# CARBON DIOXIDE AND METHANE EMISSIONS FROM POWER GENERATION IN INDIA

Shiv Pratap Raghuvanshi[a*], Renu Singh[b], A. K. Raghav[c], and A. Chandra[d]

Indian Institute of Technology Delhi, Hauz Khas, New Delhi, India. [110016]
Fax: +91 11 26581121; Tel:+91 9818604170; Email: spraghuvanshi@yahoo.com

## Abstract

Electricity is the man-made form of energy, which is mainly produced on combustion of coal, natural gas and oil. Indian power sector is mainly dependent on coal for electricity generation (over 70%). Coal is a widely available natural resource throughout much of the world, and the quantity and quality of coal reserves are better known than those of other fuels. Reserve wise India ranks sixth in world, occupying roughly 7% of the proven coal reserves of the world. India ranks 19$^{th}$ producer of the Natural Gas in the world. In the last two decades Natural Gas production in country has increased over three folds, i.e., 2358 mcm in 1980-81 to 29,740 in 2000-01.

Coal being, inexpensive in terms of its cost per joule of energy, so have always been of primary importance for power generation, but Natural gas is given attention in the light that it produces only half as much as carbon dioxide per BTU of energy than coal, which would certainly lower carbon dioxide emissions. Presently natural gas accounts for about 11% for the power generation in the country.

On an estimate for every ton of fossil fuels burnt three-quarter of a ton of carbon is released as Carbon dioxide. Energy related carbon emissions are 252.6 million tons of carbon, which is equivalent to 4.41% of world carbon emissions. Analysis states that 0.8-1.2 kg/kWh $CO_2$ is emitted from Indian Thermal power stations.

Present communication is an attempt to, provide a brief inventory of the most potent Greenhouse Gases i.e., carbon dioxide and methane, emissions from power sector in India. Possible sinks have also been classified.

*Keywords: Coal, Natural gas, Greenhouse gases, Carbon dioxide, Methane, Energy*

## 1. Introduction

Carbon dioxide, methane, $NO_x$, are Greenhouse Gases (GHGs) emitted from coal combustion and in power generation that are responsible for Global warming and associated global climate change. Carbon dioxide is a stable molecule with a two to four year average residence time in the atmosphere while methane reside for about eleven years in the atmosphere which complicates the reduction processes. Carbon dioxide produced, makes up over half of the man-made greenhouse gases and is therefore a major contributor enhancing the greenhouse effect. It is increasing at an astonishing rate of 0.4 percent per year while methane at a rate of 1 percent per year. So these greenhouse gases are of major concern. Table1 provides an introduction to these greenhouse gases with their pre-industrial and present concentration. Further their share in greenhouse effect and their respective global warming potentials at a timescale of 100 years have also been discussed in the table.

**Table 1 Introduction to major GHGs:**

| GHGs | Pre-industrial concentration (ppmv) | Present concentration (ppmv) | Share in Green House Effect (GHE) | Global Warming Potentials (100 year time horizon) |
|---|---|---|---|---|
| **$CO_2$** | 280 | 370 | 60 | 1 |
| **$CH_4$** | 0.8 | 1.75 | 20 | 21 |
| **NOx** | 270.68 | 314 | 4-6 | 6500-9200 |
| **CFCs** | In traces | In ppt* | 12 | 7525 |
| **HFCs** | In traces | In traces | 2 | 140-11700 |

* Concentration is in parts per trillion

## 1.1 National Electricity Profile

Presently India have total installed capacity of electric power generating stations under utilities as 1,08,000 MW of which thermal (coal, gas and oil) power accounts for nearly 76606.91 MW, Hydel sector 15000 MW, Nuclear 2720 MW and wind power accounts for 1735.66 MW. India's main energy resource is Coal since it is cheap & available in huge quantity. India have energy and peak shortages touching 9.3 and 12.3 percent respectively.

Per capita electricity consumption in India is 350 kWh/annum. India with almost one-fifth of the world's population and acquiring 2.4 percent of the world surface area of 135.79 million square kms., ranks among the world's ten major contributors to the global climate change. The growth rate of population i.e., 1.9 percent is more than the growth rate of world (1.4%) as well as the China (1%) which is most populated country in the world. Increase in energy demand, population and industrialization are few indicators, which indicate that Indian energy sector like other Asian countries (especially China, Indonesia and Thailand) is among the fastest growing sources of fossil $CO_2$ emissions in the world.

The national demand for electric power is likely to grow at a rate of 9 percent per annum in the next decade with a requirement of over 15,000 MW of additional capacity every year to feed more than 1billion population.

## 2. Fossil fuel (Coal and Natural Gas) Reserves:

### *2.1 Coal reserve in India*:

India is the world's second most populous country and also the third largest coal producer, after China and US. Total coal reserves of India stand at about 202 billion tonnes, which is little less than 2.8 percent of the global coal reserve while the population of India is almost about 16% of the total global population. Coal resources are of varying quality. About 85% of the total coal reserve belong to the non-coking category and about 75 percent of the non coking coal aimed to produce in 1996-97, which belong to inferior grade (i.e., 'E', 'F' &' G') (Misra, Verma and Chakrabarti, 1997). Coal, as a fossil fuel, is widely distributed in whole of India's territory and mainly reserves are found in central and eastern region of the country. Bihar, Orrisa and Madhya Pradesh account for over $3/4^{th}$ of the total reserve. Lignite reserve in the country is 30.322MT and its production is 22 MT (Teddy 2000/01).

### *2.2 Natural Gas reserve in India:*

Indian reserve of natural gas is about 0.04% of the world proven reserves of HC and account for only 1% of the world's natural gas consumption. Prognosticated geological resources of HC in country are estimated at 21.31 billion tones of which 61% are offshore and 39% on land. Half of the prognosticated resources represent natural gas of which only 12% has till now been established. Of total power sector presently Gas based generation is over 12000MW (11% of the total installed base in country). The ratio of demand of natural gas from power sector to that from fertilizer plants will change from 0.32 to 1.89% indicating a major increase in demand from the power sector as against a stagnant demand from the fertilizer sector (www.gdib.org). India accounts for only 1 % of the world's natural gas consumption. Main reasons for the low share, in spite of high efficiency of natural gas are firstly, the coal is abundant and cheap, and secondly, the supply of indigenous natural gas is minimal.

## 3. Characteristics of Fossil fuels used for power generation:

### *3.1 Characteristics of Indian coal:*

The characteristic quality of the Indian coal is attributed mainly to its origin. Due to drift origin of Indian coals, inorganic impurities are intimately mixed in the coal matrix, resulting in difficult beneficiation characteristics. Indian coal seams are thick and highly inter-banded and mixing of such impurities with coal produced in most of the cases is inevitable. On characteristic analysis of Indian coal it was revealed that in general, it contains low sulphur (less than 0.6%) and chlorine content is less than 0.1% making it an ideal fuel for power generation purpose.

Table 2 Average characteristics of the Indian coal

| Coal Mines / Characteristics | Singareni | Kushmanda | Singrauli | Jharia | Neyveli | Total Average Value |
|---|---|---|---|---|---|---|
| **Proximate Analysis (%)** | | | | | | |
| Moisture | 9.6 | 10 | 12 | 13 | 42.52 | 17.42 |
| Volatile matter | 23.3 | 23 | 20.1 | 17.51 | 24.5 | 21.68 |
| Fixed carbon | 32.9 | 25 | 27.9 | 28.22 | 19.5 | 26.70 |
| Ash | 34 | 40.5 | 40 | 36.08 | 7.5 | 31.61 |
| Sulphur | 0.363 | 0.28 | 0.31 | 0.41 | 0.63 | 0.39 |
| HHV (kJ/Kg) | 4133.3 | 5590 | 3641.6 | 3300 | 2850 | 3902.98 |
| **Ultimate Analysis (%)** | | | | | | |
| $SiO_2$ | 59.35 | 61.3 | 60.73 | 57.64 | 65.2 | 60.84 |
| $Al_2O_3$ | 22.04 | 27.42 | 25.7 | 26.39 | 13.27 | 22.96 |
| $Fe_2O_3$ | 8.05 | 5.28 | 6.4 | 10.19 | 3.6 | 6.70 |
| $TiO_2$ | -- | 1.70 | 1.76 | 1.43 | -- | 1.63 |
| $P_2O_5$ | -- | 0.54 | 0.7 | 0.82 | -- | 0.68 |
| CaO | 5.57 | 1.42 | 1.2 | 1.78 | 11.2 | 4.23 |
| MgO | 2.26 | 0.97 | 0.93 | 0.60 | 5.0 | 1.95 |
| $SO_3$ | -- | 0.23 | 0.26 | 0.59 | 1.37 | 0.61 |
| $Na_2O_3$ | -- | 1.07 | 0.26 | 0.20 | 0.32 | 0.46 |
| $K_2O$ | -- | -- | 1.73 | -- | 0.04 | 0.88 |
| MnO | -- | 0.055 | -- | -- | -- | 0.05 |

Indian coal has high ash content and low calorific value. The ash of the Indian coal is refractory in nature, which is also considered as an advantage for its use in power plant. Quality has declined further with increase in the open cast mining. Washing of coal in the country is difficult because it contains near gravity impurities and existing coal beneficiation facilities are old and have low unit capacity. Average characteristics of Indian coal are given in table 2.

*3.2 Characteristics of Natural Gas*:

Natural Gas typical composition include 92.69% Methane; 3.43% Ethane; 2.18% Nitrogen; 0.71% Propane; 0.52% Carbon dioxide; 0.15% N-Butane; 0.12% Iso-butane; 0.11% Hexane; 0.09% Pentane, with GCV 38.59 $MJ/m^3$ and NCV being 34.83$MJ/m^3$. Characteristics study of the Natural Gas is presented in table 3. Natural Gas has zero $SO_x$ emission and is low on $NO_x$ and $CO_2$ emissions, making it a better environmentally benign fossil fuel than coal. In India natural gas is found both alone and along with crude oil.

**Table 3 Characteristics of Indian Natural Gas**

| **Characteristics** | **Natural gas** |
|---|---|
| Colour, Visual | Clear bright appearance |
| Colour, Saybolt | +10 |
| RVP (psi) | 10 |
| Octane Number | 127 |
| Specific $CO_2$ emission factor for electricity generation (kg $CO_2$/kwh Gas) | 0.65 |
| Sulphur (ppm) | 100 |

## 4. Methodology for calculating carbon dioxide emissions from fossil fuels combustion:

*4.1 Carbon dioxide emission from Coal based Power Plants (CBPP)*

The high heating value (HHV) of coal is related to its carbon content. The HHV of coal consumed in power sector was computed (i.e., 14838.80 kJ/kg), on the basis of average grade of coal consumed and in terms of its ultimate analysis using equation (A1). The equation (A2) used for total Carbon dioxide emissions, from Thermal Power Plants is based on input parameters and ultimate analysis of coal. Input parameters are coal consumed per annum, fuel device efficiency and carbon content of the fuel (Garcia, 2002).

$$HHV = 33950C + 144200(H_2 - O_2/8) + 9400S \qquad (A1)$$

where

C, $H_2$, $O_2$ and S are the values of C, H, O, S obtained from ultimate analysis of Coal.

$$Q_{CO_2} = C\,\rho\,\eta \qquad (A2)$$

where $Q_{CO_2}$ =Amount of carbon dioxide emitted MT

C = carbon fraction of the fuel

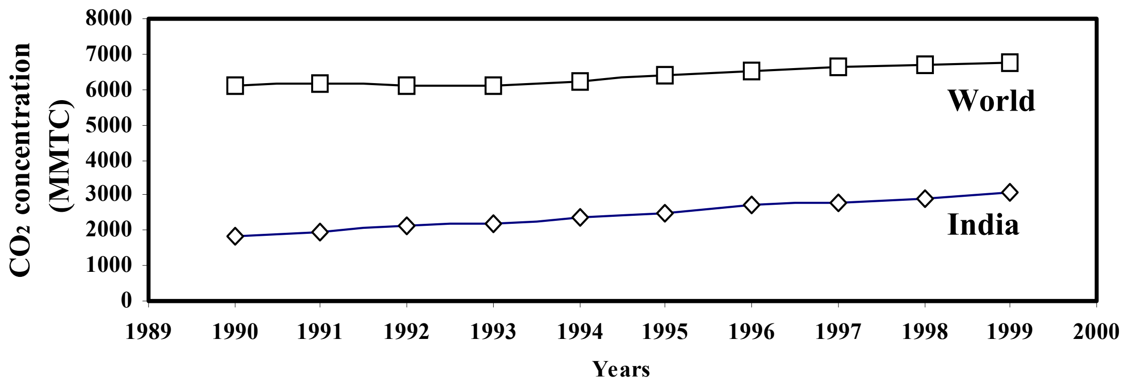
$\rho$ = amount of fuel consumed in the particular year, MT (per annum)

$\eta$ = Combustion efficiency of the fuel device

Of the total carbon burnt, Marland and Rotty (OECD, 1991), have estimated that about 1% escapes unoxidised. Specific emission factor for electricity production in India, from the hard coal have been computed to be 0.90kg $CO_2$ /kWhd. Power plants also use small quantities of diesel oil and furnace oil (FO) as supplement fuels, to boost the combustion and heat content. Generally this supplementary fuel combustion is 0.2 to 0.3 ml/unit of power and in old thermal power plants it may range from 1- 4% of the fuel consumed. Emissions from combustion of these supplementary fuels are not accounted for computation in the present communication.

Carbon dioxide emissions from fossil fuel (coal) combustion in India, during 1990-1999, have been compared with that of world in figure 1. Further it have been observed, that there is a continuous increase in the emissions along with the increase in fuel consumption, population, industries and time.

**Fig. 1 $CO_2$ Emission from Coal Cumbustion**




Power generating facilities in developing countries are often outdated and poorly maintained. Efficiencies in many countries including India, having PC boilers can be improved by 10 to 20 percent, which can lead to a reduction in carbon dioxide emissions of 20 to 60 percent. In India average net efficiency is approximately 26 percent and if these power stations work at design efficiency, increase in aggregate power output will be more than 15 percent emplying 12 percent decrease in $CO_2$ emission per kWh of energy generated and similar observation have been reported by (Kumar and Sinha, 1995).

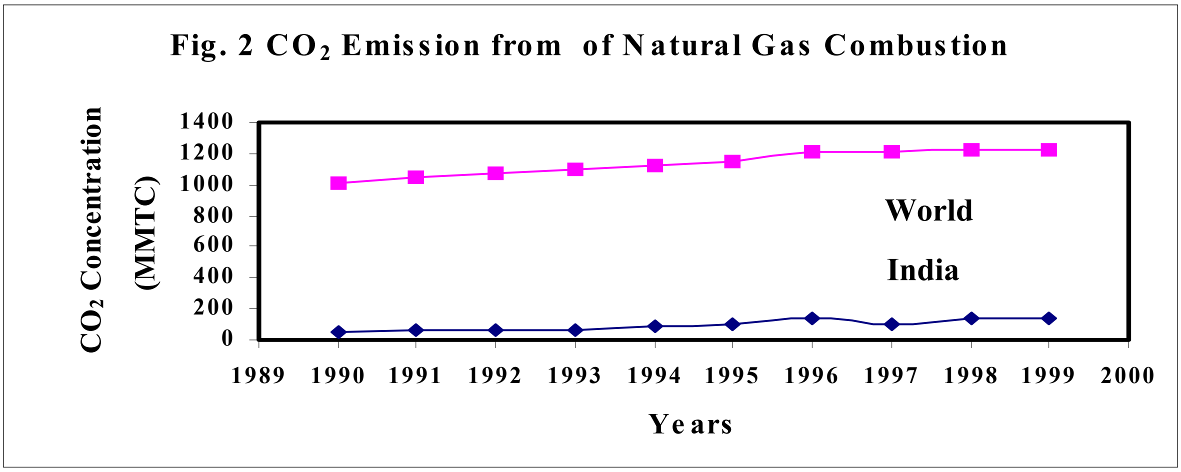
*4.2 Emissions ($CO_2$ and $CH_4$) from Natural Gas combustion Gas based Power Plants*

4.2.1 Carbon dioxide emission from Natural Gas based Power Plants (GBPP)

The emission of carbon dioxide were obtained by considering the input parameters as needed forA2. Average growth trend in consumption of Natural Gas was observed to be 7.31% for years 1996-1999.

In the total production in the country generally a part i.e., 12-14% is used for manufacture of the LPG. Of the remaining 69% is used for non-fuel purpose in fertilizer, petrochemical industry (TEDDY, 2000/01). Further, $2/3^{rd}$ of the carbonaceous matter gets oxidised in any particular year from fuel used for non-energy purpose (Ahuja, 1989). Also owing to incomplete combustion about 1% remain as soot in stack, while remaining get converted to $CO_2$ in the year of production itself (OECD, 1991).

The emissions, given in million metric tons of carbon (MMTC) are presented in fig. 2, are based on the natural gas consumption in gas-based system. There is an spontaneous growth in the year 1995-96 may be due to legal restriction made by Ministry of Environment and Forest (MoEF) for the emissions from power generations. An increasing trend in the carbon dioxide emissions with the increase in fuel consumption has been observed.




4.2.2 Methane emissions from Natural Gas based Power Plants (GBPP)

Natural gas usage is though considered to be environment friendly but $CH_4$ is having 25% more radiative force than $CO_2$. In our study we have assumed the gas based combustion systems to be highly efficient (60% to 65%), so it has been found that with the increase in the efficiency there is reduction in direct methane addition (5-20% of the total used as fuel) to the atmosphere.

Though Gas based systems have higher combustion efficiency but about 10% of natural gas get wasted before it goes to final consumption. The thorough study on methane emissions is still in process, so further results are not being presented here in this communication, but the ways by which methane can be added to atmosphere are discussed. It has been studied that Methane can be directly lost to the atmosphere during course of production, distribution and consumption of Natural Gas in four ways, firstly a portion of associated gas is vented intentionally during the process drilling; secondly some gas escapes unburnt when flared; thirdly leakage occurs from distribution lines, which account for bulk of loss of Natural gas and fourthly it is added to the atmosphere due to less efficient systems on combustion.

## 5. Possible technologies and sinks for reduction of Greenhouse gases

Advanced combustion technologies since have better efficiencies and better control options so can reduce the pollutant emission. As can be observed from the table 4, an appreciable reduction of $CO_2$ emission is projected in case of IG-MCFC technology as compared to conventional Pulverised coal (PC) technology, which is working on not more than 30% efficiency in Indian thermal power plants. Carbon dioxide, however, is not much reduced by using other advanced coal combustion systems, although there are advantages in SOx, NOx and particulate emissions ( Raghuvanshi, et al., 2003).

Energy related carbon dioxide and other greenhouse gases emissions can be reduced by lowering carbon intensity of the energy sources employed (fuel switching from coal to natural gas), increasing generation and supply efficiency, Carbon dioxide capture and disposal or switching to non-fossil fuel energy sources like solar, hydro and wind energy. Conventional natural gas however, is far less abundant than coal and a switch might not be sustainable for very long. An alternative substitute fuel should have other equivalent properties, which presently natural gas have, like it is easy to transport and storage, and also it is comparatively clean providing heat more efficiently with low level of pollution emissions ([+]Raghuvanshi et al., 2003).

**Table 4 Comparison of Pollutants Emission and Efficiencies in Advanced Technologies**

| Technology | Expected Efficiency (%) | Expected $CO_2$ Emissions (kg/kWh) | $NO_2$ Emission (g/kWh) | Sox Emission (g/kWh) | Particulate Emission (g/kWh) |
|---|---|---|---|---|---|
| **PFBCC** | 38.09 | 0.911 | 1.42 | 0.029 | 126 |
| **IGCC** | 36.8 | 0.921 | 0.43 | 4.0 | 9.5 |
| **IG-MCFC** | 46.30 | 0.778 | 0.096 | 0.096 | 6.2 |
| **PC Boiler/ Steam turbine** | 31.50 | 0.930 | 9.6 | 3.0 | 205 |

Options to reduce GHGs (greenhouse gases) emissions, depend mainly on economic growth and the development of energy efficiency of economic wide production systems. There are various sinks available which are classified in figure 3.

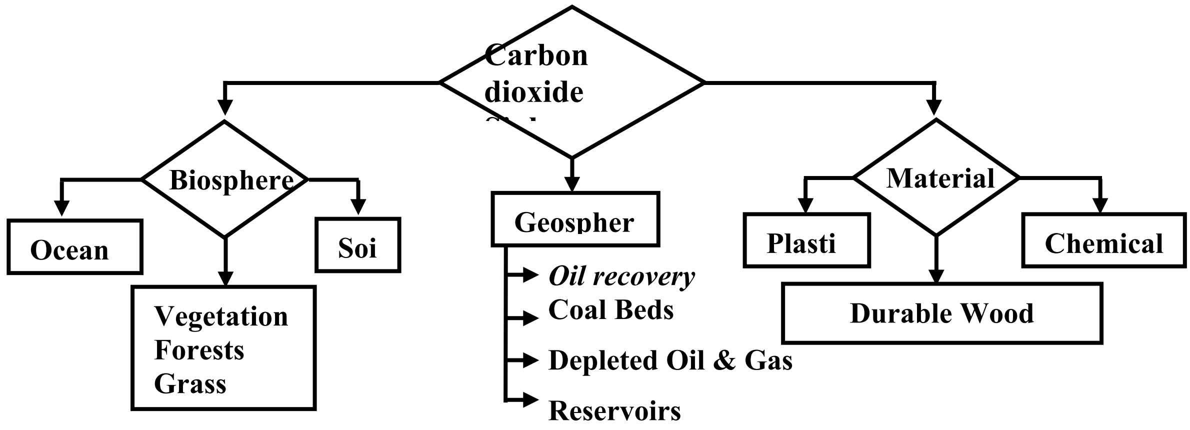



Fig. 3: Carbon dioxide sinks-classification

**Conclusion**

Efficient systems and switching to less carbon intensive fuels are the need of present day power generation systems. It is possible to study this effect from the point of view of greenhouse gases mitigation strategies which should also include the possible sinks of these gases. Energy planning and management, demands not only an adequate energy supplies but also a consideration of environmental pollution.

**References:**


1.Misra B. C., Verma S. K. and Chakrabarti R. K., 1997, *"Clean Coal technology- Indian context"* Indo-European Seminar, pp, 11.3.1-11.3.5.

2.TERI Energy Data and Directory Year book (TEDDY), 2000/01. Coal & Lignite. pp, 23.

3.www.gdib.org/Sgasgrid/DemandsupplyScenario.htm

4.Garcia I. and Zorraquino, J. V. M., 2002, Energy and environmental optimization in thermo -electrical generating processes-Application of a carbon dioxide capture system, *Energy,* 27, 607-627.

5.Organisation of Economic Co-operation and Development (OECD), 1991. *Estimation of GHG and sinks.* Final report from the OECD experts meeting 18-21 Feb 1991, prepared for IPCC.

6.Kumar S. and Sinha S. 1995. Non- $CO_2$ Emitting Renewable Energy Source in India: Paths, Realisable Potential And Requirement Of Industry Related Forestry Pattern. *Energy Conversion Mgmt,* 36(6-9), 885-888.

7.Ahuja, D. R., 1989. *Anthropogenic emissions of Greenhouse Gases.* Washington Office of Policy Analysis, USEPA.

8.Raghuvanshi S. P., Chandra A. and Raghav A. K., 2003, Carbon dioxide emission from Power sector in India, Proceedings of National Conference on Advances in Civil Engineering: Perspectives of Developing Countries, (APDEC), 2003, Kanpur, India.

9.[+]Raghuvanshi S. P., Raghav A. K., Chandra A. and Singh R., 2003. Greenhouse Gas: Carbon dioxide emission inventory from combustion of fossil fuels in Power Sector in India, Proceedings of World Climate Change Conference 2003, Moscow, Russia, pp. 557.

**Additional Author's information**

1. *[a] Shiv Pratap Raghuvanshi, c/o Dr. A. K. Raghav
Department of Applied Mechanics, Indian Institute of Technology Delhi,
Hauz Khas, New Delhi, India [110016].
E. mail: spraghuvanshi@yahoo.com, Fax No. +91 11 26581121; Phone: +91 9818604170.

2. [b] Renu Singh, c/o Prof. A. Chandra
Centre for Energy Studies, Indian Institute of Technology Delhi,
Hauz Khas, New Delhi, India [110016].
E. mail: renusinghsingh@yahoo.com
Fax No. +91 11 26581121; Phone: +91 9818419104.

3. [c] Dr. A. K. Raghav, Department of Applied Mechanics,
Indian Institute of Technology Delhi, Hauz Khas, New Delhi, India [110016].
E. mail: akr@am.iitd.ernet.in; akraghava@yahoo.com
Fax No. +91 11 26581121; Phone: +91 11 26591227, +91 9810983262.

4. [d] Prof. A. Chandra, Head, Centre for Energy Studies,
Indian Institute of Technology Delhi, Hauz Khas, New Delhi, India [110016].
E. mail: chandra@ces.iitd.ernet.in; achandra45@yahoo.com
Fax No. +91 11 26581121;Phone: +91 11 26596319.