"A Study on Performance Evaluation of Kerosene Genset on Natural Gas"

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MASTER OF TECHNOLOGY
IN
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by

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CERTIFICATE

This is to certify that the thesis entitled "**A Study on Performance Evaluation of Kerosene Genset on Natural Gas**" submitted by ***V.V.S.Chalapathy Rao Tenneti*** in partial fulfillment of the requirements for the award of the degree of Master of Technology (Gas Engineering), at College of Engineering, University of Petroleum and Energy, is a record of the work carried out by him at Indian Institute of Petroleum, Dehradun under my guidance and supervision.

To the best of my knowledge, the contents of this thesis did not form a basis of the award of any previous degree or published material by any one else.

The work is comprehensive of sufficient standard and here by recommended for the award of the degree of M. Tech. in Gas Engineering.

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This work is certified as bonafide.

15/03/06

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Executive Summary

Saving energy and keeping the environment clean are the two major challenges of 21st century also increasing crude oil prices has forced us to look for alternative sources of fuels which can generate energy more efficiently, more economically, while limiting environmental pollution to a minimum & with minimum modifications to the existing systems.

At present Natural gas looks to be the best solution to these problems, which is a cleaner burning fuel & its greater availability.

Due to the ever increasing demand for power for a developing economy like ours, where there is a big difference between demand and supply. There is acute power shortage in several states which resulted in large proliferation of small portable generator sets in the medium to large cities causing severe air pollution problem in the shopping and residential areas.

In this project, A Genset is tested using compressed natural gas (C.N.G) by making the required changes, which is generally run on Kerosene. The Performance Characteristics & emission levels for both fuels where compared.

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1.0:: Introduction:

Energy has been a big, innovative business almost forever. In fact, nature made revolutionary energy devices long before humans entered the scene. For humans, the first giant step was, of course, capturing fire. Fire solved problems of the cold and the dark, and vastly extended human range and the food supply.

The energy system relied on carbon, as it had since the wood fire in the Escalecave near Marseilles more than 750,000 years ago[1]. Wood effectively burns about 10 carbons for each hydrogen atom.

Early 19^{th} century growth of cities and their interactions with one another and the hinterland pose the most difficult technical problems of communication, transport, and other needs and focus there sources to solve them. Wood and hay, the prevalent energy sources are bulky and awkward to transport and store. Around 1900, Biomass gradually lost the competition with coal as fuel. Coal has become the primary energy source as it is available in large quantities around the world. Disadvantage is that when burnt carbon becomes soot or the greenhouse gas CO2, and hydrogen becomes water (H2O), carbon is basically a dirty element.

In coal powered automobiles weight and volume of the fuel were hard problems, especially for a highly distributed transport system. Oil had a higher energy density than coal-and the advantage of flowing through pipelines. These reasons led to use of energy system based on fluids which evolved around 1950's and Crude oil as became World's leading primary energy source.

Presently, Crude oil forms the 38 % of the World Energy mix (Fig No: 07). As any fossil fuel it is also finite .After mid 1980's there are no major oil discoveries; with depleting reserves; Increasing price of crude oil (which is presently around $ 70) and with ever increasing demand for energy from developing nations like India & china and also from an environmental point of view, the widely use of fossil fuels as a primary energy source resulted in large emissions of pollutants affecting the natural and human environment in various ways. In particular, the emission of greenhouse gases and their contribution to the global warming are frequently discussed issues.

The transport sector depends on oil to roughly 98% and the demand will grow the most rapidly of all end-use sectors, especially in the developing countries like China, India, and other countries may rapidly recapitulate the energy history of the already rich countries on a large, destructive scale.

So, considering the above factors we are forced to look at alternative sources of fuels to meet the demands from Transport & Power sectors which are the major consumers.

"Hydrogen" is considered as the future fuel, as it is a clean burning fuel with water as end product.

World over various countries taken up R& D activities related to hydrogen generation, storage & application technologies including fuel cells have been pursued. Indian Government also came up with the "Hydrogen road map for India".

H_2 as a source of fuel will not be available in the near future for a large number of customers, so the focus must be on optimizing the combustion engine in use today. By doing so the objective must be to run them in the medium term, on Alternative, highly efficient, sources of fuel. This is the only way to ensure the effective use of available resources in the coming decades & bridge the gap until the ultimately global use of H_2 fuel cells.

Methanol, Ethanol, Natural Gas, Bio-diesel, and DME are some of alternative fuel which are being used. Ethanol blended gasoline is very successful in Brazil. India also taken steps to implement Bio-diesel which is produced from Jatropha &

Ethanol blended Gasoline, which is produced from sugar cane.

Among these natural gas has emerged as the best alternative fuel, with substantial reserves available at or nearer to the places of demands & another main factor is when used as a fuel for IC engines it produces much less emissions than Gasoline or Diesel engines. So, it is considered as fuel of 21st century.

World over natural gas as been used as a fuel for transportation & power generation. Indian itself there are around 2.5 lakhs of NGV's (Natural gas vehicles).

India which ranks 5th position in terms of energy demand and having a per capital consumption of 304 kgoe (kilograms of oil equivalent). With an economic growth rate at around 7-8 %, it is estimated that energy demand will increase at a rate of 2-3 % annually and also since India being a crude oil deficit nation with around 70% demand met with imports [2]. To meet the future demand government has taken various measures like stepping up the domestic exploration activity using NELP (New Exploration and licensing Policy), after five round of NELP reserves estimated at 700 MMt of oil & gas have been discovered, also ONGC overseas arm OVL have acquired overseas oil & gas producing fields and also looking for alternative sources of energy like natural gas which is discovered in large quantities recently and also proximity to Middle East which has huge reserves. Presently share of natural gas is about 9% of total energy mix in India and it will increase to 20 % by 2025, with bulk of consumption from power, fertilizers, transportation & other industries, this share will increase further.

In power sector, Central Electricity Authority (CEA) has estimated that India needs a Capacity addition of about 61,000 MW during 11th plan period (2007-12) to meet the All-India peak demand of 1,57,107 MW and energy requirement of

9,75, 22 MkWh at the end of 11th plan (2011-12). So the generation needs to be increased to 212,000 MW by 2012.

About 40 % of world electricity is produced using primary energy sources such as coal, thermal, fossil fuels. In India using these sources for meeting the future demand will be an up hill task. Natural gas based power plants evolved over few decades, have the advantages like high efficiency, less gestation period, less emission. Around 53 gas-based power plants will be there end of the 10 th five year plan.

As per the 10th Plan, the total gas based power generation capacity in the country would be to the tune of 15609.42 MW, an increase of 5273.8 MW. The aggressive growth would continue in the 11th Plan as well. The Government of India has set a target of 13704 MW at the end of 11th Plan, March 2012.

Presently there is big gap between demand supply this led to acute power shortage in several states in India has resulted in use of small portable generator sets in the cities & rural areas causing severe air pollution problem in the shopping and residential areas. Which are increasing the pollution levels in big metros, which are highly polluted.

Central pollution control board of India has come up with Regulations for emissions from generators. To meet present and future standards we need to look for other fuel sources and better technologies.

Natural gas has been particularly significant as a fuel for prime over powering electric generators in the electric utility, Commercial & industrial cogeneration sectors. Through this project we have tested Genset with Natural gas as a fuel.

2.0:: Air pollution in urban areas:

The growth of population plus the growth in energy consumption per person have combined together to give dramatic increases in both air & water pollution problems, especially in urban areas.

Three broad sources of air pollution are stationary or point, mobile, and indoor. In developing countries especially in the rural area, indoor air pollution from using open fire for cooking and heating may be serious problem. Industries, power plants e.t.c are the cause of stationary air pollution. But in urban areas both developing and developed countries, it is predominantly due to I.C Engines which are used in automobiles, stationary units (generator).

In Delhi, the data shows that of the total 3,000 metric tones of pollutants belched out everyday, close to two-third (66%) is from vehicles. Similarly, the contribution of vehicles to urban air pollution is 52% in Bombay and close to one-third in Calcutta.

The worst thing about pollution from IC engines is that it cannot be avoided as the emissions are emitted at the near-ground level where we breathe. The pollution from engines are due to discharges like CO, unburned HC, Pb compounds, NOx, soot, suspended particulate matter (SPM) and aldehydes, among others, mainly from the tail pipes.

The different air pollutants due to vehicles can have effects at all the three levels – local (e.g., smoke affecting visibility, ambient air, noise etc.), regional (such as smog, acidification) and global (i.e., global warming). The vehicles besides being the prominent source of air pollutants also account for a number of external effects, such as congestion, noise, accidents, road wear and tear, and 'barrier effects'.

Emissions from IC Engines are generally low, since they are used in large numbers in cities in automobiles & stationary units they are the major polluters of urban air.

If perfect combustion takes place in an IC engine end products will be CO2, H2O, and unburned N2.

Fuel (H-C) + Air (O2 +N2) $\longrightarrow$ CO2 +H2O + Unburned N2

Since use of additives like sulphur in fuel, short combustion time for chemical oxidation processes, rapid variation in temperature leads to the formation of some unwanted compounds & also incomplete combustion products are oxides of N2 formed due to high temperature oxidation of the N2 present in air fuel mixture.

Fuel (H-C) + Air (O2 +N2) $\longrightarrow$ Unburned H.C +NOx +CO+CO2 +H2O + Other pollutants.

2.1:: Emissions from a typical automobile / I.C Engines can be classified according to the source of emission:

1) Tail Pipe Emissions:

a) HydroCarbon Emissions (H.C):

H.C emissions result when fuel molecules in the engine don't burn (or) burn only partially, H.C include a wide variety of compounds with varying impact on human health. In particular, unburnt H.C contains a large proportion of CH_4 which is inert in human health respect. Added to these are the oxygenated compounds, Aldehydes, ketones. Phenols, Alcohol, Ester e.t.c, all of which are more reactive than methane, a number of this H.C are also toxic, with a potential to cause cancer.

H.C reacts in the presences of NO & Sun light to form ground level Ozone, Major component of smog. It is one of the main urban air pollution problems.

H.C in C.I Engines:

As the fuel is present in combustion chamber for a very short duration. This is the main reason for lower level of unburnt emissions from diesel engine.

H.C emissions can form due to

1_Emisiions by too lean mixtures

2_Emisiions by too rich mixtures

3_Flame quenching and misfire

b) Nitrogen oxides (NOx):

Under high pressure & temperature conditions in an engine, N_2 & O_2 atoms in the air react to form various nitrogen oxides. Nitric oxides & NO_2 are the main oxides formed during this reaction and are collectively grouped together as NOx, in which NO largely predominates. The main source of NO is molecular N2 in the air used as a combustent feeding the engine. Gasoline & diesel fuels contain too little nitrogen for their contribution to NO formation to be significant .Like HC, NOx are precursor to the formation of O_3 .They also contribute to the formation of acid rain.

NOx from S.I Engines:

High temperature and availability of O_2 are the two most important reasons for the formation of NOx. When proper amount of O_2 is available, the higher the peak combustion temperatures, the more is the NO formed .The NOx is formed in the atmosphere as NO oxidizes.

The most important factors governing NO emissions are the Fuel –Air ratio, the fraction of burnt gases within the unburnt mixture in the cylinder and the ignition timing.

NOx from C.I Engines (NOx):
Quantity of NOx varies from a few hundred to well over 1000 ppm in diesel exhaust.

c) Carbon Monoxide:

CO is a product of incomplete combustion and occurs when carbon in the fuel is partially oxidized rather than fully oxidized to CO_2. The main parameters governing CO emissions are the Fuel –Air Ratio. In a rich mixture, the CO concentration increases steadily with the Fuel –Air ratio and the lack of O_2 causes incomplete combustion.
CO reduces the flow of O_2 in the blood stream.

CO in S.I engine:

Some CO emissions are always there from a S.I engine in all operating condition, CO levels in engine exhausts are always lower than the maximum values present in the combustion chamber. It has also been found that in general CO emissions are very high in few specific operating conditions in a S.I engine like, engines running at A-F ratio of one during partial load, engines running at A-F ratio of one during partial load, engines running at full load with rich mixtures, starting of SI engine using choke e.t.c.
The means applied so far to reduce CO emissions consist of mainly improving the uniformity of the composition of Air –Fuel mixture & making the mixture leaner

CO in C.I Engines:

As it runs on lower overall lean mixture .CO emissions are much lower than petrol engine.

d) Carbon Dioxide:

CO_2 is a product of perfect combustion process, but is a Green house gas that traps the earth's heat & contributes to the Global warming.

e) Suspended Particulate Matter (SPM):

Diesel particulate matter is generally defined as any material that is collected on a filtering medium at a temperature of 52 degrees centigrade (or) less after dilution of raw exhaust.

Diesel particulate are composed of a carbonaceous material (soot) generated during combustion, on which various organic species (SOF) are absorbed.

Diesel engines produce more particulate emissions than do petrol engines with or without catalytic converters.

Soot particles are primarily produced from the carbon contained in the fuel and depend on the type of fuel, the number of carbons in the molecule, and the carbon/H2 ratio.

Soot emissions from diesel engines mainly arise from three processes occurring partly in parallel.

SPM is emerging as one of the most serious problems in India with regard to air pollution. There is a growing concern all over the world about particulate matter of size 10 microns & 2.5 microns (PM 10 & PM 2.5) or less.

2) Evaporative emissions:

H.C pollutants also escape into the air through fuel evaporation. Around 15 to 25 percentage of total H.C emissions are from gasoline engine.

2.1.1:: Main factors for Emissions:

In proper combustion due to

1) Quenching effects.
2) Imperfect Air – Fuel mixture ratios.

Other factors like:

1. Design of engine
2. Internal geometry
3. Running conditions
4. Effect of deposits
5. Post oxidation of hydrocarbons.

2.1.2:: Control Techniques:

To reduce these emissions the exhaust gas need to be treated before leaving into atmosphere. For this exhaust after treatment systems are developed, which are probably the single most important area of emissions control development.

To meet the present emission norms, almost all the vehicles need some or other type of pollution control equipments.

Some of the equipments that are commonly used are:

1) **Catalytic Converter**:

It is the most important after treater. It is basically a cylindrical (or) metal. The substrate is made up of hundreds of very small, but long cells configured in a shape similar to honey comb. The substrate is coated with a substance containing precious metals, rare earth metals and base metal oxides that are known as the catalyst wash coat.

Generally a three-way Catalytic Converter is used in preset day vehicles.

2) **Exhaust Gas Recirculation system (EGR):**

One of the most effective means of reducing engine –out NOx emissions is exhaust E.G.R. By recalculating spent exhaust gases into the Catalytic Converter, the Air –fuel ration is diluted, lowering peak combustion temperature & reducing NOx.

3) **Particulate Trap:**

These can eliminate upto 90 % of diesel Particulate Matter emissions and is the most effective control system available today for design. These are located in the exhaust muffler.

4) **Oxygen sensor:**

Monitors the O2 content in the exhaust and provides this information to ECM to make necessary correction in Air / Fuel ratio to obtain Maximum conversion of pollutant in the Catalytic Converter.

In future, the number of automobiles is going to increase to such an extent that despite the maximum technology possible reduction in emissions from the conventionally fueled I.C engines, air pollution from vehicles will remain a highly potent threat to the public health. Also to meet the future emission standards laid for Automotive, Bharat stage –III & Bharat –IV (table: 01,02) which are shown in the next page) for various light duty & heavy duty vehicles and for Stationary engines used to run generators Central Pollution Control Board came up with Emissions standards (particularly for petrol & kerosene run gensets).

So, only option is alternative fuelled vehicle, with which the dream of producing zero emissions vehicles become real.

Table No:01

Euro & Bharat Emission Norms:

INDIAN AND EUROPEAN VEHICLE EMISSION NORMS

Vehicle Category and Emissions		Euro-I 1993	Euro-II 1996	Euro-III 2000	Euro-IV 2005
		India 2000	Bharat *- II (2000)	Bharat * Stage-III(2005)	
GASOLINE CARS					
CO	g/Km	2.72	2.20	2.30	1.00
HC+N0x	g/Km	0.97	0.50	0.2+0.15	0.1+0.08
DIESEL CARS					
CO	g/Km	2.72	1.0	0.64	0.50
HC+N0x	g/Km	0.97	0.7(IDI) 0.9(DI)	0.56	0.30
PM	g/Km	0.14	0.08	0.05	0.025
DIESEL HEAVY DUTY					
CO	g/KWh	4.5	4.0	2.1	1.50
HC	g/KWh	1.1	1.1	0.66	0.46
N0x	g/KWh	8.0	7.0	5.0	3.5
PM	g/KWh	0.36	0.15	0.10	0.02

Table No:02

INDIAN AND EUROPEAN VEHICLE EMISSION NORMS

Vehicle Category and Emissions		India 2000	India 2005	India 2008
GASOLINE TWO WHEELERS				
CO	g/Km	2.0	1.5	1.0
HC+N0x	g/Km	2.0	1.50	1.0
GASOLINE THREE WHEELERS				
CO	g/Km	4.0	2.25	1.25
HC+N0x	g/Km	2.0	2.0	1.25
DIESEL THREE WHEELERS				
CO	g/Km	2.72	1.0	0.50
HC+N0x	g/Km	0.97	0.85	0.50
PM	g/Km	0.14	0.10	0.05

1. *Implemented Only in the Metro Cities!
2. Norms still under discussion ; Indian Driving Cycle;With D.F

Table No: 03

EMISSION STANDARDS (G/Kw-hr) FOR NEW GENSETS (UP TO 19 KILOWATT, KEROSENE AND PETROL BASED) WITH IMPLEMENTATION SCHEDUL

A. From June 1, 2000

Class	Displacement (cc)	CO (g/kw-hr)		HC + NOx (g/kw-hr)	
		2-stroke engine	4-stroke engine	2-stroke engine	4-stroke engine
1	<65	603	623	166	65
2	>65<99	-	623	-	36
3	>99<225	-	623	-	19.3
4	>225	-	623	-	16.1

B. From June 1, 2001

Class	Displacement (cc)	CO (g/kw-hr)	HC + NOx (g/kw-hr)
1	<65	519	54
2	>65<99	519	30
3	>99<225	519	16.1
4	>225	519	13.4

C. Test method shall be as specified in SAE J 1088. Measurement mode shall be D1 cycle specified under ISO 8178 (weighting factor of 0.3 for 100% load, 0.5 for 75% load and 0.2 for 50%load)

D. Following organizations are recommended for testing and certifying the genets:

i. Automotive Research Association of India, Pune
ii. Indian Institute of Petroleum, Dehradun
iii. Indian Oil Corporation (R & D Centre), Faridabad
iv. Vehicle Research Development Establishment, Ahmednagar

Source: [3]

3.0:: Natural gas:

Extracted from underground reservoirs, natural gas is a fossil fuel composed primarily of methane (about 85-99%), along with other hydrocarbons such as ethane, propane, butane and inert gases such as carbon dioxide, nitrogen and helium.

Table No: 04 **TYPICAL COMPOSTION OF NATURAL GAS:**

COMPONENT	%
METHANE	70-98%
ETHANE	1-10%
PROPANE	5%
BUTANE	2%
PANTANE +	1%
NITROGEN	TRACE-1.5%
CO2	1%
H2S	TRACES

Methane is a hydrocarbon whose molecules are made up of hydrogen and carbon atoms. The simple, one carbon, molecular structure of methane gives a nearly complete combustion of natural gas. Because of its clean burning nature and the fact that it is not extracted from petroleum, many automakers around the world are developing vehicles to run on natural gas. Cars, vans, buses and small trucks generally use natural gas that has been compressed (called compressed natural gas) and stored in high-pressure cylinders. Natural gas turns into liquid for easy storage or transport by extreme cooling to -327.20 F (-1640 C). Liquefied Natural Gas (LNG) is almost pure methane and has the energy storage density much closer to gasoline than CNG. Several vehicles available today operate on CNG, out of which some run on natural gas only and others can run on natural gas or gasoline (called bi-fuel vehicles).

Natural gas has been particularly significant as a fuel for prime over powering electric generators in the electric utility, Commercial & industrial cogeneration sectors.

New opportunities for Natural gas are being developed stimulated by energy security concerns, trade imbalances, created by petroleum imports and abundance of Natural gas.

3.1:: AS A FUEL FOR INTERNAL COMBUSTION ENGINES:

As natural gas is extremely low photochemical reactivity, non-toxic, high Ignition temperature & good anti-knocking properties, high Octane number (RON-130).

Use of Compressed Natural Gas (CNG) as a fuel will lead to longer engine life and reduced maintenance cost and increase in life of spark plug.

Natural gas is normally used like gasoline in spark-ignition engines with a conversion kit. Diesel engines can also be easily converted to gas operation. Unlike diesel, however, natural gas hardly ignites in a compression-ignition engine due to its higher self-ignition temperature. Using natural gas in a retrofitted diesel engine therefore requires a separate spark plug ignition. Another possibility is the conversion of the CI engine into an SI engine.

Most of the vehicles used today are bi-fuel Natural Gas Vehicles (NGVs) with two separate fuelling systems that enable the vehicle to use either natural gas or gasoline. On the other hand, dedicated NGVs are designed to run on natural gas only and, show better performance and lower emissions.

For medium or heavy-duty operations, diesel engines are normally chosen and converted to natural gas engines.

Natural gas has a higher net calorific value than gasoline and diesel, but the volumetric energy density is much lower due to the low density of natural gas.

Therefore, natural gas is usually stored pressurized at 200 bars and ambient temperature on board an NGV. The range of NGVs is small due to the extra weight and space required for storage tanks this lead to reduced fuel storage by energy of some 50–60% between CNG and gasoline operation.

The performance and emission characteristics of NGVs on light-duty vehicles without further adjustments of engine parameters, a power loss up to some 20% can be expected when switching from gasoline to natural gas due decreased in Volumetric efficiency & loss of power due hardware of conversion kit.

The energy of the air/fuel mixture is somewhat lower for natural gas than for gasoline considering stoichiometric mixtures due to a lower density of the mixture and a higher stoichiometric air/fuel ratio.

The cycle efficiency is influenced by the lower flame speed when switching from gasoline to natural gas, which increases the combustion duration and consequently results in a reduction of the cycle efficiency. In other words, the lower burn rate leads to a combustion that is spread over a greater crank angle interval.

An improvement on engine performance can be achieved by some simple modifications like advanced ignition timing according to the lower burn rate leads to a complete combustion within the correct portion of the engine cycle. As natural gas has a higher knock resistance than gasoline due to higher ROG which allows combustion at higher compression ratios, and also improves both engine efficiency and power output. Another method is direct injection (DI) of CNG.

NGVs can not optimally use the advantage of higher compression ratios in order to increase the engine performance, since most of the present NGVs are equipped with bi-fuel engines and, hence, limited by the lower knock resistance of gasoline. As a result, the power output of bi-fuel engines generally decreases by some 10% when switching to natural gas.

Emissions from a natural gas engine are very low compared to Gasoline & Diesel engines.

The group of unburned hydrocarbons consists of methane (CH_4) and Non-methane hydrocarbons (NMHCs). Unlike the unburned hydrocarbons from gasoline, the unburned hydrocarbons from natural gas mainly consist of methane (approximately 85%). Methane has a very stable molecular structure and is, therefore, more difficult to convert in a conventional gasoline catalyst. As a result, methane emissions from gasoline vehicles converted to natural gas can be relatively high as the catalyst converter is not optimized for Gasoline only.

CO and HC emissions are the result of an incomplete combustion of the fuel .CO production is strongly a function of the air/fuel ratio. HC is influenced due to the oxidation. Higher temperatures support higher oxidation rates and consequently lead to reduced HC emissions. Methane which is main constituent of CNG is baring only one Carbon atom to four Hydrogen atoms .so, it is a carbon poor fuel ,which is the reason for low CO & CO2 emissions than those from a comparable engine running on gasoline. On the other hand, the slow reaction and low burning velocity of natural gas might also lead to a combustion that could not be completed before the exhaust valve opens and, thus, contribute to higher emissions.

The formation of NO_x during the combustion process primarily depends on combustion parameters like the reaction temperature, reaction duration and availability of oxygen. An increase of any of these parameters leads to an increase in NO_x emissions.

NO_x can be higher from an engine running on natural gas than the same one running on gasoline because of the higher in-cylinder temperature and longer duration of the combustion. This can be overcome by advanced ignition timing in order to increase the engine performance or by using Exhaust Gas Recirculation (EGR).

Compared to gasoline vehicles, the range of NGVs is normally restricted and the power output somewhat lower, whereas the efficiency tends to be slightly higher. HC and NO_x emissions from dedicated NGVs are generally lower, whereas bi-fuel NGVs tend to have higher emissions.

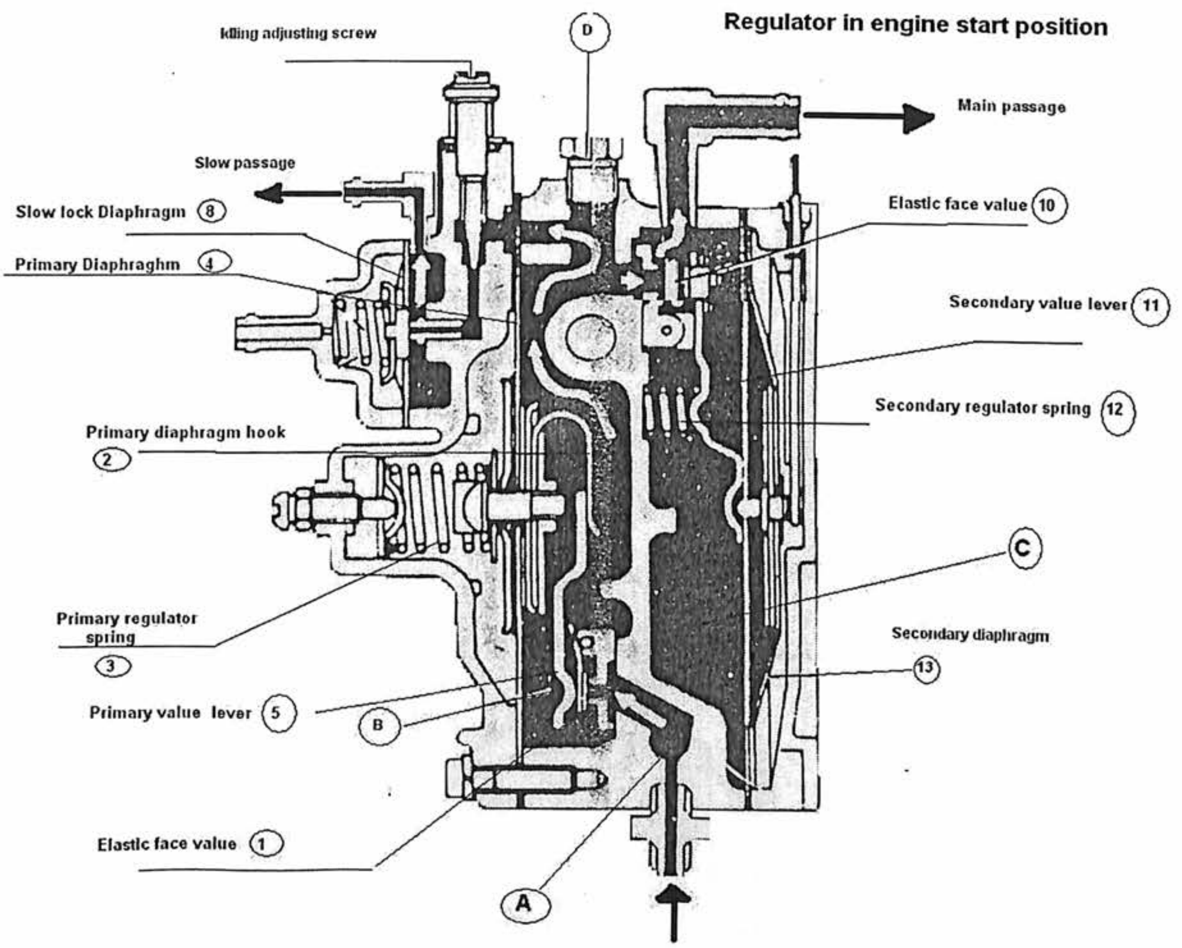
Compared to diesel vehicles, both dedicated and bi-fuel NGVs normally show lower HC and NO_x emissions. In general, emissions of CO and CO_2 are lower for NGVs.

Main disadvantage with Natural gas is low flame speed compared to gasoline which leads to slow combustion process, improper combustion. This draw back has been rectified using Hydrogen, which has high Flame propagation speed.

4.0:: Regulator for CNG fuel system:

It is the important part the conversion kit, to run an engine on CNG. It called the "**Heart**" of the system.

Fig No: 01



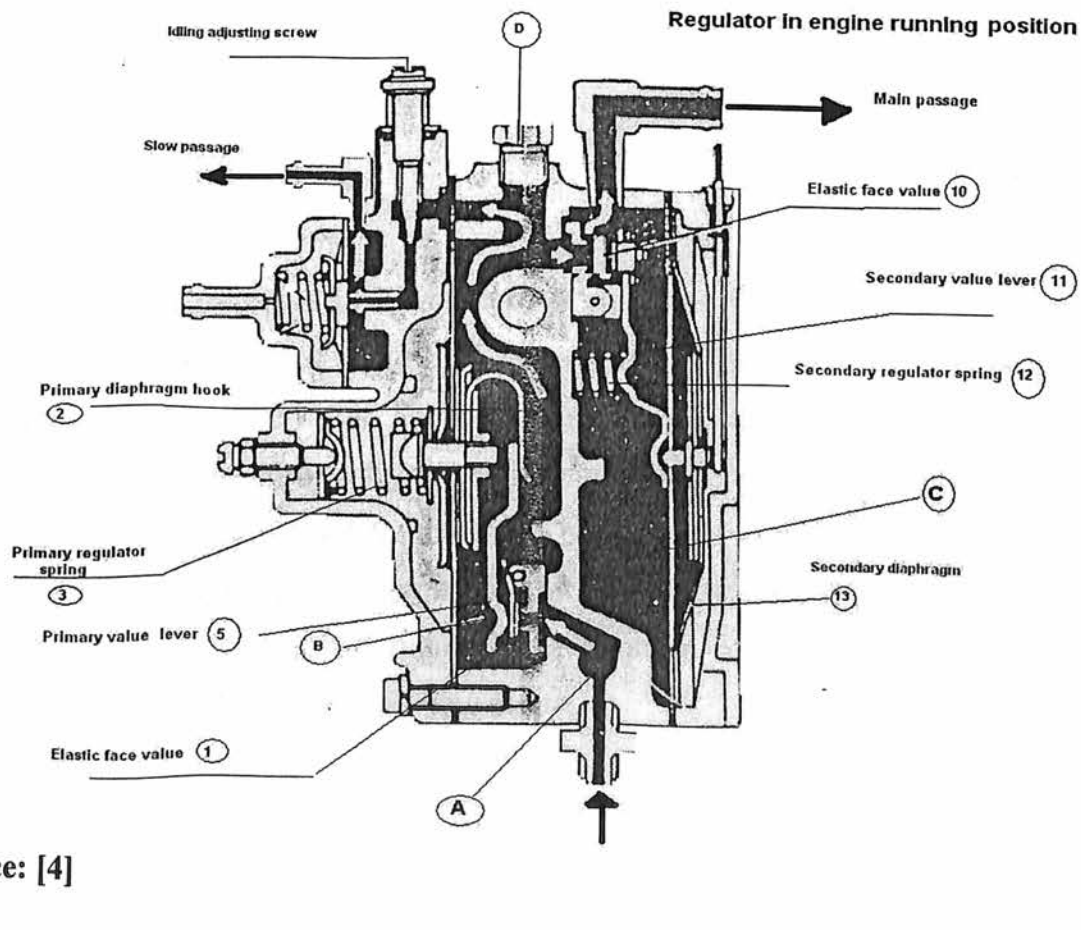
Source: [4]

When starting the engine using CNG regulator functions as follows:
When turning "ON" the ignition switch and the CNG regulating valve, CNG introduced into the chamber "A" pushes open the elastic face value "1" with its own vapor pressure to enter the primary reducing chamber"B" and the slow path "D" to be reduced & evaporated there. When pressure in the primary reducing chamber " B" reaches 0.25-0.35 Kg / Cm2.The primary diaphragm "4" pushes the

primary regulator spring "3" to operate the primary value lever "5" by the primary diaphragm hook "2" in order to close the elastic face value "1" and to keep the pressure in the primary reducing chamber "B" constant. When setting the engine switch to the START position, the slow lock diaphragm "B" is locked to the carburetor through the slow path "D" to cause the initial explosion.

When opening the carburetor throttle value slightly. The negative pressure applied to the carburetor vacuum port is applied to the regulator secondary reducing chamber "C" through the start Solenoid value path. Under this Condition, the secondary diaphragm "13" operates to open the elastic face value "10" by the secondary value lever "11" .Fuel is fed from the primary reducing chamber "B" to the secondary reducing chamber "C". Fuel is also fed from the secondary reducing chamber "C" and complete explosion occurs.

Fig No: 02



Source: [4]

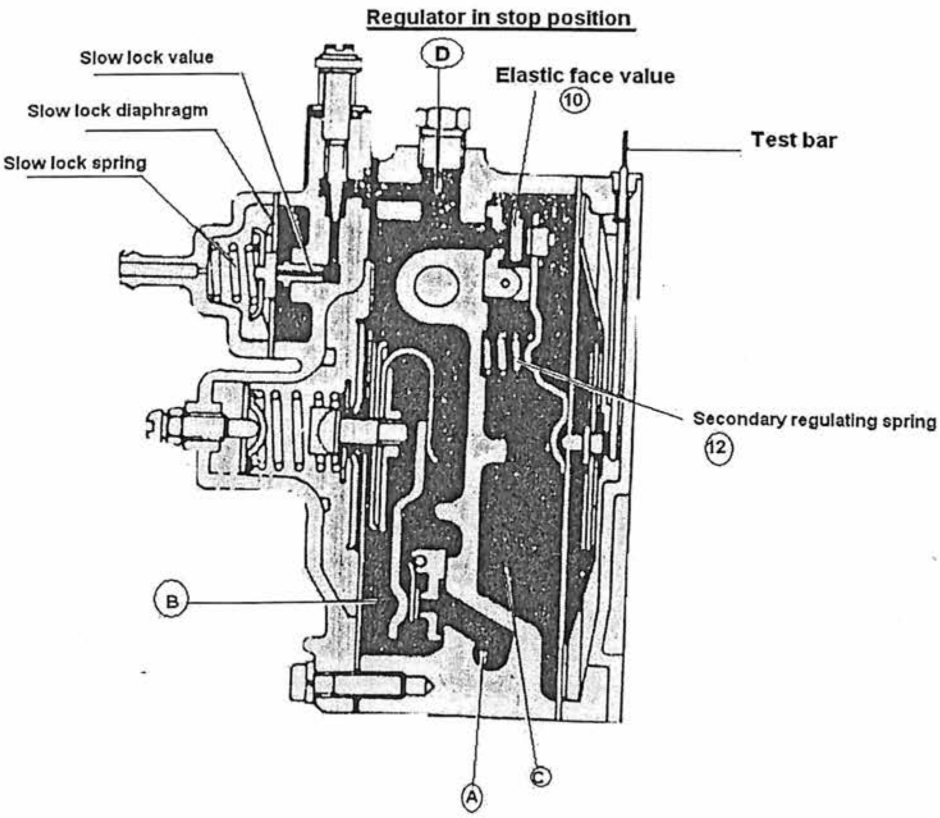
When Engine is running:

CNG flowed in the regulator chamber " A" pushes open the elastic face value "1" with its own vapor pressure to enter the primary reducing chamber " B" to be reduced and vaporized there .When the pressure in the chamber "B" reaches 0.25-0.35 Kg / Cm2.The primary diaphragm "4" pushes the primary regulator spring "3" to operate the primary value lever "5" by the primary diaphragm hook "2" in order to close the elastic face value "1" and to keep the pressure in the primary reducing chamber "B" again. By repeating this operation, the elastic face value "1" keeps "B" to the chamber "C" through the elastic face value" 10" is reduced down to the atmospheric pressure. The chamber "C" is connected to the carburetor main path. When the secondary diaphragm " B" is operated by the Venturi tube negative pressure, the elastic face value "10" is opened by the secondary value lever"11", and closed by the force of the secondary regulator spring "12" to keep the primary pressure constant.

When stopping the engine:

The Venturi tube negative pressure on the chamber " C" is released. Under this condition the elastic face value"10" is closed by the force of the secondary regulator spring"12", So fuel in the chamber "A" and the primary reducing chamber "B" is prevented to flow into the secondary reducing chamber "C". The slow lock value "6" is closed by the force of the slow lock spring "9" to stop fuel supply from the primary reducing chamber "BP" to the slow path "D". The slow lock diaphragm "8" is locked off under the intake manifold negative pressure higher than 25 mm Hg & the fuel flow stops.

Fig No: 03



Source: [4]

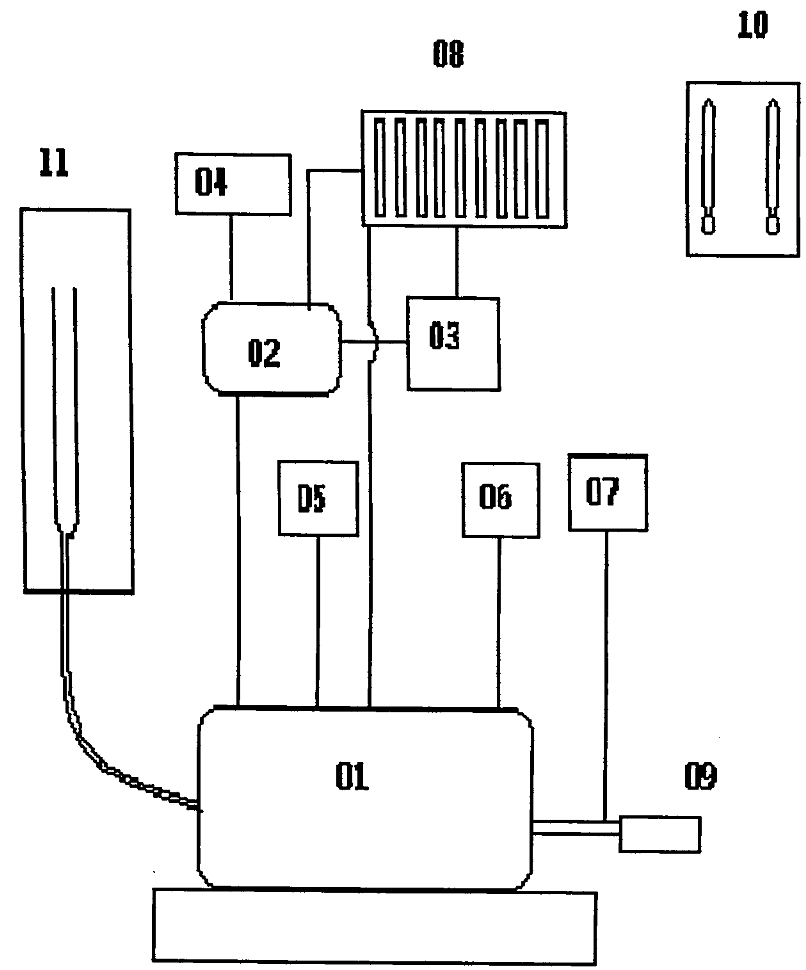
5.0:: Physical properties of fuels:

Table No: 05

Properties	Kerosene	CNG	Gasoline
Chemical formula	$C_9 - C_{17}$	Mainly C_1	C_4 TO C_{12}
Molecular weight	170	16	100-105
Specific gravity,60° F/ 60° F	0.792	0.424	0.72-0.78
Vapour pressure at 38 °C (Kg / cm^2)	0.120	--	0.515
Latent heat of evaporation at atm pr (Kcal /kg)	65.5	121.68	70
Stoichiometric Air fuel ratio	15.0	15.7	14.5
Calorific value (Kcal / kg)	10167	8460	10389
Octane number	50 - 58	120-130	90-100 (RON) 81-94 (MON)
Flammability limit ,Volume % Lower Higher	 0.7 7.0	 5.3 15	 1.4 7.6
Auto ignition temperature	210 °C	812 K	49.5 °F
Flash point	40.5° C	43-72°C	Below room temp
Fire point	64 °C	--	Below room temp

Source: [5]

6.0::EXPERIMENTAL SETUP



01 - Genset
02 - Dimmerstat
03 - Ammeter
04 - Potentiometer
05 - Temperature Sensor for Combustion chamber of Engine
06 - Temperature Sensor for Engine Oil
07 - Temerature Sensor for Exhaust Gas
08 - Load
09 - Exhaust Gas Analyser
10 - Thermometers for measuring Dry & Wet bulb Temperatures
11 - Volumetric flow measuring unit

Fig . 04 Schematic Layout for Experimental Setup of Genset on Conventional fuel

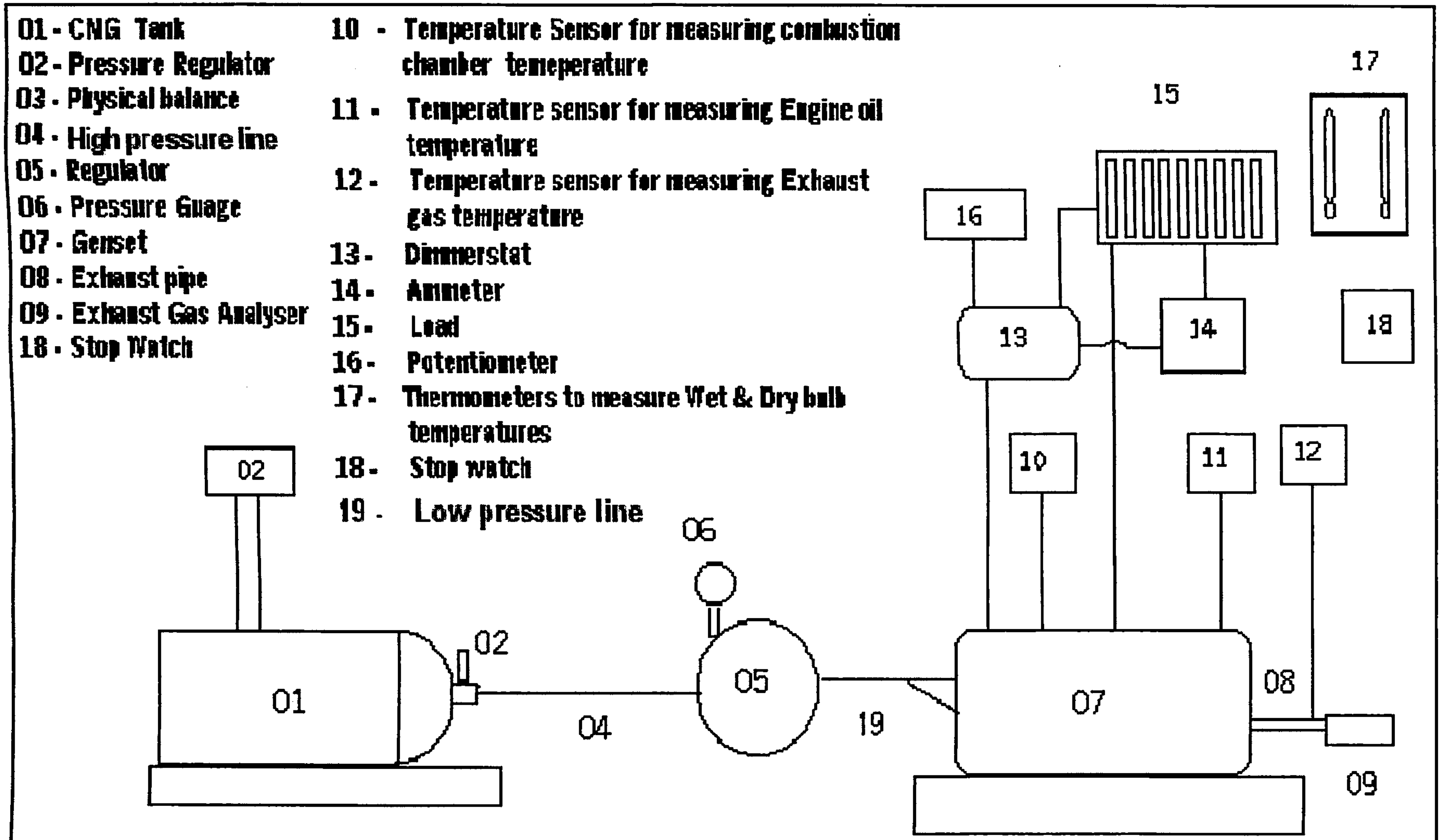


Fig 05 Schematic Layout for the Experimental Setup of Genset (Running on CNG)

6.0:: Experimental setup:

6.1:: Design features:

As shown in Fig -04, Experimental setups consist of a Genset – Birla Ecogen 2000 with maximum output of 1600 VA & with petrol start, kerosene run unit. (Technical specifications of Genset are given in Table -08)

Initially, Genset is run with Conventional fuel (i.e. Kerosene) (Fig .05), Experimental setup consists of:

1) Genset
2) Temperature Sensors
3) Exhaust gas analyzer
4) Ammeter, Voltmeter.

To run the Genset on Compressed Natural Gas (CNG) following changes need to be made:

1) A regulator.
2) Venturi
3) CNG Tank
4) Non- Return value.
5) Pressure Indicator.
6) Physical Balance
7) High pressure & Low pressure line

Pressure Regulator:

It is connected after the CNG tank using a high pressure line and connected to Venturi through low pressure line.

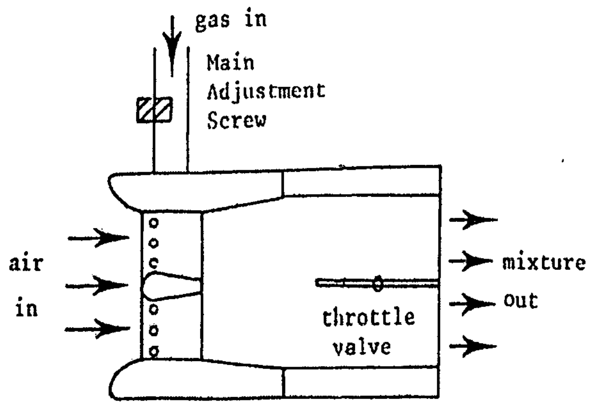
Basic function of a regulator is to reduce the pressure of natural gas from 200 bars to atmospheric pressure. It happens in three steps inside the regulator.

Venturi:

It is connected to Low pressure line on the down stream side and before the carburetor on the upstream side.

This used to provide proper mixer of natural gas & Air to the engine.
Venturi Carburetor is a redesign of a type very close to the idealized carburetor, which has a gas admission slit in the circumference of the Venturi throat with a wing shaped cross with gas-admission holes, in order to distribute the gas more evenly over the air flow.

Fig No: 06



Venturi Carburettor

Source: [5]

Gas for the wing-shaped cross is supplied from a chamber around the throat. In the circumference of the throat, additional gas-admission holes connected to the supply chamber are present. The gas flow can be controlled with a variable restriction in the supply pipe.

Normally, the throttle value body is flanged to the carburetor body as shown.

Physical balance:

Balance used is an electronic weighing platform. CNG cylinder is placed on this balance to measure the weight of cylinder. Time taken for consumption of particular weight of gas in noted and fuel consumption can be calculated.

CNG Tank:

It is made up of 34Cr Mo steel .It is a 60 liter water capacity tank. With maximum filling pressure of 200 bar at 15 ^{O} C, burst pressure of 450 bar.

It is connected to the high pressure regulator by high pressure tube & from high pressure regulator to Gas-air mixer mounted between the air cleaner and the petrol carburetor by low pressure flexible tube.

Fuel lines (High pressure & Low pressure lines):

These are made of soft copper (or) steel and can be shaped with proper tools. It can with stand a maximum operating pressure of 300 bar. This pipe connects the fuel cylinders to the Natural gas solenoid value & the latter to the regulator.

Non- Return value:

It is used to control the flow of CNG from the tank.

Resistive load bank:

It is a single-phase load circuit. Consist of a combination of stable resistive elements of appropriate rating, wired such that the total load current is adjustable to any value upto 125% of maximum full throttle current per phase of the genset under test.

6.2:: Test Procedure:

Load conditions:

Various load condition for which the Genset is tested are:

1) Part Loads
2) Full load

For every load condition, Specific fuel consumption is measured by the time taken for consumption of 50 gm of CNG.

Temperatures to be monitored:

During the test the following temperatures are need to be monitored:

1) Temperature of the Exhaust gas.
2) Temperature of the Engine oil.
3) Temperature of the Combustion chamber.
4) Temperature of Wet & Dry bulb.

These temperatures are monitored so as to check for any sudden raise in temperatures for various loads. Monitoring of Exhaust & Combustion chamber temperatures help in NOx levels and pre-ignition conditions.

Exhaust gas analyzer:

Exhaust emission tester, checks the exhaust gas to determine what % of the fuel has not been burned.

It draws a small part of the exhaust gas from the tail pipe and runs it through an analyzing device, which then indicates, on one or more meters, the amount of COx, THC, and NOx.

In this project Exhaust Gas emissions are analyzed using "Pier burg exhaust gas measuring system" for both the fuels.

6.3:: Procedure of Test:

a) With Kerosene as fuel:

Starting the Genset:

With out load terminal connected, setting engine switch at the 'ON' position & CIRCUIT Breaker in 'OFF ' position, pull the petrol fed knob until kerosene drips in one or two drops through the overflow pipe. Then push the petrol feed knob back to its original position, Use choke if engine is cold started. Pull the starter handle, when engine has started connect the load to AC terminal and switch 'ON 'the AC switch.

1- Genset is started and load is applied gradually from No load to Full load condition.

2- Set up is set tested for Full load condition using a dimmer stat.

3- Fuel consumption is noted by noting the time taken for 50 ml consumption using a stop watch.

4- At this condition Voltage, Frequency are noted and Temperatures of Wet bulb, dry bulb, exhaust gas, Engine oil & Combustion chamber temperatures are also monitored.

5- Emissions from the engine exhaust are measured using Exhaust analyzer.

6- Step 2 to 5 is followed for remaining load conditions.

b) With CNG as fuel:

When Genset is to running with CNG, Set up the Fuel cock lever at 'OFF 'position & Non-return value on the CNG cylinder is opened. Pull the starter handle, when engine has started connect the load.

1- Genset is started and load is applied gradually from No load to Full load condition.

2- Set up is set tested for Full load condition using a dimmer stat.

3- Fuel consumption is noted by noting the time taken for 50 gm reduction in weight of the CNG tank, using a Stop watch & Physical balance.

4- At this condition Voltage, Frequency are noted and Temperatures of Wet bulb, dry bulb, exhaust gas, Engine oil & Combustion chamber temperatures are also monitored.

5- Emissions from the engine exhaust are measured using Exhaust analyzer.

6- Step 2 to 5 is followed for remaining load conditions.

7.0::RESULTS & DISCUSSION

Table No: 07 Experimental Results when Genset running on CNG:

Load	Dry / Wet bulb temp ^{O}C	Current (amp)	Frequency (Hz)	Voltage (Volts)	Temperature ^{O}C			Time for 50 grams of C.N.G consumption (Min.Sec.Msec)
					Exhaust Gas	Oil Temp	Spark Plug	
Full load	23 /21	6.3	49.9	228	465	99	156.9	5.27.27
¾ Load	23 /20	4.8	51.2	241.4	429	104.7	146.6	5.52.94
½ Load	24 /20	3.2	52.1	247	407	102	137.4	6.49.09

Table No: 06 Experimental Results when Genset running on Kerosene:

Load	Dry / Wet bulb temp ^{O}C	Current (amp)	Frequency (Hz)	Voltage (Volts)	Temperature ^{O}C			Time for 50 ml of Kerosene consumption (Min.Sec.Msec)
					Exhaust Gas	Oil Temp	Spark Plug	
Full load	23 /21	6.8	49	228	334	95	136	2.02.28
¾ Load	23 /21	5.1	51.4	241.4	275	106	125	2.21.71
½ Load	24 /20	3.4	52.6	247	254	102	109	2.45.57

<u>Table No: 08</u> Performance & Emission test results for Genset running on Kerosene

Voltage (volts)	Current (amp)	Power (K.Va)	Fuel Consumption (g / hr)	CO dry (%)	CO_2 dry (%)	HC (ppm)	NOx (ppm)	CO (g /hr)	HC (g /hr)	NOx (g / hr)	CO (g / Kw-hr)	HC (g / Kw-hr)	NOx (g/ Kw-hr)	HC + NOx(g/ Kw -hr)
222	6.8	2 ..27	1106..3	7.7	9.74	1215	244..5	942..04	2 5.5	5.56				
222	5.1	1.78	952..63	8.75	9.05	1180	160..5	904 22	20 .89	3.07	494.4	12.58	1. 94	14.53
224	3.4	1..28	815..36	9..95	8.4	1685	114	846 .61	24.48	1.79				

Table No: 09 Performance & Emission test results for Genset running on CNG

Voltage (volts)	Current (amp)	Power (K.Va)	Fuel Consumption (g / hr)	CO dry (%)	CO_2 dry (%)	HC (ppm)	CO (g /hr)	HC (g /hr)	NOx (g / hr)	CO (g / Kw-hr)	HC (g / Kw-hr)
228	6.3	2. 39	550	0.59	11.59	138 .02	46 .29	1.86	1.88311		
241.4	4.8	1..93	510	1.02	11.28	219 .8	73. 31	2.71	1.32957	32.32225	1.30323
247	3.2	1 .31	440	1.0	11.28	291 .5	61 .97	3.10	1.21142		

7.1:: Calculation of Weighted Average Specific Emissions:

Step-1: Conversion of molar concentration in dry exhaust to wet exhaust

Species concentration, wet = K* Species concentration, dry

Where:

$$K = \frac{1}{1 + 0.005 * (CO\%_d + CO_2\%_d) * y - 0.01 * H2\%d}$$

$$H2\%d = \frac{0.5 * y * CO\%_d * (CO\%_d + CO_2\%_d)}{CO\%_d + 3 * CO_2\%_d}$$

y = H /C atomic ratio of test fuel
= 2.47 for C.N.G
= 1.53 for Kerosene

Step-2: Conversion of molar concentration of species to mass emission in gms / hr

Using carbon balance method.

$$\mathbf{W_{HC}} = \frac{\mathbf{MHCexh}}{\mathbf{MF}} * \frac{\mathbf{GF}}{\mathbf{TC}} * \frac{\mathbf{HC, ppm, w}}{\mathbf{10000}}$$

$$\mathbf{W_{CO}} = \frac{\mathbf{MCO}}{\mathbf{MF}} * \frac{\mathbf{GF}}{\mathbf{TC}} * \mathbf{CO\%, w}$$

$$\mathbf{W_{Nox}} = \frac{\mathbf{MNOx}}{\mathbf{MF}} * \frac{\mathbf{GF}}{\mathbf{TC}} * \frac{\mathbf{NOx, ppm, w}}{\mathbf{10000}}$$

Where:

WHC = Mass emission rate of HC in exhaust in gms / hr
WCO = Mass emission rate of CO in exhaust in gms / hr
WNox = Mass emission rate of NOx in exhaust in gms / hr

GF	Mass flow rate of fuel in gms / hr
TC	CO% wet + CO2 % wet + HC % wet
MHC exh	MF (This assumes that the exhaust hydrocarbons are identical to unburnt fuel)
MF	Molecular weight of fuel per carbon = 12.011 + 1.008 * y + 15.999 * z
MCO	Molecular weight of CO = 28.01
MNOx	Molecular weight of NO_2 (NOx) = 46.01
Y	H /C atomic ratio of the fuel
Z	O /C atomic ratio of fuel

Step-3: **Calculation of Weighted Average Specific Emissions**

$$A_{WM} = \frac{\Sigma (Wi * WFi)}{\Sigma (Pi * WFi)}$$

Where:

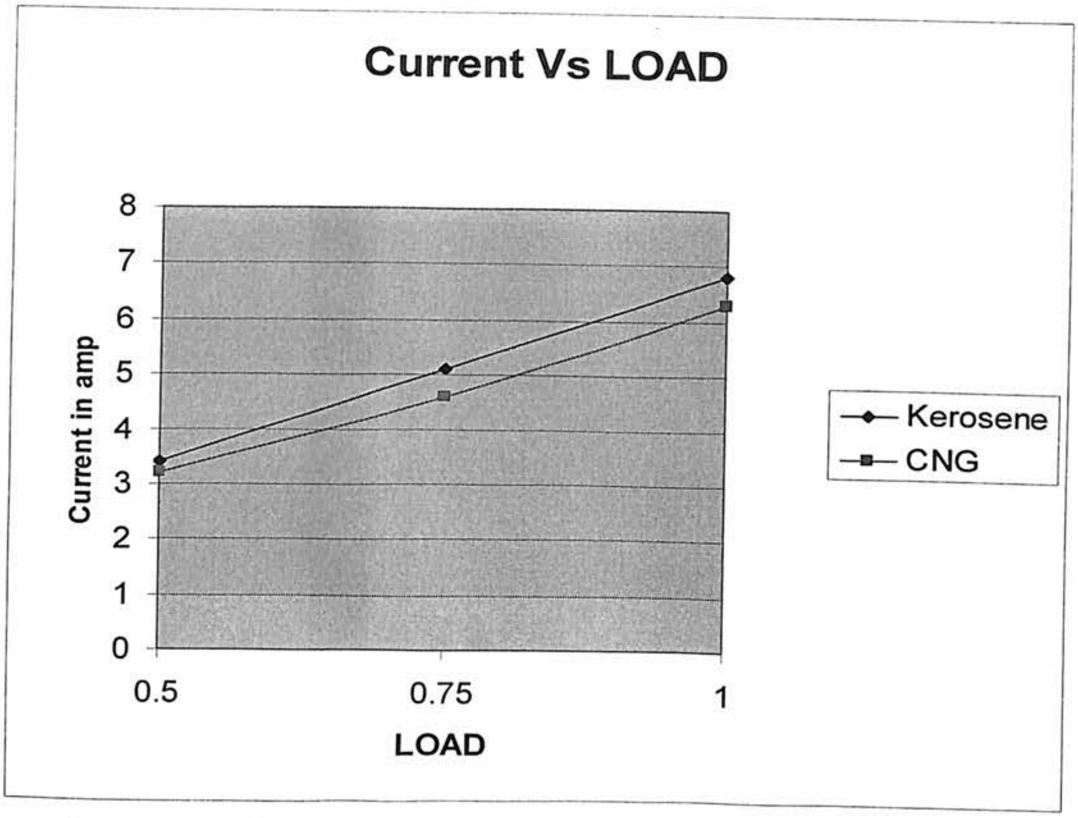
A_{WM} = Weighted average specific emission of a particular species (HC, CO, NOx) in gms / Kw -hr
Wi = Mass emission rate of the particular species during Mode (i) in gms / hr
WFi = Weighting factor for mode i

Mode No.	1	2	3
Load Percent	100	75	50
Weightage Factor	0.3	0.5	0.2

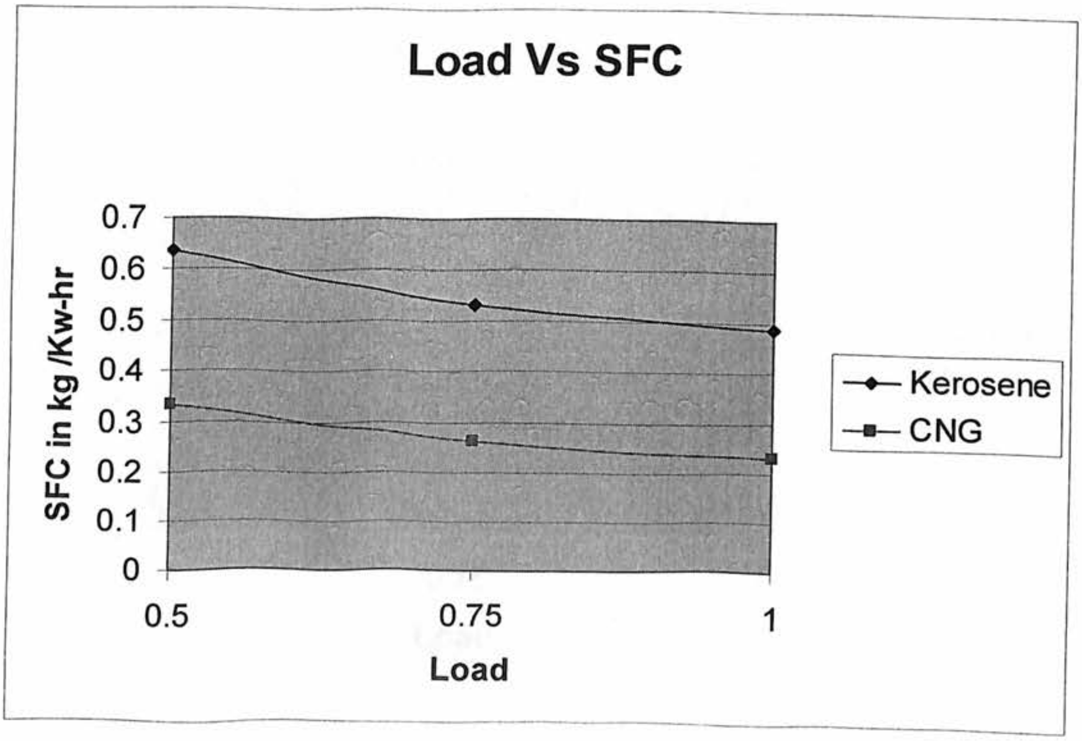
Pi = Gross average engine power generated during mode (i)

$$= \frac{\text{Genset output voltage in volts * Load Current in Amps}}{\text{1000 * Efficiency of alternator}}$$

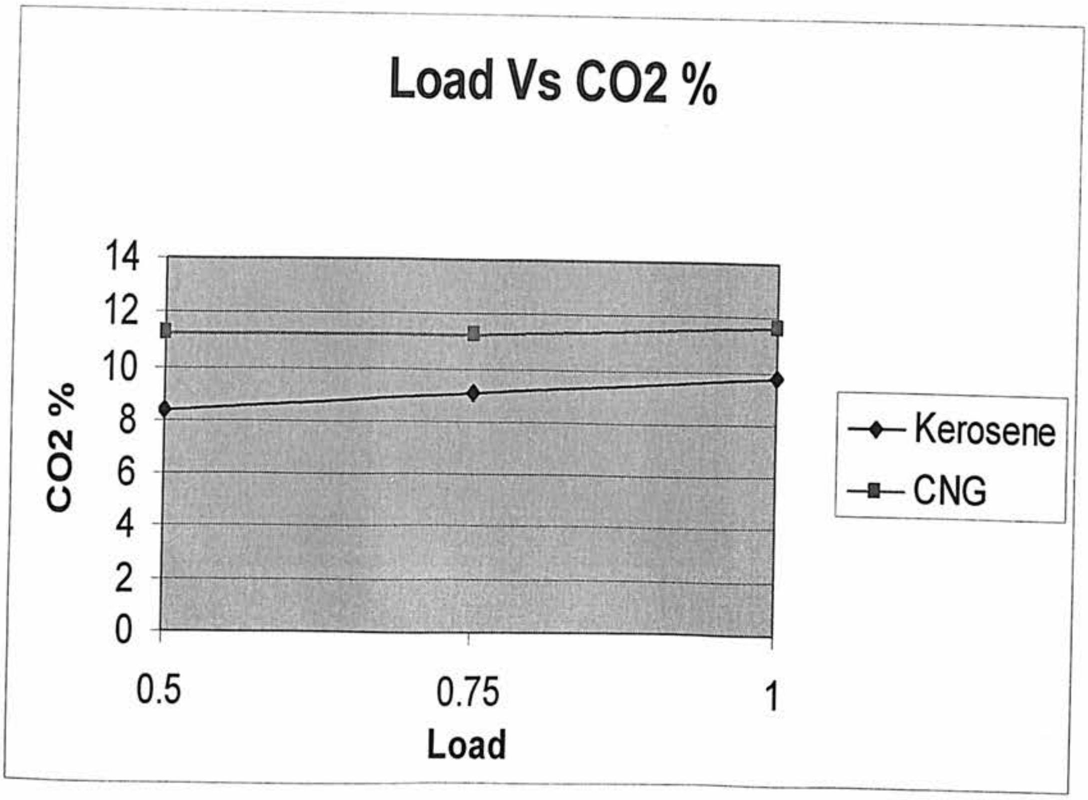
Efficiency of Alternator = 60 % (as given by manufacturer of Genset)



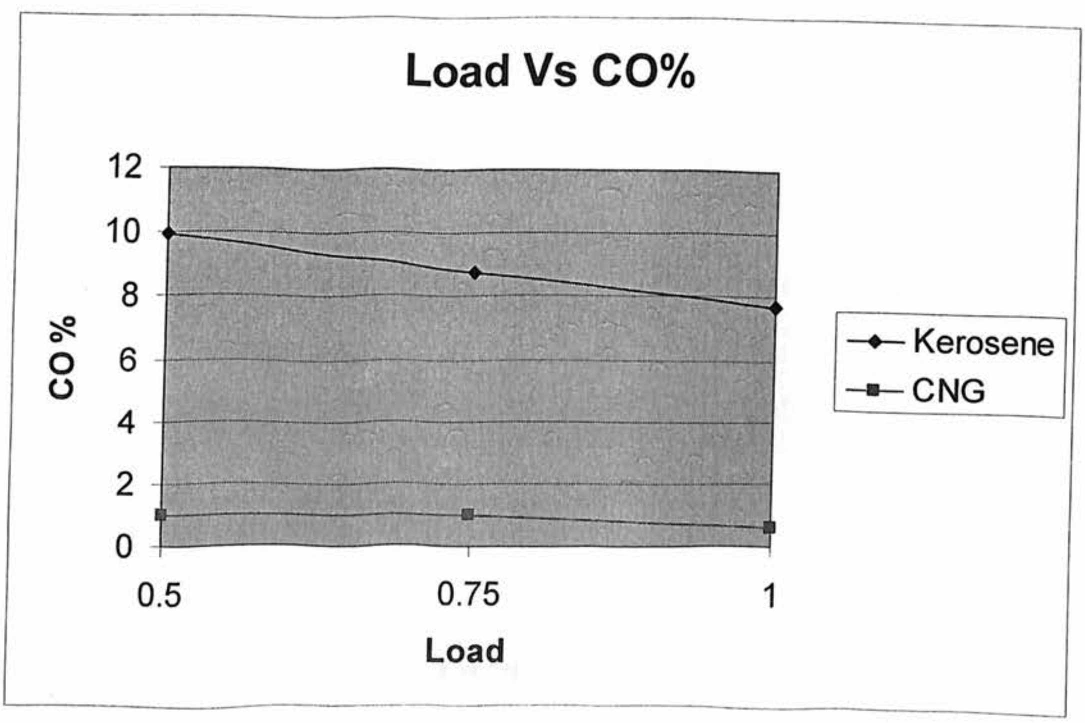
Graph No: 01 Load Vs Power



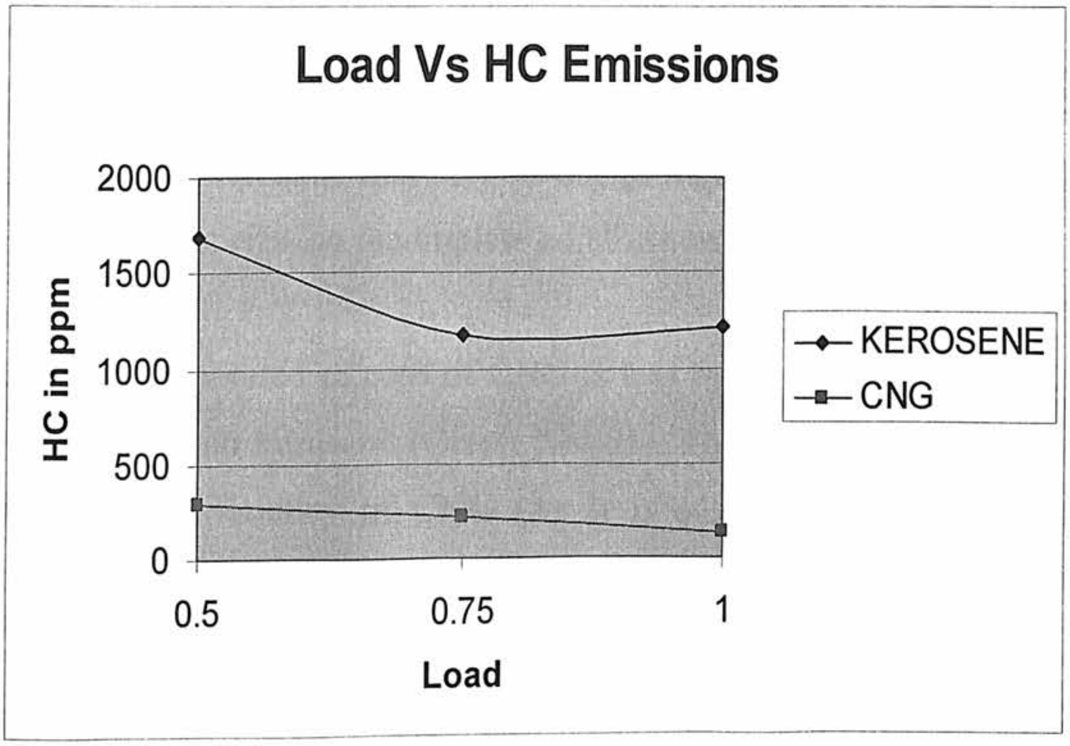
Graph No: 02 Load Vs Specific fuel consumption



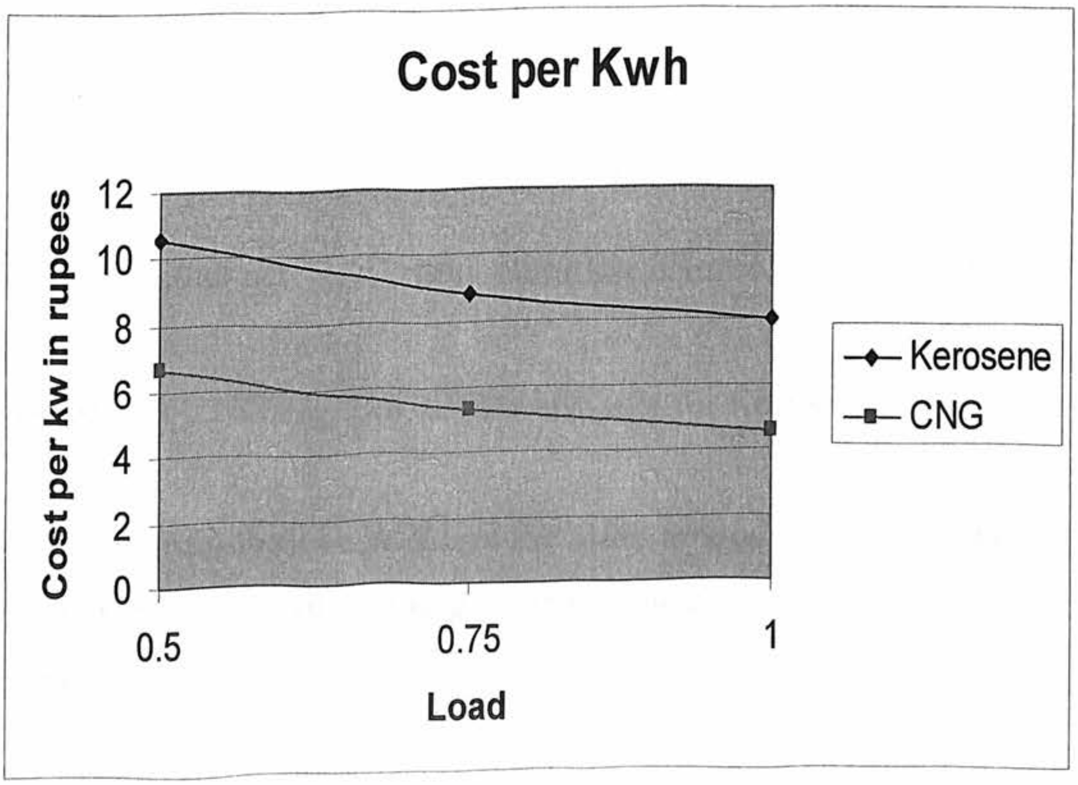
Graph No: 03 Load Vs CO_2 % Emissions



Graph No: 04 Load Vs CO % Emissions



Graph No: 05 Load Vs HC (ppm) Emissions



Graph No: 06 Cost per Kwh generated

7.0:: Results & Discussion:

1) From, Graph No: 02 SFC is less in case of CNG at various loads compared to kerosene this may be due to higher density of kerosene ,which is hard to vaporize ,so incomplete combustion take place.

2) Power generated in case of CNG is less by around 6-7% in various load conditions than kerosene (Graph No: 01). This may be due to reduction in volumetric efficiency of CNG (As It is a gaseous fuel, which occupies around 12-14% of inlet manifold area so less space is available for air which leads to reduced volumetric efficiency).

3) CO emissions in case of CNG are minimum due to complete combustion of CNG mixtures (Graph No: 03 & 04).

4) HC emissions in case of CNG are less compared to kerosene as the emissions from CNG are mainly due to Methane (Graph No: 05).

5) Regulations set by Central pollution control board (CPCB) for Genset below 19 Kwh where met in both case for CO (g/Kw-hr) and very less in case of CNG. NOx (g /Kw-hr) are also met for Kerosene.

6) Considering the cost of Kerosene / litre around Rs.15 & CNG /Kg around Rs.20. Cost per Kwh power generation for CNG is less incase all the three cases.

8.0:: Conclusion:

Genset which generally runs on Kerosene was tested with Compressed Natural Gas (CNG) and it was found that emissions for CO % has reduced to around 80-90 %; HC ppm are negligible; power has reduced slightly (around 7-8 %).

Also, Emission are well below emission standards of CPCB & Bharat emission norms.

So, CNG can be practically used to run Genets in Metros & Other cities where CNG infrastructure is available, which will be a cheaper & much cleaner option compared to Conventional fuels.

ANNEXURE

Table No:10 **Technical specifications of Genset**

Genset Manufacturer & Model: Birla Ecogen 2000

Dimensions of Genset			
Length (mm)	Width (mm)	Height(mm)	Dry Wt. (Kg)
618	413	470	46

Engine Data										
Type	No. of Cyl	Bore x Stroke (mm)	Displa-cment (cc)	Comp. Ratio	Fuel	Fuel tank Capacity (Ltr)	Fuel con at rated load (Ltr)	Lube oil Capacity (ml)	Ignition system	Starting System
4 - stroke	01	65 x 54	179	5.1:1	Petrol (start) Kerosene (run)	8.8 (kero) 01 (petrol)	1.4	680	TCI	Recoil Starter

Generator Data			AC			
Generator	Phase	Voltage Regulation	Max. O/ P (VA)	Genset Rate O/ P (VA)	Rated Voltage (V)	Frequency (Hz)
Brushless, Self excited	Single	Built in	1600	1400	220	50

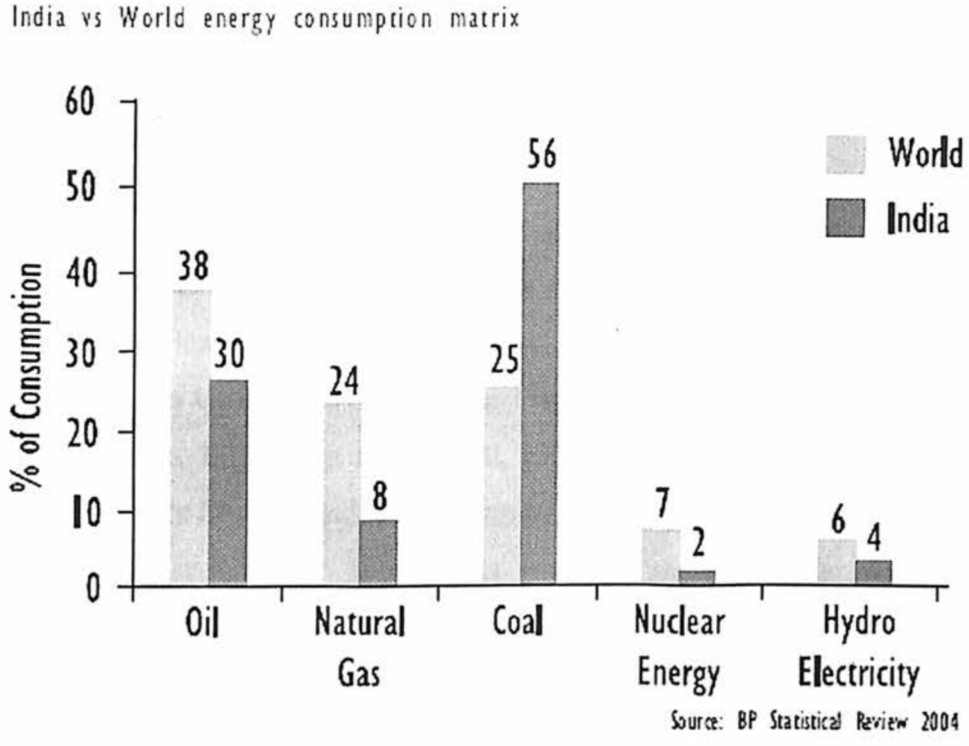
Source: [6]

Table No: 11 **Natural gas composition:**

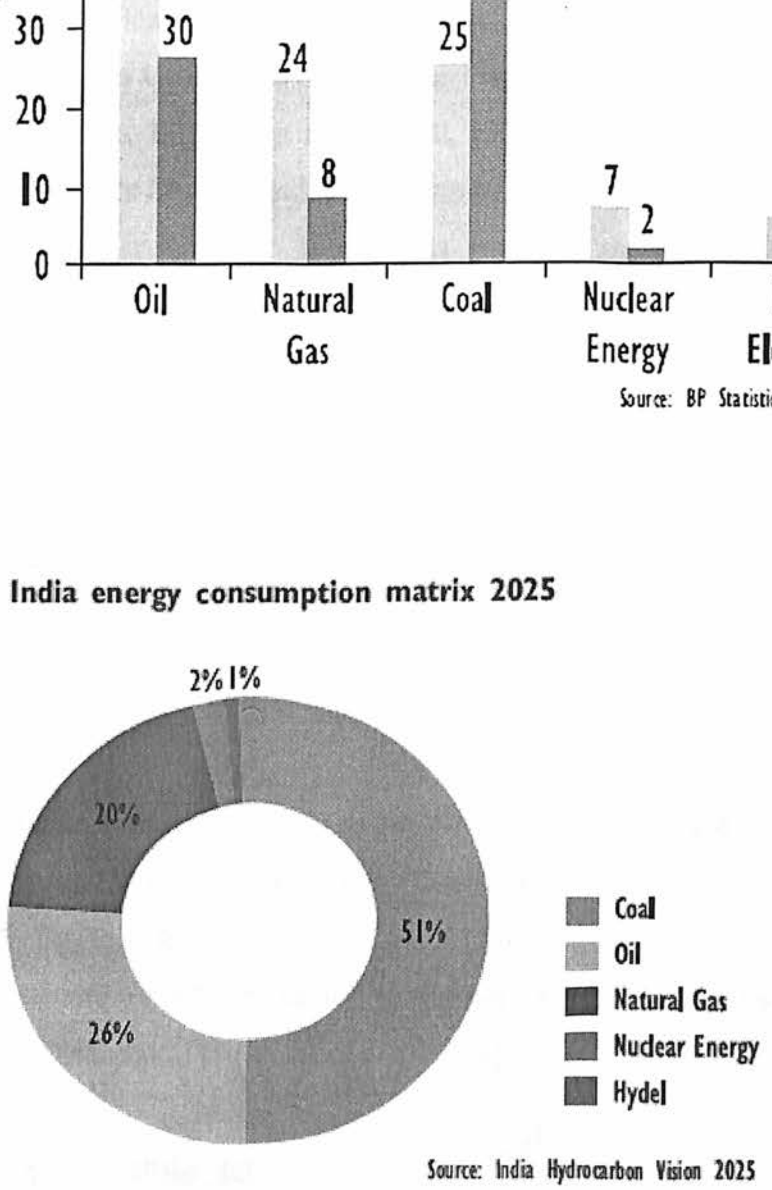
Source: HBJ pipeline **Gas type:** Natural gas

S.no	Component	
01	Nitrogen	0.17383 %
02	Methane	86.1901 %
03	Carbon dioxide	4.76414 %
04	Ethane	7.26644 %
05	Propane	1.41404 %
06	I-Butane	0.09333 %
07	N-Butane	--
08	I-Pentane	--
09	N-Pentane	--
10	Hexanes	0.09812 %
11	H_2S	--
12	Net.Cal.Value (Kcal / sm^3)	8415.5
13	" Z" factor	0.9975
14	Sp.gravity	0.6546
15	Others	--

Figure No: 07 World & Indian energy Scenario



India energy consumption matrix 2025



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12. Central electricity Authority: www.cea.nic.in.

Books:

1. Internal Combustion Engine Fundamentals by Heywood
2. Internal Combustion Engine by Ganeshan
3. I.C Engines & Air Pollution by E.F.Obert
4. Alternative Fuels Emissions, Economics & performance by Maxwell /Jones, SAE.
5. User Manual of Birla Ecogen 2000. [6]

Regulations & Standards:

1. Stoichiometric Air / Fuel ratios of Automotive Fuels –SAE J1829 JUN87
2. Emission Standards (G/Kw-hr) For New GENSETS (Up to 19 Kw, Kerosene & Petrol based) with implementation schedule, Central Pollution Control Board.[3]