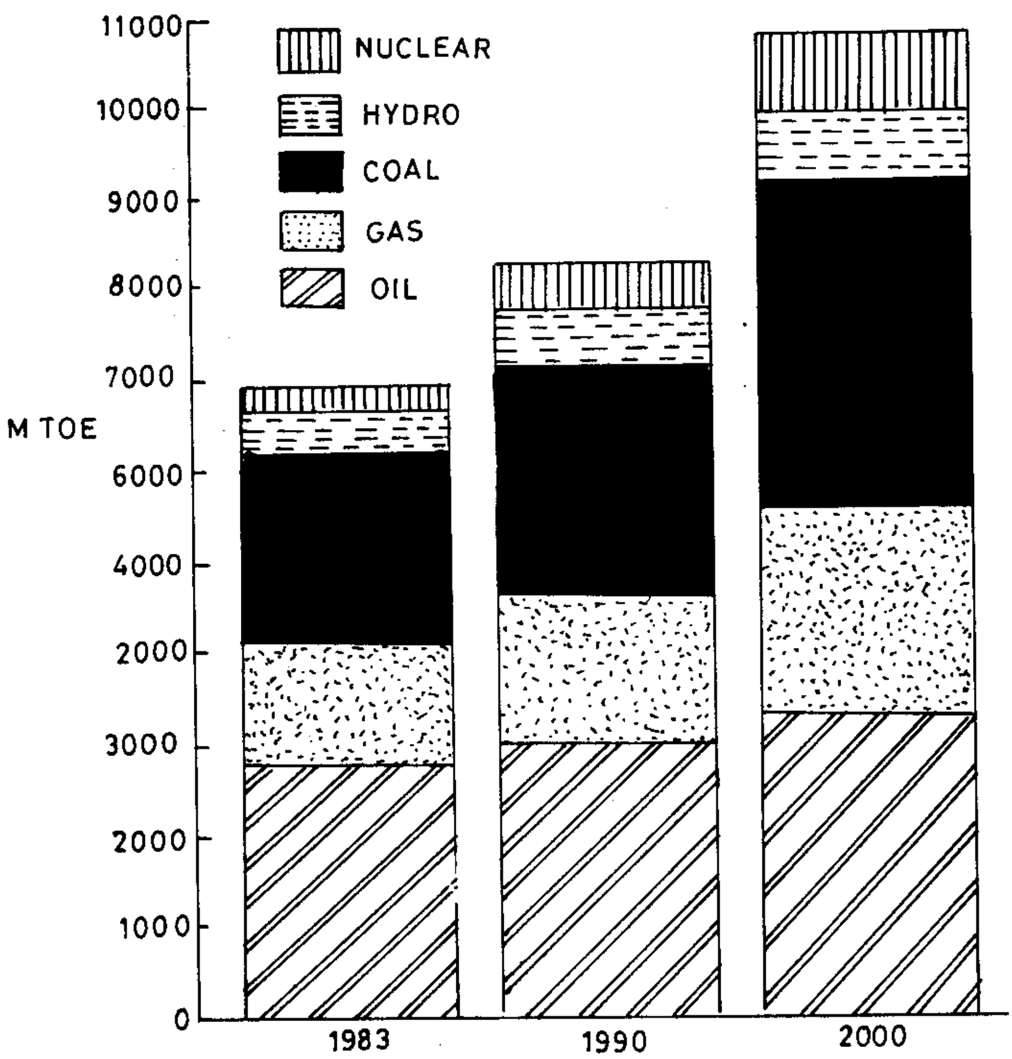


Fig. 40.1. (*b*) World Coal Consumption from 1983-2000.

40.3. DISTRIBUTION OF ENERGY CONSUMPTION

Fig. 40.2 shows the distribution of energy consumption in U.K., U.S.A. and India. It is obvious from the figure that industry and transport consume almost 75% of the primary energy. Power industry is the single biggest consumer of energy in U.K. whereas in U.S.A., it is transport.

The pattern of energy consumption in India is also similar to that of USA & UK. Industry and transport consume almost 75% of the primary energy. One can conclude from this that the consumption of energy in industry and transport should be looked into some detail as the scope of energy saving could be very good in these sectors.

Efficiency of an energy industry may be defined as the ratio of energy delivered to final consumers to the energy in the primary fuel input during a particular accounting period. The energy efficiencies of the U.K. energy industries are shown below and the distribution for Indian energy sector is likely to be similar.

World Oil Consumption 1983-2000

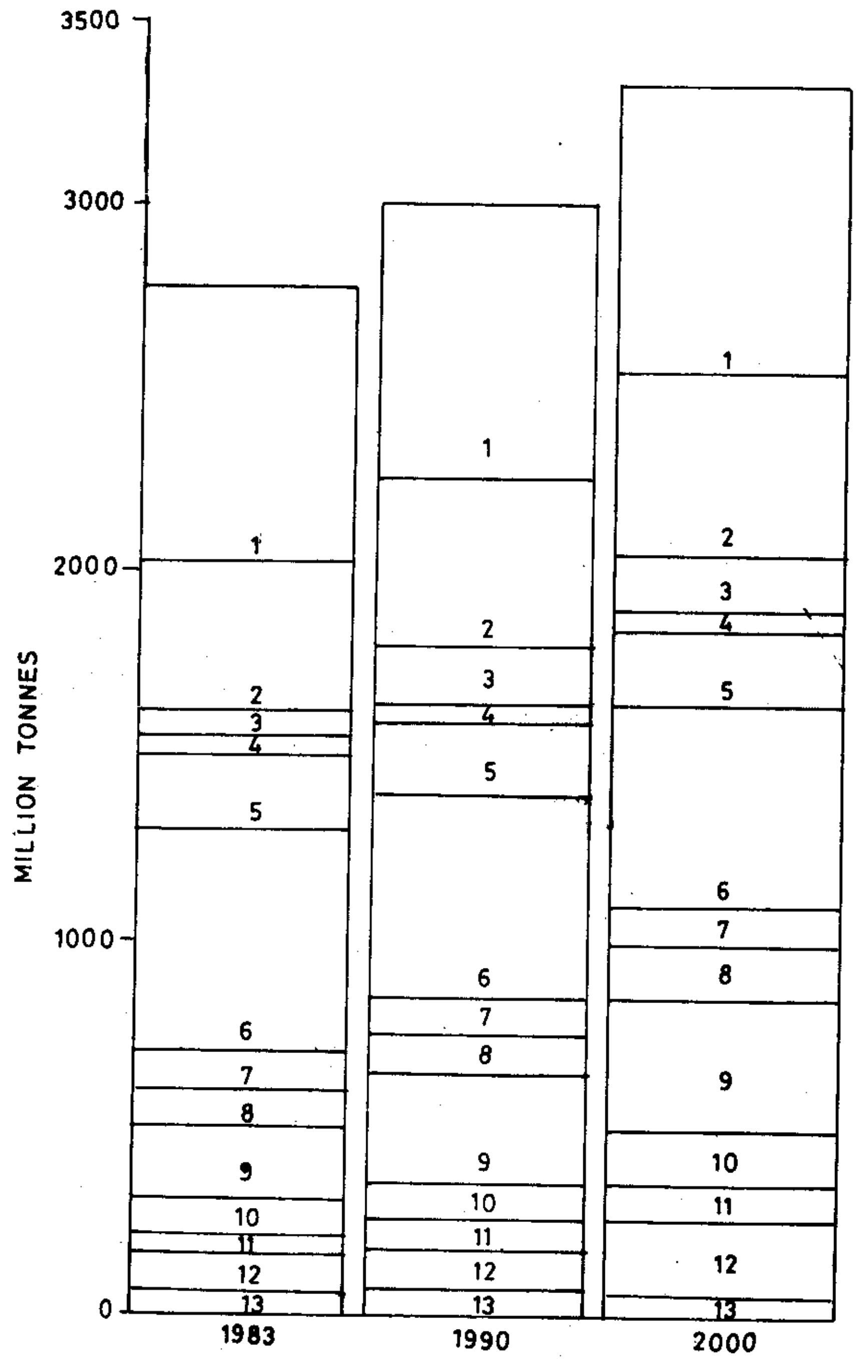


Fig. 40.1. (*c*) World Oil Consumption 1983-2000

Energy Efficiencies of U.K. Energy Industries

Year ↓	*Coal*	*Coke*	*Gas*	*Oil*	*Electricity*
1963	95.5	75.5	64.7	80.8	22.00
1968	96.0	84.7	71.9	88.2	23.9
1972	95.5	88.0	81.1	89.6	25.2

We should not use electricity for applications where oil, coal or gas can be used as energy efficiency factor for electricity is very low.

Production and manufacturing consume a large amount of energy. The analysis of each stage of activity helps in locating possible areas of savings. The pay back period in some cases may be only 3 months to one year.

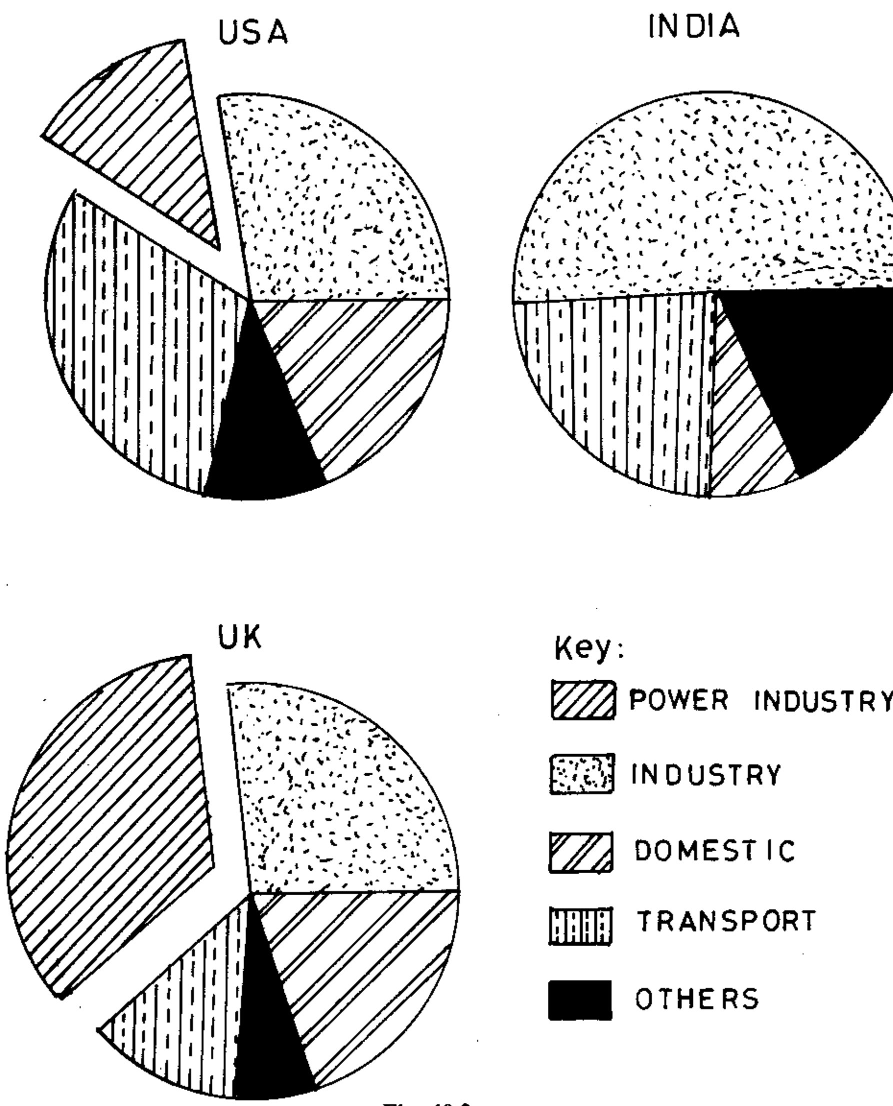


Fig. 40.2.

40.4. NEED FOR ENERGY CONSERVATION

There is an acute shortage of energy in the world nowdays. The demand of energy is increasing rapidly as listed below.

World Energy Consumption

Year	1960	1965	1970	1975	1980	1985	1990
Energy consumed in kWh	13.17×10^{12}	16.34×10^{12}	21.69×10^{12}	23.39×10^{12}	29.63×10^{12}	35.09×10^{12}	41.65×10^{12}

In view of limited resources and ever increasing demand of energy, it is essential to find out the major areas for use of energy so that the capability of energy conservation in various fields can be analysed and inefficient energy consumption can be minimised.

One of the most effective ways to meet the growing gap between demand and supply of power is to implement energy conservation techniques. Energy conservation is a single step which can effectively contribute towards reduction of shortages. This is absolutely essential at present when availability of finance is a big constraint and investment in energy conservation measures is known for short pay back period of only 2 to 3 years.

40.5. METHODS OF ENERGY CONSERVATION

The prospect of depleting fossil fuel supplies and progressive degradation of the environment has turned world attention to various aspects of energy use. In the process of upgrading the living standards, man has been consuming more and more energy to satisfy his material wants. Coupled with the degradation of forest lands, ever increasing consumption of commercial energy sources has been contributing to the pollution of air, water and soil.

Energy being a major requirement of modern society, its development and management carries a lot of significance in the economic development of any country. There is a close relationship between the level of energy consumption in a country and its economic development. Energy is required for domestic use, agriculture, industry, commerce, transport and in almost every sphere of life. A developing country like India needs progressively increasing amounts of energy for its men and machines, so as to move forward to prosperity and modernization. During the foreseeable future, the main burden of producing heat energy will continue to be on the fossil fuels.

Since the two oil shocks during last two decades, awareness of the efficient use of energy has increased, specially in the developed countries. In the developing countries, due to lack of political will, paucity of capital and failure to adopt newer energy efficient technologies have hindered the progress towards better energy efficiency. Moreover, the environment has received much less attention than it deserves. Only now the benefits of conserving scarce energy resources and the indirect benefits of lesser pollution have been realized in both developed and developing countries.

With industrial development, energy consumption has been rising much more rapidly than the rate of discovering new resources. Therefore, optimum energy utilization through the use of energy conservation technologies thus becomes a compulsion for survival and to maintain a quality of life.

On close examination of the problem, we find that we are on the path of diminishing returns in the use of most energy sources, larger capital and energy expenditures, costly research and developmental goals and the prospect of greater environmental deterioration. Energy resources must be used efficiently so that they last longer and pollution is reduced.

Presently, we are at the cross roads where the energy choices we make now will determine what kind of natural heritage we leave behind to future generations. As the population of the world increases, so does the demand for energy, which would make the task of pollution control more difficult.

Energy conservation can be defined as the reduction of energy use per unit of product, changing from a scare fuel to a more readily available fuel. Though conservation measures in industry would be different from those in the domestic sector, the final aim is to conserve depleting natural resources.

The Inter-Ministerial Working Group of Energy Conservation set up by the Govt. of India estimated that energy saving potential of 25% is presently existing in Industrial Sector. This was mainly by introducing short and medium term measures. If long term measures such as co-generation, boiler replacement, process modification and advanced controls are included, the potential would be much higher.

Energy conservation is essential and economical to prolong our existing resources and indirectly, save the ecology from its damage which is the present day problem before the planners.

Attention would need to be focussed on the following key thrust areas for energy conservation and energy management in power sector.

(*a*) **Supply End.** This includes efficiency improvement by all possible methods in thermal power plant, increase the plant load factor of thermal power stations and substitute new power generating systems such as solar, tide, wind and hydel instead of increasing the present thermal generating capacity.

Efficiency Improvement in Thermal Power

(1) Saving in Auxiliaries. The average all India auxiliary power consumption in thermal plants during 1990-91 was around 10%. With concerted efforts, it may be possible to reduce it by 1%. Saving potential on account of 1% reduction in auxiliary power consumption will be 13000 million units and additional revenue on account of above will be Rs. 1027 crores considering average rate of Re. 1 per kWh. This one example is sufficient to insist the importance of energy conservation. It is not possible to discuss all the auxiliaries where saving in energy consumption is possible in this text as there are thousands of auxilaries in thermal plant and each requires detailed study.

(2) Saving Potential in Coil and Oil. The present average specific coal consumption on all India basis of thermal power station is 0.72 kg/kWh. With improvement in thermal efficiency, it may not be difficult to bring down the specific coal consumption level to 0.70 kg/kWh in the country. Saving in coal consumption with reduction of 0.02 kg/kWh in specific coal consumption during VIII plan was 24 million tonnes and saving was of the order of Rs. 1200 crores taking coal price as Rs. 500 per tonne.

(3) Plant Load Factor Improvement (PLF). The present average PLF of thermal power plants is around 54%. With the implementation of renovation and modernisation programme and other necessary measures, it is possible to increase PLF by 3%. Additional generation due to increase in PLF from 54% to 57% will be 13000 million units.

(4) Modern Methods of Thermal Power Generation. A few modern methods, like co-generation, fluidized bed combustion system and new boiler design and control systems and non-conventional energy uses, are presently under consideration and applications in Indian Power Industry.

There is a trend to use natural-gas or crude oil instead of low grade coal for power generation as pollution hazard from these sources are less than the use of coal. These substitute fuels are used mostly in Gas Turbine Plants whose coal based thermal efficiency is considerably low than conventional thermal plants.

4.1. Co-generation System. Co-generation is the combined production of two forms of useful energy from the same fuel. In industry, two forms of required useful energy are thermal and electrical. Co-generation systems are sequential in nature because the exhaust from producing one form of energy is used as input for producing the next form of energy.

In co-generation system, high pressure steam is used for generating the power and the exhaust steam is used in manufacturing processes. The efficiency of co-generation system is as high as 85% whereas the efficiency of steam power plant is hardly 40%. The higher efficiency in the conversion of fuel into useful energy translates into a substantial reduction in pollution and reduction in the energy costs associated with production operations.

Co-generation is most often used in industrial units requiring significant amounts of thermal energy and electricity and where the ratios of the two forms of energy are favourable towards combined production of thermal and mechanical energy.

There are two types of co-generation systems as topping cycle and bottoming cycle.

(1) Topping cycle. In this system, shaft power is first developed as shown in Fig. 40.3 (*a*) and the exhaust is used for supplying thermal energy. Whereas, in bottoming cycle, the sequence is reversed as shown in Fig. 40.3 (*b*).

Topping cycle is oftenly used when temperatures and pressures for a given industrial process are relatively low. Bottom cycle is typically feasible when the temperatures of process waste stream are relatively high.

The important benefits of co-generation are reduction in the overall energy cost. These savings, combined with the benefits of minimal operating and maintenance costs and high reliability of the components can lead to an overall positive cash flow.

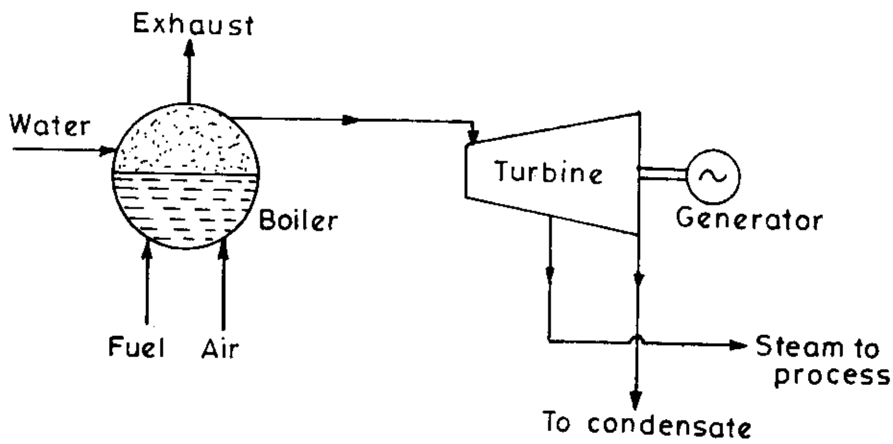


Fig. 40.3 (*a*). Topping cycle.

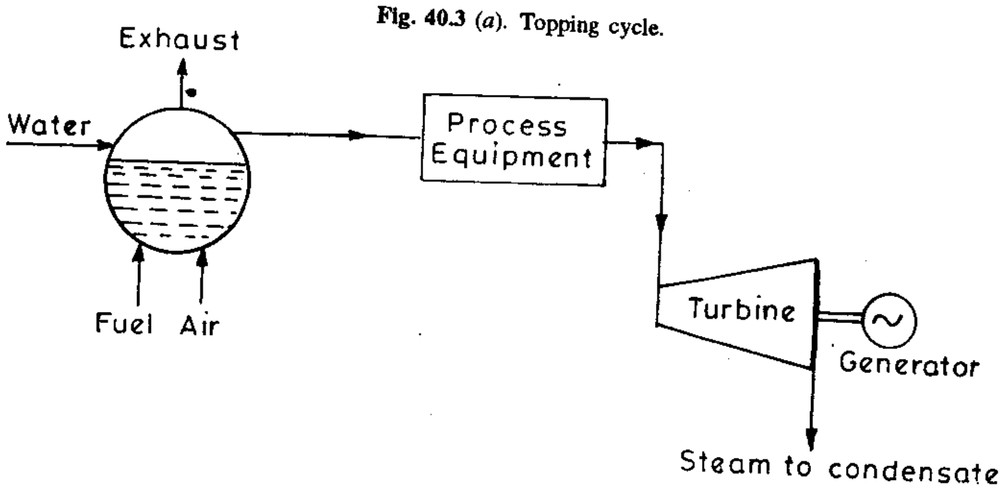


Fig. 40.3 (*b*). Bottoming cycle.

A strong case for co-generation in Indian industry prevails on account of :

(*i*) Energy saving of 0.3 kg/kWh of coal is possible using co-generation.

(*ii*) PLF can be increased from 55% to 75%.

(*iii*) Capital cost will be reduced from Rs. 2 crore/MW to Rs. 1 crore/MW with the use of co-generation.

Nearly 2000 MW co-generation potential has been identified in Indian industry and it is worthwhile to adopt co-generation wherever possible as it has low capital cost and low running cost also.

4.2. Combined Cycle Systems. This is generally used to increase the overall efficiency of the gas turbine cycle as the efficiency of basic gas turbine cycle is considerably low (20 to 25%).

Different modifications over the basic gas turbine cycle to improve the thermal efficiency of the plant are shown in Fig. 40.4. Fig. 40.4 (*b*) and Fig. 40.4 (*c*) show the modifications to use the heat in the exhaust of gas turbine to improve the overall efficiency of the plant. Fig. 40.4 (*d*) shows the arrangement for co-generation where the exhaust heat is used for steam generation which is used further for process plant.

There are number of combinations to improve the overall efficiency of the system and to reduce the operating cost. But, the purpose of this chapter is not to discuss all of them except to introduce the method which can help for energy conservation.

In the majority of cases, a reasonable match can be made between process heat demand and Gas Turbine exhaust conditions. However, it is also necessary to review turndown and off-design operating conditions to ensure that the match is maintained.

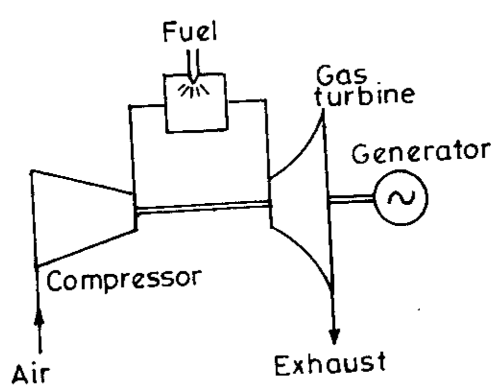


Fig. 40.4. (*a*) Basic Gas Turbine Cycle.

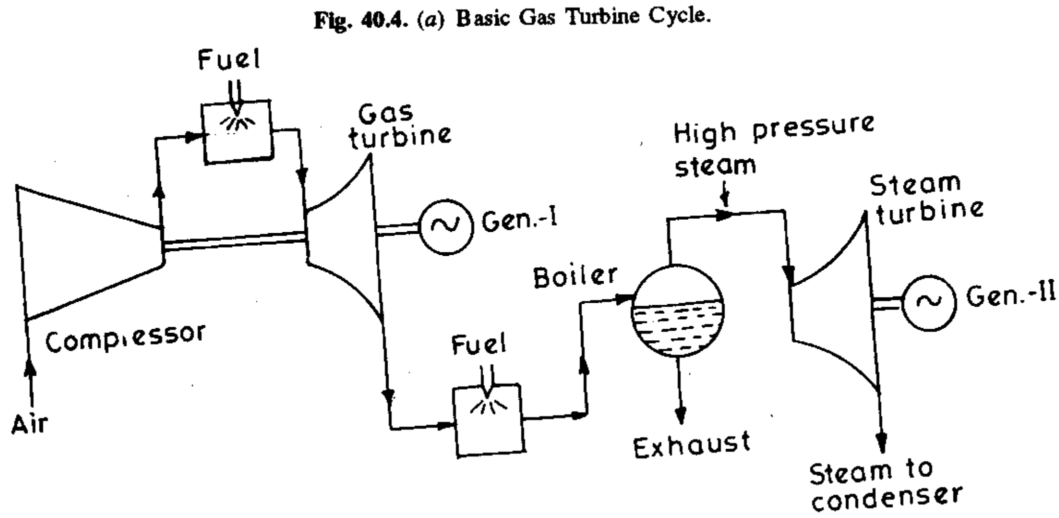


Fig. 40.4. (*b*) Combined cycle plant.

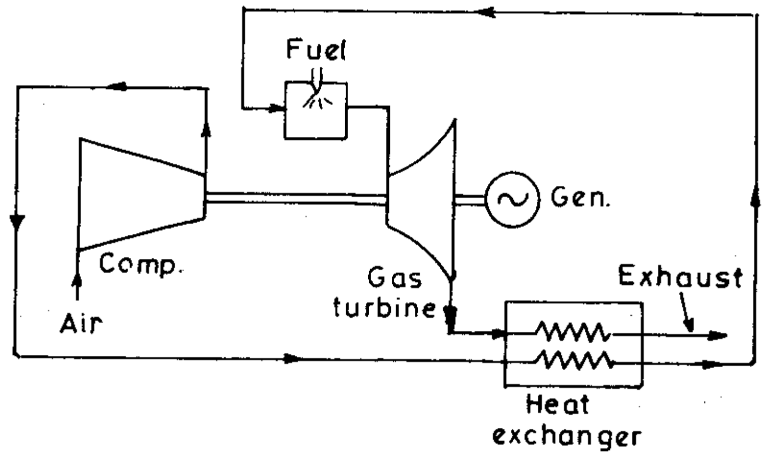


Fig. 40.4. (*c*) Air-Preheater Arrangement.

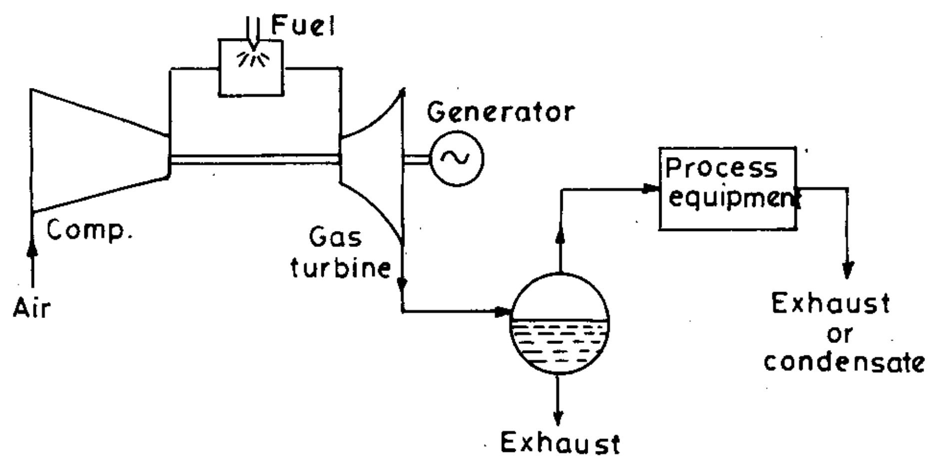


Fig. 40.4. (*d*) Co-generation Arrangement.

4.3. Fluidized Bed Combustion System (FBC). The principle of FBC is known for many years but it was used only in 1970 in three plants in USA. The energy efficiency of FBC unit is comparable to those of pulverised coal fired boilers or oil or gas fired boilers. FBC boilers are capable of burning a wide range of fuels as coal of varying ash content, waste, or biomass and can contribute to the more rational use of energy. Moreover, from the environmental point of view, this type of combustion is very attractive.

A simple FBC system is shown in Fig. 40.4 (*e*).

FBC system has the following advantages over conventional boilers :

(*i*) Ability to use coal of high ash content and other low grade fuels.

(*ii*) Low emission of NO_x.

(*iii*) Potential for SO_2 removal while burning high sulphur coal.

In India, FBC technology basically developed to use low grade coals (low sulphur and high ash content) BHEL has developed this technology in 1970 only. They have supplied a 7 MW FBC based power plant to Tata Iron & Steel Co. for using washery rejects having 65% ash content.

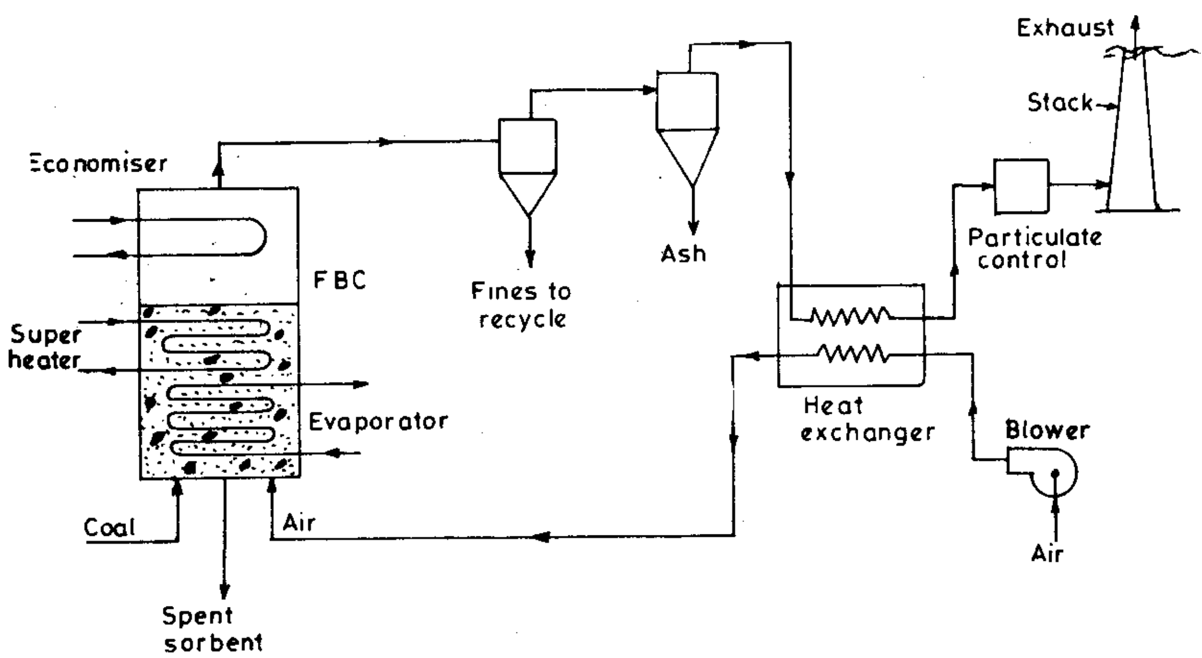


Fig. 40.4. *(e)*

The objectionable emission reduction is another advantage by using the methods discussed for energy conservation. For the electricity saving of 1 million kWh/year by adopting methods discussed for energy conservation, reduces 1260 Tons/year of CO_2, 6 tons/year of SO_2 and 206 Tons/year of particulates. Each one has different effect on the environment.

4.4. Use of Non-Conventional Energy Sources. A big challenge that our rural population facing today is inadequate availability of energy for their needs. It is a right time, we should look for non-commercial sources of energy so that people in rural areas can get locally available cheap and reliable energy for their different needs.

About 75% population of India live in rural area and majority of them are engaged in agriculture activities. Cooking and agriculture are their mainly energy consuming areas. Forestwood and kerosene are the main source of energy to them for cooking. India is the largest importer of kerosene in the world. The total import of crude oil costs Rs. 9800 crore in 1990-91 and likely to go to Rs. 25000 crore in the year 2000 A.D. Therefore, there is urgent need to conserve more and more oil. It can be achieved by making use of locally available non-commercial energy sources like solar energy, biogas, wind energy, micro-hydel plants and energy from ocean. The details of these sources of energy are discussed below.

(1) Solar Energy. Sun is the largest source of energy and biggest fusion reactor which supplies to the earth daily free of charge about 10,000 times energy needed by the world population (170 trillion kW). It means that 8 days of sun energy falling on earth is equal to a total of all available sources of energy in the world for a period of one year.

India receives nearly 5.6 kW/m^2 of solar energy daily as an average. Therefore, solar energy can play an important role in the development of Indian power requirements.

Solar energy can be used to generate the electrical power through two different methods. The photovoltaic system converts solar energy directly into electricity with the help of solar cells. The capacity of generation varies from a few kW to a few MW.

Solar electric power plants based on thermal energy in a capacity of a few kW to 80 MW are in operation for the last several years. Solar Tower technology is used in USA (10 MW), Frame (2 MW) and Japan (1 MW).

A few solar power plants in a range of 1 kW to 5 kW have been installed in a number of villages in Andhra Pradesh, Goa, Karnataka, Tamil Nadu, Tripura, U.P., Himachal Pradesh & Lakshadweep. Many villages are lighted with the help of solar photovoltaic system. Entire area around Dabok Civil Airport near Udaipur in Rajasthan is lighted with the help of solar energy. In addition to this, solar energy can also be used for refrigeration and air-conditioning purposes.

In India, there are about 1 Lakh solar cookers, 1078 solar water pumping systems, 546 community lighting, 1294 solar battery charging systems and a few hundred water heating systems are used as per the data available in 1989.

Solar energy has two distinct advantages. First, it is an infinite source of energy at a much cheaper rate. Second, this is ideally suited to human environment as it is free from pollution and noise.

(2) Biogas. Biogas is mixture of CH_4 and CO_2 and its composition depends upon the type of input material fed to the biogas plant. Main input sources for biogas production are cattle dung, animal waste, human excreta and agriculture residues. Animal dung is the main source for the biogas production in India. There are one million biogas plants installed in India and mainly used for cooking in rural areas (as per 1989 data). The burning of biogas in new modified stoves does not emit smoke and pollution hazards are reduced.

The biogas plant is a device which harnesses and controls the process of anaerobic fermentation. This is decomposition process which takes place in the absence of air (or oxygen). Similar type of process is *aerobic fermentation* which requires the presence of O_2. Any kind of organic matter (animal or plant) may be decomposed by either of these process but the nature of decomposition will be different.

Anaerobic fermentation leads to evolution of *methane, carbon dioxide*, hydrogen and traces of other gases and does not produce heat during the process.

When anaerobic fermentation is carried out under proper conditions, the residue produced contains higher nitrogen content, (nitrogen phosphorus), potassium and other necessary nutrients to make it a good manure. Further weed seeds and harmful germs are killed due to lack of oxygen in anaerobic fermentation.

The process of anaerobic fermentation is the result of digestion by various bacteria of raw waste material fed to them.

Products released by these bacteria life processes ultimately lead to the production of methane.

The digestion is carried out in stages, as different types of bacteria become active. First the complex organic molecules in the raw material are broken down by acid producing bacteria into simpler ones such as sugar, alcohol, glycerol, peptides and amino acids. When these products accumulate in sufficient quantity, a second group of bacteria can be supported which produces methane. These bacteria, especially the second group are quite sensitive to the conditions in which they must function.

Generally speaking, a kilogram of fresh cowdung can produce 0.04 to 0.05 cu.m of gas at a temperature of 20°C. If a temperature control system is used in bio-gas plant a greater yield, as much as 0.08 cu.m per kg of dung, can be expected. Vegetable waste can produce as much as 7 to 8 times that could be produced by animal dung.

Fig. 40.5 shows schematic arrangement of a double-chamber bio-gas plant, which allows the fermentation process – to proceed for a greater length of time thereby leading to complete fermentation of organic material. Dung slurry (organic matter mixed with enough water to bring down the solid concentration) is introduced or fed through the inlet pipe (earthen or concrete) to the bottom of one chamber, which is separated from

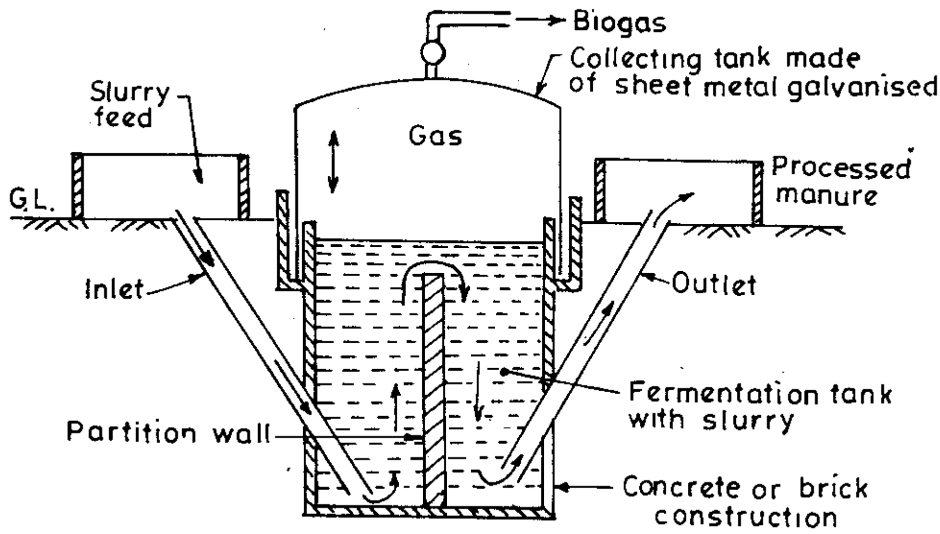


Fig. 40.5.

the other by a wall. The first chamber acts more or less as a single-chamber digestor, where the fermentation process begins. As the temperature gets elevated, the slurry rises slowly through it and overflows at the top, but not out of the plant. It now falls into the second chamber where fermentation continues. The gases produced during digestion bubbles up through the slurry and get collected in the collecting tank, which is sealed by a ring of water ; the tank can move up or down depending on the pressure of gas produced during fermentation. The collected gas can be drawn through a valve and pipe located on the top of movable tank. In the second chamber, automatically the separation of solids and liquids takes place and more concentrated slurry is thrown out from the bottom through an outlet pipe. For any condition cooler than sub-tropical climate, some insulation (heat) system should be incorporated in the construction. Winter temperatures can lower gas production significantly. If vegetable matter is to be digested, agitation of slurry may be essential, otherwise the leaves etc. will begin to float on top of the slurry, thereby blocking the escape of gas to the tank, leading to reduced fermentation rate.

When a large volume of raw materials have been digested, a two-stage plant may be set up. In this design, the process of fermentation is divided between two single-stage (single tank) bio-gas plant, digestion being carried out in the first tank until 60% of the total gas volume is evolved. The second tank attached to first in series receives the effluent of first tank, and allows the process to continue until it is completed.

The bio-gas has a calorific value about of 20 kJ/lit.

Some of the advantages of bio-gas plants are listed below :

1. The bio-gas which is used for cooking can also be used for home lighting after simple treatment.
2. The process of lighting will be simple without much recurring expenditure.
3. The villagers will be able to rectify the faults in case of its failure.
4. The maintenance cost is considerably less.
5. The cattle dung and agricultural waste being available at the place of plant, the question of availability of ingredients to run the plant does not arise.
6. The plant is simple in working therefore the chances of its failure are rare.

(3) Wind Energy. There are many locations in India where wind energy is used for generation of electric power. A total wind generating capacity is 35 MW and are in operation in Gujarat, Maharashtra, Tamil Nadu, Orissa. India's total wind power potential is about 20,000 MW but it is not developed because of high capital cost and lack of development in the wind mill designs.

Wind mill can be used for pumping water from the underground for irrigation as well as for drinking purposes in rural areas which have no access to electric power.

(4) Hydel and Micro-hydel Power Plants. Water power projects also should be boosted up as they provide long tangibie results not only in power production but also in increased agricultural production. Although cost of building dams, channels and turbines is very high, yet it remains the cheapest source of energy in long run. Currently we are using only 12% of the known hydel potential of 40 million kW which is a replenishable source.

Micro-hydel power plants (1 kW to 100 kW) have enormous potential in India. Presently, steps are taken by the Govt. of India to develop these projects throughout the country. These can be installed with fairly low capital cost in mountain streams and in canals. No heavy investment is also required for transmission as the generated power can be used locally.

Hydel power is very safe from environmental degradation point of view and it is a continuous source of power generation, naturally available.

(5) Ocean Energy. Major portion of our rural population is scattered all over coastal areas of the Arabian Sea & Bay of Bengal. We can tap non-commercial energy from sea for the energy requirement of these people.

The two common methods used to tap the ocean energy are ocean tides and ocean thermal energy conversion (OTEC).

(*a*) **Ocean Tides.** The ebb tides are produced by astronomical gravitational force of the Sun and Moon. If the difference between the high and low tides is large and if a natural or artificial water storage facility (reservoir) is available, power can be produced using the head of water created in the reservoir. Such plants are economical where tidal range is high. A few tidal plants are in operation in France, USSR and Canada.

In India, a tidal plant is planned in the bay of Kutch, where tides have been found of sufficient range. Tidel power is more stable compared with hydel power which is dependent on season that is monsoon cycle.

(*b*) **OTEC-Plant.** In ocean, we find warm water at the surface and cold water in deeper layers. The difference between the two within 1000 m depth is about 20°C. This thermal potential energy, available in large quantity, can be used for power generation, using Rankine cycle. The working fluid in Rankine cycle should be a refrigerant which boils at considerably low temperature as well as condenses at atmospheric temperature. A few such refrigerant are used in OTEC plants. Indian port, Kulasakharapatnam in Tamil Nadu is going to have an OTEC plant.

Our vast rural area is scattered all over the country and it would be much more convenient to use decentralised form of energy like solar, wind, biogas and ocean for their requirements. Wind and tidal power possibilities in the coastal areas can be explored. Solar power could be harnessed in desert areas in the country in summer. There is no need to supply power from a central power station through long distances transmission and distribution lines which cause heavy losses. The technical viability of many non-commerical forms of energy has been proved during the last decade. Some of the technologies are cost effective even today. For example, the solar energy, biogas systems and wind energy have proved their economic viability.

It is high time that right thinking people and policy planners sit together and take account of what we are heading for and what we should do about it so that the efforts of the scientific community are not wasted.

Rural energy planning should therefore, evolve the necessary mechanisms for transferring the available technologies to the villages, to enable rural communities themselves to formulate and implement energy development programmes to meet their needs.

These developments, apart from releasing pressure on oil, would also contribute to improving atmosphere which is increasingly becoming polluted in urban areas.

4.5. Other Energy Conservation Measures. Among the other measures for thermal energy conservation, the important ones are :

(*a*) Recovery of waste heat by using heat pipes.

(*b*) Waste heat boilers.

(*c*) Vapour absorption refrigeration systems.

(*d*) Use of heat pump systems.

(*e*) Electrical energy conservation can be achieved by energy efficient motors and lighting systems as well as variable speed drives.

These methods are discussed below in short.

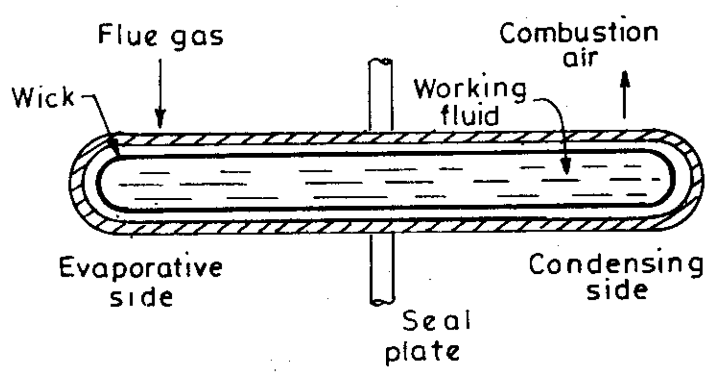


Fig. 40.6. Heat pipe-heat exchanger.

(1) Heat Pipe System. Heat pipe is a typical type of heat exchanger as shown in Fig. 40.6 which transfers the heat effectively and efficiently with minimum capital cost. In this type of heat exchanger, flue gas transfers heat to a working fluid. The fluid vaporizes and travels to the opposite direction. Incoming air picks up heat as it flows over it, causing the working fluid to condense. The condensed working fluid then flows by gravity back to the fluid-filled end. The transfer of heat from hot fluid (gas) to cold fluid (air) takes place by phase change of the working fluid. Therefore, large amount of heat is transferred with small mass of working fluid with lower capital cost of the heat pipe. Heat pipes are used in wide variety of industrial applications for the last 20 years. More recently, it is also used as air-heaters in thermal power plants. For *further details, the students are advised to see the book* Heat & Mass Transfer by the same author.

(2) Waste Heat Boilers (WHB). The WHBs recover energy from gas streams in a wide range of chemical process plants. They play the same role as in co-generation and combined cycle plants that generate steam and electric power.

The steam generating rate and space available determine the particular type to be used in a given situation. As well as, the type used also depends upon temperature, pressure, chemical composition and purity of the gas. Such properties vary widely as listed in the following table.

The main purpose of using WHBs is to maximise the amount of energy recovered, consistent with economic and technical limitations (*e.g.* high or low-temperature corrosion problems). In many chemical plants, the main purpose is to cool the gas stream to a paricular temperature level that is needed from a process stand point, with the energy recovery being a welcome but secondary consideration.

FBCs and fixed bed incinerators are used to burn a wide variety of industrial, municipal and other wastes. Large plants to burn municipal wastes ranging in capacity from 500 to 2000 tons/day, resemble with coal fired boilers. The gas temperature from such boilers are in the range of 1000°C. The design considerations should take into account dirtiness of gas, percentage of particulate matter that can cause slagging and corrosion at low temperatures.

Table I. Composition of typical waste gases

Gas	Temp. °C	Pressure (bar)	Composition, %													
			N_2	NO	H_2O	O_2	A	SO_2	SO_3	CO_2	CO	CH_4	H_2S	H_2	NH_3	HCl
1.	300 – 1000	1	78 – 82			8 – 10		8 – 11								
2.	250 – 500	1	80 – 82			10 – 12		0.5 – 1.0	6 – 8							
3.	250 – 850	3 – 10	65 – 67	8 – 10	18 – 20	5 – 7										
4.	200 – 1100	1	70 – 72		16 – 18	2 – 3				9 – 10						
5.	300 – 1100	30 – 50	12 – 13		40 – 41					6 – 8	7 – 9	0.3		30 – 32		
6.	500 – 1000	25 – 50	13 – 15		34 – 36					13 – 15	0.2 – 1			38 – 40		
7.	200 – 500	200 – 450	18 – 20				1 – 5							56 – 60	18 – 20	
8.	300 – 1200	40 – 80	0.2 – 0.5				0.3 – 0.5			4 – 6	46 – 48	0.2 – 0.5	0 – 0.8	45 – 49		
9.	100 – 600	1	70 – 80		6 – 10	13 – 16				3 – 4						
10.	175 – 1000	1	70 – 75		8 – 12	5 – 8				10 – 13						traces
11.	250 – 1350	1	75 – 80		6 – 10	3 – 5				6 – 8						5 – 7
12.	150 – 1000	1	65 – 72		16 – 25	1 – 3				4 – 6						
13.	300 – 1450	1.5	50 – 55		20 – 25			3 – 5		5 – 7	2 – 3		2 – 3	3 – 4		

1. Raw sulfur gases
2. SO_3 from convertor
3. Nitrous gases
4. Primary-reformer fluegases
5. Secondary-reformer gases
6. Converted gases
7. Synthesis gas
8. Shell gasifier effluent
9. Gas turbine
10. Modular municipal-solid-waste incinerator
11. Chlorinated-plastics incinerator
12. Fume incinerator
13. Sulfur condensor

In incineration of chemical wastes, the exit gas temperature lies between 1100 to 1300°C. The gas stream poses risks of high and low temperature corrosion. Gas side corrosion problems associated with high temperature gas can be broadly divided into two categories. The first is high temperature, liquid phase corrosion, caused by molten alkali-metal salts that have low melting points. If flue gases containing these salts are in contact with WHBs tubes above these temperatures, the salts melt and deposit on surfaces. This cannot only plug tubes but also build up corrosive deposit that may destroy the tubes.

The second category is corrosion due to hydrogen chloride or chlorine, formed during combustion of waste plastics, is very corrosive above 450°C. So, care should be taken to see that if superheaters are used, their tube wall temperature should not exceed that level. Therefore, WHBs associated with the burning of such waste are used to generate saturated steam at pressures that keep the temperature below 200°C but above acid vapour dewpoint.

The use of waste heat boilers indirectly conserve the commerical resources like coal and oil and the wastes which are otherwise, to be disposed and may cause many other health problems. For further details, see the chapter on waste heat boilers.

(*c*) **Vapour Absorption Refrigeration System.** The large quantity of refrigeration systems at low cost are required for preservation of fruits and vegetables. Many times, commerical energy cost to run the refrigeration system may exceed the production cost of the fruits and preservation becomes uneconomical. The waste heat either from gas or steam can be used to run such system even of 1000 tons refrigeration capacity at considerably low cost. The arrangement of the components of such refrigeration system is shown in Fig. 40.7. For the operation of this system and analysis, the students are advised to see the book *Refrigeration & Air-conditioning* by the same author.

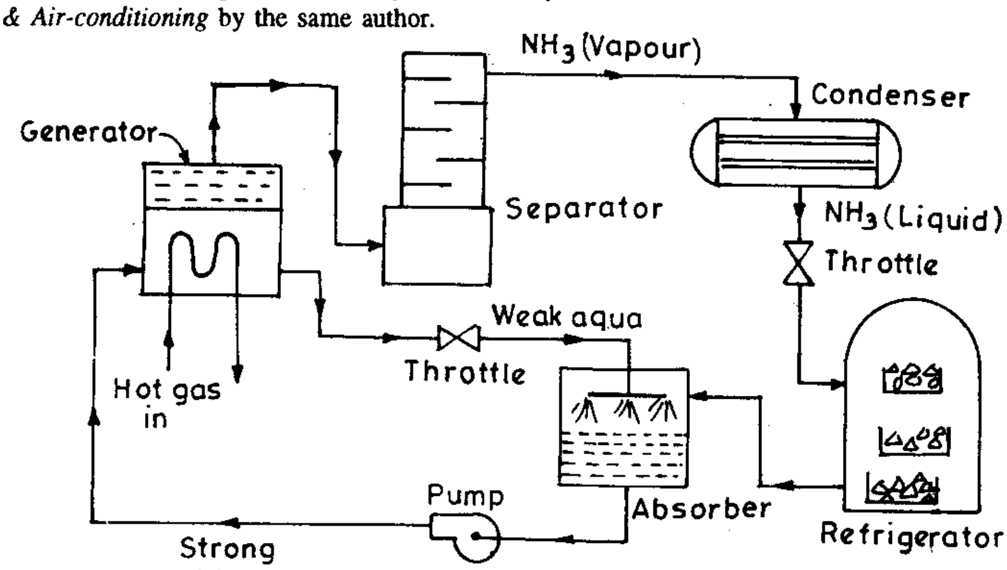


Fig. 40.7. Vapour absorption refrigeration system.

(Aqua – It is a solution of water with dissoved NH_3)

This avoids the use of high quality energy (electrical) and uses that energy which should have been ischarged to the atmosphere. This is very economical as it uses the waste energy.

(*d*) **Use of Heat Pump System.** The heat pump systems are used to supply the heat energy at a lower cost where heating is essential.

Assume an electrical energy W is to be used for heating, then the heat energy is also nearly equivalent to W units. But this electrical energy can be used more effectively in heat pump system as shown in Fig. 40.8. In this system, the electrical energy W is used to lift energy Q which is at low temperature (T_1) and raise its temperature to T_2 ($T_2 > T_1$) which is required at the place (source). In this case Q may be as high as 4 W and the amount of energy supplied to the source is 5 W by using electrical energy W. Therefore, this type of system is widely used for heating the buildings at a considerably low operating costs.

The students are advised to see the book *Refrigeration & Air-conditioning* by the same author for further details.

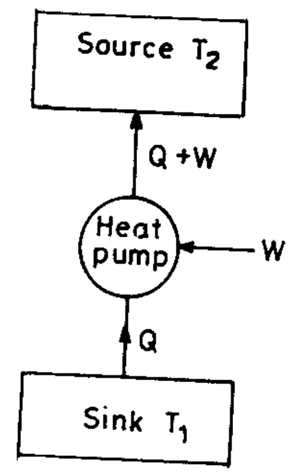


Fig. 40.8.

(B) Saving Potential on Account of Reduction in Transmission and Distribution Losses

Transmission and distribution losses during 1989-90 reportedly were 22.9% which are too high compared with the losses in USA and UK. The losses can be reduced by 4% by saving 13000 million units which can yield an revenue of Rs. 1300 crores considering the energy cost of Re. 1 per kWh.

These losses can be reduced by Grid operation using the following methods :

(1) Backing Down. It is reported that there was a Backing Down of 13000 million units in the country during 1990-91 mostly in western and northern regional grids. If 50% of backed down energy is used after providing inter-regional links, rational tariffs are evolved for inter-regional power transfers, large differential peak and off-peak demand reduced through demand management and concessional tariff during off-peak period and system load diversities of the neighbouring regions are optimised. As implementation of these measures is likely to take about 3 to 4 years, one can safely assume possible saving in the backed down energy of 7000 million units by the end of the present plan period.

(2) High Frequency Grid Operation. Present PLF incentive scheme for thermal power plants in India encourages employees to generate excess power during off peak periods though not required by the system demand.

It is reported that grid frequency was higher than 50 Hz during 1990-91 in Northern Region (58%), Western Region (43%) & Eastern Region (25%). Estimated excess generation though not required by system demand on account of above was 1500 million units. And the excess coal burnt on account of above was 11 lac tonnes per year. The estimated cost was Rs. 55 crores (Rs. 500 per tonne of coal) should have been saved if grid frequency should have been normal.

Nearly 20% generated electrical energy was lost in transmission and distribution. This accounts to be 2100 crores at a cost of Rs. 1/kWh. This amount is equivalent to installed capacity for producing 4200 MW which exceeds 21000 crores. Therefore, effective steps should be taken to cutdown these losses.

(*c*) **Energy Conservation at User's End.** The efficiency of end use of electricity is another *key-area* which could result in much improved utilization of electricity. It has been assessed that the possible energy saving potential in industry is 25%, agriculture is 30% and domestic/commerical is 20% if effective conservation measures are adopted.

Wasteful use of agricultural pumps in Gujarat alone accounts for energy drain of about Rs. 50 crores a year. By improving the efficiency of these pumps, energy of 3000 million kWh would be saved which would serve installed capacity of 800 MW. Conservation of 1 MW power per year would mean a gain of Rs. 7 crore for the nation. In India, energy can be saved to the extent of 15% which will increase the present capacity by (96000 × 0.15) 14400 MW and will save Rs. 72800 crore per year. This itself indicates the importance of energy conversation at the user's end.

The scope of increasing efficiency exists in the performance improvement of motors and pumps, fans, lighting systems, building construction, different processes in different industries, boilers, heat exchangers and uncountable fields where engineering techniques can be used for their improvement.

It is not the purpose of this chapter to discuss the details concerning the steps to be taken for the performance improvement of these end users.

In view of existing energy crisis, there is need to conserve more and more energy. By energy conservation, the following advantages can be achieved :

(*i*) The demand of commercial energy sources can be reduced. The following table shows the estimated conservation of commercial energy sources by 2000 A.D. :

(*ii*) The life of commercial energy sources can be increased.

(*iii*) The atmospheric pollution can be reduced.

(*iv*) Cost of product can be reduced and productivity can be increased.

Table II. Estimated Conservation of Commercial Energy Sources by 2000 A.D.

Source of Energy	*Estimated Consumption by 2000 A.D.*	*Estimated Consumption with Energy Conservation by 2000 A.D.*
Coal (mt)	472	426
Oil (mt)	92	69
Electricity (TWh)	492	454

The energy can be conserved by avoiding the waste, decrease in demand and improvement in technology.

It is absolutely essential to accord higher priority for allocation of funds for implementation of conservation programmes as compared to the new generating capacity additions.

Energy is the one area where there is no alternative to self-reliance either now or in the future. Our development programme to eradicate poverty by continuously accelerating production and to redistribute equitably means that we must act now to expand, develop, redevelop, transmit, convey and distribute our energy resources, and do all this in a manner which will conserve them. A sound policy of energy production and development is also a sound means of energy conservation.

Energy can be saved and environment protected only with the active co-operation and participation of end users, ESCOS, manufacturers, intermediaires, entrepreneurs and industries.

COOKING

* Up to 30 per cent energy can be saved through good cooking habits.
* Use only high efficiency ISI marked gas or kerosene stove.
* Use pressure cooker. It cooks faster and saves between 20 to 46 per cent fuel.
* Surplus water consumes up to 65 per cent additional fuel. Use optimum water.
* Soak dal, rice, etc. before cooking. This reduces cooking time.

TIPS ON FUEL CONSERVATION

* Place a lid on an open cooking vessel or pan. An open vessel loses heat to the atmosphere.
* Regularly clean the burner and trim or replace wicks of kerosene stoves.

Keep frozen food out of the Freezer for some time before putting them on the stove.

MOTORISTS

* Keep engine tuned. Clean filters regularly as choked exhaust ports and silencers cause poor combustion.
* Drive in correct gear. Incorrect gear can lead to as much as 20 per cent increase in fuel consumption.
* Maintain correct tyre pressure.
* Do not ride with clutch pressed as it leads to fuel loss.
* Turn off the engine if you stop for more than two minutes. Idling causes fuel wastage.
* Drive two-wheeler at a steady speed of 35-45 kmph.
* Join a car pool.

* Keep wheels properly aligned as improper alignment results in fuel wastage.
* Drive car at a steady speed of 45-55 kmph.

THERMAL ENERGY

* Regular energy audits have to be undertaken.
* Plug oil leakage : Leakage of one drop of oil per second amounts to a loss of over 2000 litres per year.
* Oil should be filtered in stages as impurities affect combustion.
* For proper combustion, oil must be pre-heated and oil should be at right viscosity at the burner tip.
* Observe the colour of smoke emitting from the chimney. Black smoke indicates improper combustion and fuel wastage. White smoke indicates excess air and hence loss of heat. Hazy brown smoke indicates proper combustion.

Industrial Sector

FOR FURNACES

* Use of low air pressure "film burners" helps save upto 15 per cent oil in furnaces.
* Reduce heat losses through furnace openings. Studies show that a furnace operating at a temperature of 1000 degree C, having an open door (1500 mm × 750 mm) results in a fuel loss of 10 litres per hour. For a 4000 hour furnace operation, this translates into a loss of around Rs. 4 lakh per year.

FOR BOILERS

* A coating of 3 mm thick soot on the heat transfer surface can cause an increase in fuel consumption by as much as 2.5 per cent.
* Boilers should be monitored for flue gas losses, radiation losses, incomplete combustion, excess air etc. This can lead to 20 per cent reduction in fuel consumption.

ELECTRICAL ENERGY

* Improve power factor by installing capacitors to reduce kVA demand charges and line losses within the plant.
* Avoid repeated rewinding of motors. Rewound motors show an efficiency loss of up to 5 per cent.
* Use of variable frequency drives, slip power recovery systems and fluid couplings for variable speed applications like fans, pumps help to minimise consumption.
* Use of electrical ballast in place of conventional choke saves up to 20 per cent energy.
* Replacing aluminium or fabricated steel fans by moulded FRP fans with aerofoil designs results in electricity savings between 15 and 40 per cent.
* Improper selection of pumps can lead to large wastage of energy. A pump with 85 per cent efficiency at rated flow may have only 65 per cent efficiency at half the flow.
* Loose belts between pumps and motors can save between 15-20 per cent energy.

40.6. WHAT IS ENERGY MANAGEMENT

Management and conservation of energy are two sides of one coin. The very purpose of management is to conserve the energy. Once all methods as discussed earlier are used to conserve the energy then management techniques should be applied to use the existing sources for its optimum output with economical way.

Energy management is a combined technological and management function which includes engineering, economics, operational research and computer programming as well as day to day management of fuels and equipments and modes of energy flow. The use of energy always has an uneconomic effect on natural resources and ecological systems due to degradation of fuels and mass pollution. Thus, the energy management has to look after material conservation, waste reduction, control of pollution and disposal of waste together with recycling possibilities for economical output.

Because of a large number of complex factors influencing the decisions in the field of energy management, it is generally difficult to have an optimum solution. However, a beginning may be made with a few inputs with the objective improvements on a continuous basis.

Even today most commerical manufacturing processes consume over twice the energy that they really utilise. Most thermal power plants using coal as fuel operate at overall efficiency of 30% to 40%. Most furnaces used by metallurgical industries operate at efficiencies of 10% to 30%. Most chemical plants using steam hardly use 50% of the heat originally contained in the fuel. These are just a few examples. In view of the constraints involved in developing additional power sources, it has become clear that the only immediate solution to the energy supply lies in energy conservation by using proper management techniques.

On account of poor operational and maintenance practices, most of the machines and equipments like electric motors, air-conditioners, air-coolers, lighting systems etc. operate at low efficiency. Therefore, proper management should be used to utilise the sources for optimum power generation and generated power should be used with maximum efficiency by proper design and operations of equipments.

40.7. ENERGY MANAGEMENT TECHNIQUES

The following procedures should be adopted for the improvement of energy generation, transmission and uses :

(1) Analysis of Inputs. All industries are used to prepare profitability projections based on the costs of :

(*i*) Raw materials (*ii*) Labour and supervision (*iii*)) Annual cost of plant and machines and (*iv*) Interest and insurance.

To this, may be added an item of energy costs. Energy analysis seeks to account for the consumption of energy at each stage in the production of a product. Thus, the total energy inputs represent the energy cost of a finished product as energy uses during mining and conversion of raw materials, direct and indirect energy inputs during manufacture, including the energy costs of transport, communication and support services.

Energy costs of a few materials and products are given in the following tables. There is need to compile and update such information for all the raw materials, services and products so that one is able to compare the energy costs of the product with the currently national and international data and try for improvement.

Table III. Energy contents of materials and finished products

Materials	*Energy MJ/kg*	*Cost of energy/cost of product*
Steel	25 – 50	0.3
Aluminium	60 – 270	0.4
Copper	25 – 30	0.05
Magnesium	80 – 100	0.1
Glass	30 – 50	0.3
Plastic	10	0.04
Paper	25	0.3
Inorganic chemicals	12	0.2
Cement	9	0.5

Table IV. Energy cost of some finished products

Finished product	*Energy cost (kg coal equivalent)*
Motor Car	2700
Bicycle	200
Washing Machine	280
Refrigerator	170
Colour T.V.	870

(2) Reuse, Recycling and Reclamation of Waste. Almost every discarded commodity may be reclaimed, reused or recycled. The technologies needed for reclamation are reasonably well-developed. Utilization of agricultural and industrial waste is now gaining acceptance. Proper utilization of sewage and municipal solid waste is yet to take-off.

Waste management for energy generation is presently gaining ground as it solves the problem of waste disposal and helps to energy conservation.

In developing countries, landfills are often used for municipal solid waste because of purely cost economics. This dumping of solid city wastes heaps into an area which is not prepared and go under a process of natural decomposition. This requires lot of area and creates many health problems.

The use of city waste for energy generation in Bombay and Delhi is recently operated. A net energy recovery of 100 kWh per ton of solid waste was found possible from 300 tonnes of waste collected per day in Delhi. This means, 10 to 15 kWh/capita per annum energy could be available from this source in the form of electricity which will reduce the burden on conventional plant and solve the problem of waste disposal.

(3) Energy Education. It is high time that education about the sources, uses, misuses and crisis of energy is not given to the beneficiaries. Also, serious efforts are needed to develop altitudes in them which are functional to the conservation and judicious use of the resources and respect to the environment.

(4) Ways to Conserve Energy. Some important ways of conserving energy are listed below :

(4.1) Efficient Combustion of Fuel in Boilers. Efficient combustion of fuel with minimum excess air to burn the fuel completely is essential for energy conservation. Both air and fuel should be mixed properly and supplied to the combustion chamber at the correct temperature and pressure as required for efficient combustion.

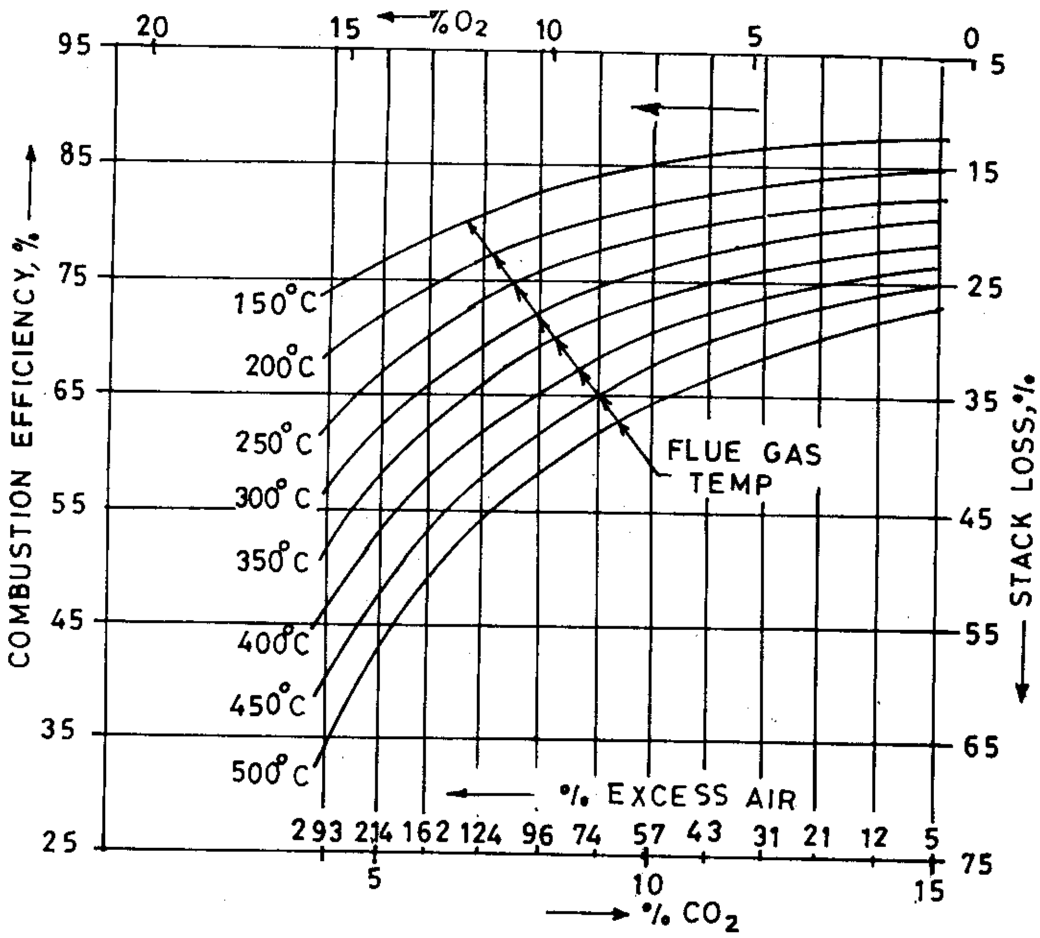


Fig. 40.9. Benefits of controlling excess air for oil fired furnaces.

The percentage of excess air must be estimated. Too little air would lead to incomplete combustion and smoke. Too much air would result in increased stack losses. Hence there is optimum excess air level for each type of fuel combustion system to maximise fuel saving. The Fig. 40.9 shows the heat loss and combustion efficiency with different levels of CO_2 and O_2. Flue gas analysis must be done regularly and efforts must be made to keep the CO_2 level at its optimum.

(4.2) Waste Heat Recovery. Recovery and utilization of all waste heat should be done which is technically feasible and economically viable. This should take into consideration, the quantity and temperature of flue gases as well as its quality (as corrosive or not). Then we have to identify potential energy use points along with the required temperature and quantity. Then the waste heat recovery system should be designed and return on the investment should also be evaluated.

A monogram for evaluating fuel saving using waste heat recovery system is shown in Fig. 40.10.

(4.3) Thermal Insulation. Use the "Economic Thickness" of insulation for both hot and cold applications to optimise on energy losses and insulation costs.

When the price of energy was low, surfaces which were at 100°C were not insulated. However, today's energy costs would make it economical to insulate even surfaces at 50 to 60°C. The following table gives the base surface heat losses in kW/m^2 :

Most equipments were not insulated earlier when the cost of fuel was low. Consideration of economical thickness is given importance because of surging fuel prices. Therefore, the insulation needs to be upgraded to optimise or saving fuel at current costs. For upgrading insulation, higher thickness or superior insulation should be used.

Table V. Bare Surface Heat Losses in kW/m^2

	Bare Surface Heat Losses (kW/m^2) at operating temperatures (°C) of						
Pipe Dia (Inchees)	*100*	*200*	*300*	*400*	*500*	*600*	*700*
$\frac{1}{2}''$	1.15	3.93	8.30	14.83	24.30	37.50	55.60
1″	1.09	3.74	7.95	14.32	23.60	36.65	54.50
$1\frac{1}{2}''$	1.04	3.60	7.70	13.98	23.10	36.00	53.75
2″	1.01	3.53	7.75	13.78	22.83	35.60	53.30
3″	.97	3.40	7.35	13.45	22.40	35.10	52.60
4″	.95	3.30	7.20	13.21	22.10	34.70	52.20
6″	.90	3.19	6.95	12.89	21.63	34.10	51.40
8″	.89	3.16	6.90	12.75	21.50	33.95	51.25
10″	.87	3.10	6.80	12.62	21.40	33.75	51.00
12″	.86	3.06	6.72	12.52	21.18	33.60	50.70
14″	.85	3.04	6.68	12.47	21.10	33.45	50.60
Flat surfaces	.84	3.01	6.63	12.40	21.00	33.30	50.45

Use of Monogram shown in Fig. 40.10. You can asses the saving through heat recovery for your equipment.

How to use the nomogram : (figures in brackets refer to the data used in the illustrated example)

(1) Connect T_1 (400°C) to T_2 (200°C) intersecting the pivot line '*A*' (at point '*X*').

(2) Connect this point (*X*) to the given figures of CO_2% (12%) in exhaust flue gases.

(3) The point at which this line intersects the reference scale '*B*' (10% on oil, 11% on coal) indicates fuel saving in percentage.

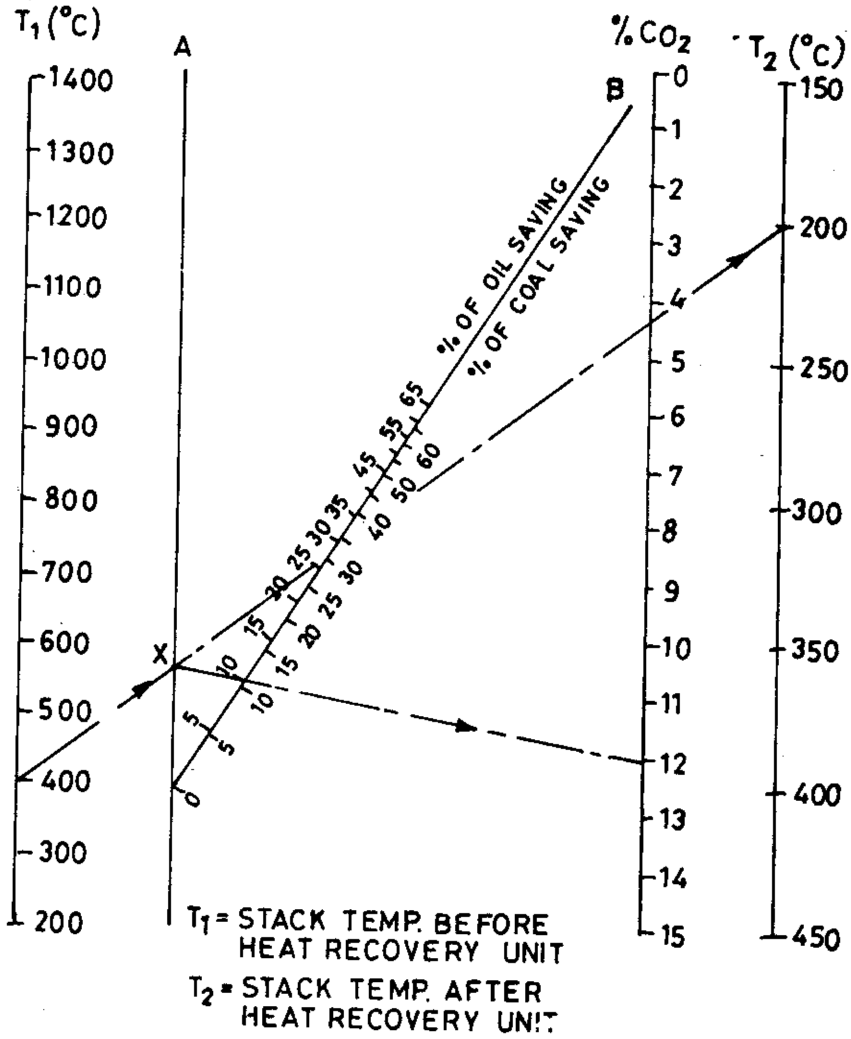


Fig. 40.10. Nomogram for working out approximate fuel-saving.

(4.4) Heat Distribution System. There are many sources of energy wastages in heat distribution system. Some methods of energy conservation are :

(*a*) **Condensate Recovery.** Condensate recovery is one area with high potential for energy conservation. High pressure condensate can be flashed to lower pressure steam. This is often advantageous when long distances make it inconvenient to return the condensate to the boiler plant.

(*b*) **Reduction in Steam Leakage.** Useful saving can be achieved by reducing steam leakages by improving maintenance standards.

(*c*) **Improve Steam Trapping.** Regular checking of steam trap is of great value to steam economy.

(4.5) Electricity Conservation. The industrial sector is the largest consumer of electricity and presently accounts for 60% of the total generating capacity. More than 75% of the industrial consumption is used for electric motors. Therefore, it is essential to select proper motor for proper application.

(*a*) **Optimising Motor Loads.** Every motor is designed for optimum performance at full load. But it has been frequently observed that the motors are operated at as low as 30% of their rated load. This increases power consumption substantially. The correct selection of motor for the required job not only reduces the energy consumption but also reduces the power demand. The following table gives an idea of the energy saving by using the correct sized motors :

Table VI. Comparison of Performance of Motors at Rated Partial Load

	Case 1 *7.5 kW Motor* *at Full Load*	*Case 2* *11 kW Motor* *Loaded to 2/3 Load*	*Case 3* *15 kW Motor* *Loaded to 1/2 Load*
Motor Load (kW)	7.5	7.5	7.5
Motor Efficiency %	88	84	79
Motor Input (kW)	8.5	9.0	9.5
Unit Consumed (5000 Hrs./Year)	42500	45000	47500
Cost Rs. (@ Re. 0.90 per unit)	38250	40500	42750

(*b*) **Effective Load Management.** This is every effective method to reduce the power consumption. Its purpose is to control the timing and peak of customer power used with a view to reduce the peak demand to minimum. The pumping of drinking water and supply of agricultural water during the night time when industrial load is considerably reduced can use the existing power capacity for maximum use. Whenever possible, load levelling should be attempted by rescheduling the power demand whenever possible.

(*c*) **Power Factor Correction.** The improvement of the power factor increases the system capacity since the transformer load can be increased.

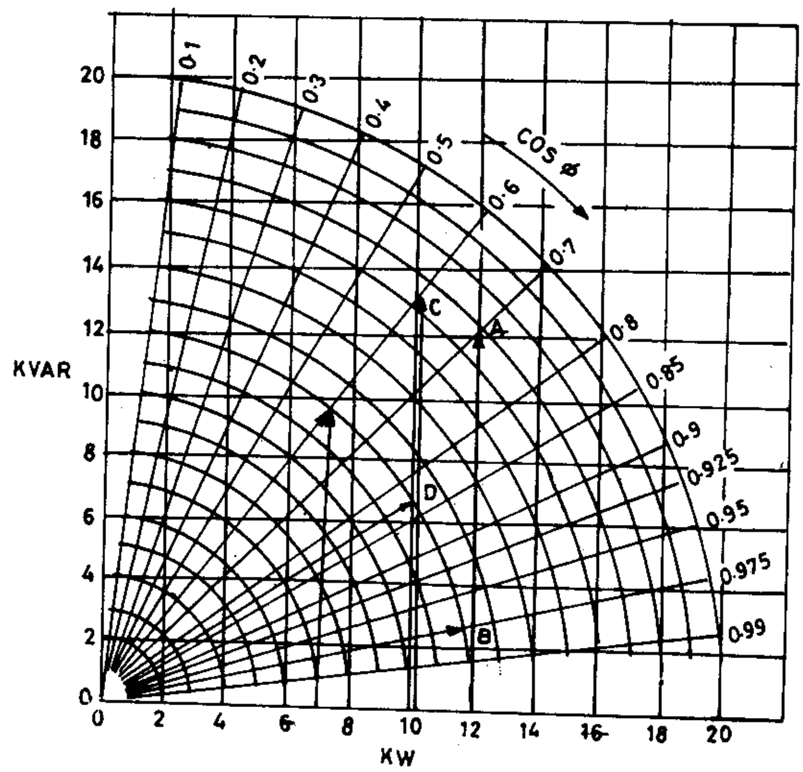
The power factor can be improved by improving motor loadings as motors operating at low loads have low power factor and by providing external capacitors. These provide the reactive kVARs. The correct location of power capacitors is important for optimum results. Often best results are achieved if the power capacitors are located to the point of use. Fig. 40.11 gives some idea of how to select a power capacitors.

(4.6) Lighting. Excessive lighting should be eliminated. Lighting levels are frequently much higher than necessary, particularly in stores, godowns and corridors. In these locations, illumination may be reduced by removing some lamps and energy can be saved. Owing to a simple cause such as dust on light surfaces, the illumination is considerably reduced. Better illumination can be achieved by frequent cleaning.

Table VII. Luminous Efficiency and Life of Light Sources

Light Sources	*Efficiency (Lumens/watt)*	*Average working life (hours)*
1. Incandescent lamps	10 – 18	1,000
2. Cool daylight fluorescent tubes	61	5,000
3. White fluorescent tubes	69	5,000
4. High pressure mercury vapour lamp		
80 W	36.9	5,000
125 W	41	5,000
400 W	52	5,000
5. High pressure Sodium lamp		
70 W	82.8	10,000
250 W	100	10,000
400 W	117.5	10,000

Diagram for solving power factor problems



Example 1

Given	:	Effective Power = 120 kW
		Power Factor = 0.70
Wanted	:	Power Factor = 0.975
Result	:	Capacitor kVAR = AB = 96 kVAR

Example 2

Given	:	Transformer kVA = 120,
		Power factor = 0.60,
		Effective load now possible is 72 kW because of power factor of 0.60.
Wanted	:	Capacitor requirement for increasing effective load to 100 kW.
Result	:	Distance CD = 67 kVAR got by drawing a vertical line at 100 kW to insert 0.60 P.F. line at C and 120 kVA are at D.
		The new power factor is 0.833.

Fig. 40.11. Diagram for solving power factor problems.

(4.7) Control Systems. Without proper operation of control systems, no energy conservation is possible. Many times, it is found that owing to poor maintenance, the controls lose their calibration which results in erroneous readings, playing havoc with not only with energy consumption but also the process output as well as system safety.

(4.8) Proper Maintenance of Equipments. Keep the instruments and equipments in proper working conditions. For example, cleaning the economiser tubes, superheater tubes and condenser tubes improve the heat transfer capacity and saves lot of energy.

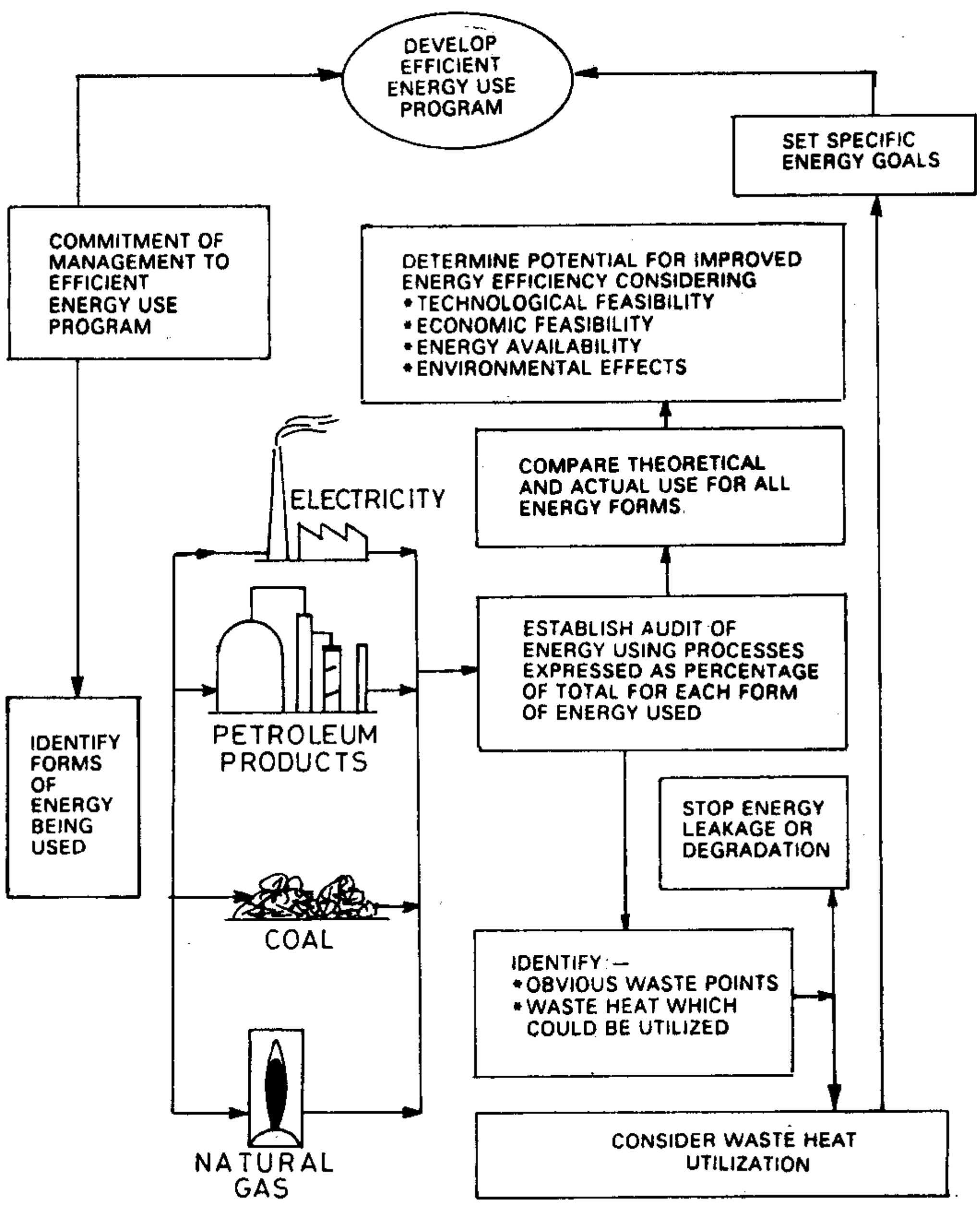


Fig. 40.12. Energy management flow chart.

(4.9) Proper Design. Avoid oversize of the equipments as oversized equipments higher than necessary contribute to wasted energy.

(5) Energy Audit. The main purpose of energy audit is to establish quickly and reliably, the basic relative costs of the various forms of energy purchased, their main uses and to identify the principle locations where losses, wastages or inefficiency occurs.

There are five basic steps involved in energy audit as described below :

Step 1. Evolve a Comprehensive Energy Management Policy.

The first step in energy conservation is to take a decision that it must be done, what target can be set and in what time frame, these are to be achieved. The Fig. 40.12 shows the energy management chart.

Step 2. Conducting a Detailed Energy Audit.

The next step is to identify all forms of energy being used and to carry out an audit for each type of energy used.

An *energy audit* identifies the cost of energy and where and how it is used. It will identify the amount of energy expended in a process with the help of mass and energy balance for each process. Then energy flow diagram is prepared showing the quantity, form, source and quality (temperature) of the energy required for various processes. Next step is to make a critical analysis for energy used and energy wasted. This is followed by identification of potential areas for energy conservation.

A typical energy audit of a factory would be as shown in Fig. 40.13. Experience with energy audits in different plants indicate the more common causes leading to inefficient energy use as listed below in the table.

Table VIII. Energy Losses

Primary Losses	*Secondary Losses*
Leaks (fuel, steam, water, compressed air, etc.)	*Exhaust Gases* (from stacks of furnaces, boilers, d.g. sets, etc.)
Through Lining (pipes, vessels, furnaces, buildings, or any other surface that is either heated cooled via radiation and convection)	*Condensate and Flash Steam* (from steam heated systems)
Faulty Traps (wrong types, oversizing poor maintenance)	*Blowdown* (from boilers and process vessels)
Faulty Combustion Excess air, poor fuel/air pressure, inefficient burners, etc.	*Hot Effluents* (Waste liquors))
Overheating *Overcooling* (Absence of control, faulty control)	*Cooling water* (to cooling towers)
Excessive Ventilation	
Low Power Factor	
Ill Matched Motors (to require duties)	
Excessive Lighting	

Detailed formats for conducting energy audits in typical areas including energy cost evaluation, boiler house energy consumption, checklist for heat generation, distribution and consumption are provided at the end. Similar format can be developed for all other activities using energy.

Step 3. The efficiency of energy utilization varies with the specific industrial operations, the materials produced and nature of manufacturing operations. Therefore, an effective energy conservation programme has to be undertaken.

Initial measures to conserve energy (fuel and electricity) in each plant are just to follow the operating practices listed in previous table which can result in as much 10 to 15% saving with no capital investment. Higher saving upto 30 to 40% can be achieved with capital investment on major energy saving schemes. Energy consumption even can be halved if the problem is tackled in a scientific and methodical manner.

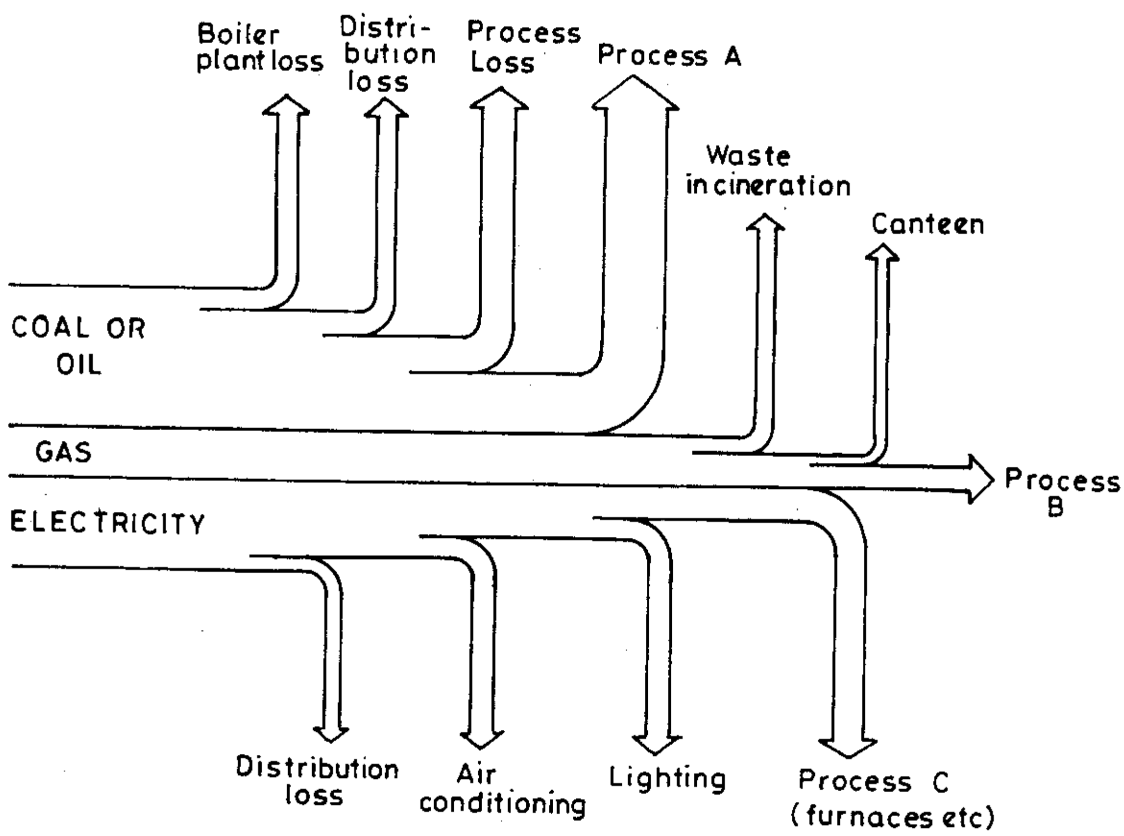


Fig. 40.13.

A positive plan of action should be undertaken after analysis and then detail design work is to be carried out to draw up the specifications for practical modifications of the existing processes.

Step 4. Implementation of Energy Conservation Programme. Implementation of energy conservation measures will yield saving but pilot scale projects should be undertaken to establish their technical feasibility.

Step 5. Review of Achievements. Proper measurement and control systems are to be incorporated to monitor the performance of the equipments used for energy conservation. Monthly review of all important parameters responsible for energy conservation should be conducted to ensure that the programme is progressing in the right direction.

The management of energy systems used in each industry like energy saving in buildings, energy saving in boilers, energy optimization by scheduling the loading, and grid load distribution are some examples where energy management is required for energy conservation.

Many publications are available to study in details the management techniques used for each industry and each process in industry. To discuss all these in one text is not possible and that is not the purpose of this text except to bring out the methodology used for energy conservation.

Keeping in view the resource constraints, new generation capacity addition has limited scope. The thrust areas of Energy Conservation, Energy Management and optimal utilisation of existing installed capacities/facilities have vast potential for energy saving/improvement and involve comparatively less capital investments. These areas must be given greater attention and high priority to mitigate the anticipated power shortages during IXth and subsequent Plan periods. During VIIth Plan, renovation and modernisation programme of thermal power stations was accorded a high priority and benefits achieved from it were very encouraging. The Plant Load factor during VIIth Plan increased from 50% to 56.5% and an additional generation of about 10000 million units was reportedly achieved from old thermal sets which underwent substantial renovation and modernisation. The implementation of concrete time bound Action Plans in the key areas discussed above can also yield encouraging results if high priority is accorded to them and concerte and determined efforts made in the implementation of these programmes.

EXERCISES

40.1. What is the trend of power development in India in future ?

40.2. What do you understand by distribution of energy consumption ?

40.3. What is energy conservation ? What are its advantages ?

40.4. Energy conservation will help to reduce the energy growth in India. Discuss.

40.5. Discuss different methods of energy conservation.

40.6. Use of non-conventional sources is considered a proper and logical method to meet the energy demand in India. Discuss.

40.7. Discuss the different methods used to improve the efficiency in thermal power plants.

40.8. What do you understand by energy management ?

40.9. Discuss different energy management techniques used in practice.

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