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Performance and Emission Characteristics of Exhaust Gas Recirculation System and Ethanol Operation in SI Engine

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ABSTRACT

This paper deals with the use of an Exhaust Gas Re-circulation (EGR) system on a given Spark Ignition engine for studying the performance and emission characteristics. For various openings of EGR-Valve, experiments are carried out on a set of loads varying from 0 to 15 percent of engine loads at a cruising speed of 3500rpm. The results when compared with those obtained from the same engine without EGR system, show nearly a 10 percent fuel savings when 4.8 percent of exhaust gas was recirculated. Also, fall in engine friction by 8% leads to a marginal 2% improvement in engine power. The exhaust gas emission contents like carbon monoxide and unburned hydrocarbons are reduced from 5.3 percent and 1530 parts per million to 3.21 percent and 640parts per million respectively for the above position of the EGR valve. An energy conservation study using neat ethanol as a fuel to replace gasoline shows a remarkable reduction of engine emission by three and half times with respect to the above emission values. In other words, EGR system for gasoline operation and neat ethanol (without EGR) as an eco-friendly substitute to gasoline fuel curtail engine emissions by 40 to 50 per cent.

Key words: Exhaust gas Recirculation, Ethanol and Gasoline operation, SI Engine

INTRODUCTION

Energy is closely linked to economic development and environment quality for which developing countries like India entirely depend on conventional fossil fuels like diesel and gasoline which may deplete in the near future. Increased energy consumption leads to higher carbon dioxide and other greenhouse emissions. India is world's sixth largest CO_2 emitter [1] which accounts 3 percent of total global greenhouse gas emission at present. But, it grows at more than 4 percent which is twice [2] the average world rate. Vehicle emission can be curtailed either by reducing emission per vehicle kilometer travelled or by reducing total number of kilometers travelled [3]. In view of an overall growth the travelled kilometers cannot be reduced.

India for her sustainable development should approach for environmentally compatible and economically viable transport systems. As such, emission norms (Bharat Stage) of automobiles are modeled from European regulations (Euro Standards) [4]. We still lag behind Euro Standards by about 8 years though it has been enforced since April 1991. Following these norms, automobiles of today are 96 percent cleaner and 50 percent more efficient than the ones of 1970s [5]. Need of the hour now is to switch over to some alternative and renewable sources of energy for the present fuel crisis or to modify the existing prime movers by different technologies.

Ethanol can be a good alternative and renewable fuel. India is the fourth largest producer of ethanol in the world. It is used to make alcohol and in petrochemical sectors but surprisingly not introduced for transport. Bureau of Indian Standards now specified the use of ethanol up to 5 percent with gasoline [6] in vehicles without engine modification. Uttar Pradesh is the first state to supply 5 percent ethanol blended gasoline from all the retail outlets [7]. Neat ethanol fuelled engine has been developed by Scania in Sweden; combined with some additives, ethanol blended fuel not only keeps the fuel system clean but also reduces particulate matter, greenhouse gas emissions, oxides of nitrogen and fossil fuels considerably. Engine modifications on the other hand, have been suggested by various technologies which include ceramic engine coating, charge stratification, air assisted fuel injection, catalytic converters, use of intake resonators, positive crankcase ventilation, active thermo atmosphere combustion, exhaust gas recirculation (EGR) and so on.

This paper describes the performance and emission characteristics of a stationary spark ignition engine fitted with an EGR facility. EGR valve controls the small passage between intake and exhaust manifolds. Engine performance and efficiency is increased with the recirculation of a small quantity of exhaust gas into the combustion chamber. An energy conservation study is made using neat ethanol as an alternative fuel to the conventional gasoline fuel. It is environmentally beneficial, market opportunity for farmers/ rural areas and an energy security to the imported crude.

EGR CONCEPT/ IMPORTANCE

Exhaust gas re-circulation is a method of reducing peak combustion temperature which in turn reduces oxygen available for combustion. It essentially consists of a reaction chamber in the immediate vicinity of exhaust manifold. Air is injected to the exhaust in this chamber and makes it inert. A part of this exhaust sample is re-circulated back to the engine combustion chamber. An EGR gate valve calibrates and controls the flow of exhaust gases so as to displace a part of fuel air mixture into the intake manifold. This valve can work by pressure or vacuum technique. It is presumed that 60% of exhaust flows through EGR system from which controlled mass is sent to intake regime at various gate valve openings. Fig.1 shows the schematic representation of an EGR system manifold. This valve can work by pressure or vacuum technique. It is presumed that 60% of exhaust flows through EGR system from which controlled mass is sent to intake regime at various gate valve openings. Fig.1 [8] shows the schematic representation of an EGR system.

Both at idling and wide open throttling, EGR system are ineffective but an effective operation can be carried out only at cruising speed of the engine. It considerably minimises emissions of oxides of nitrogen, carbon monoxides and unburnt hydrocarbons so that fuel economy is achieved. Though EGR facility is quite common nowadays in an engine system, care should be taken in the design of EGR valve which otherwise may seriously affect on engine performance and its life. In view of better accuracy, the present trend is to incorporate electronic systems instead of the mechanical one.

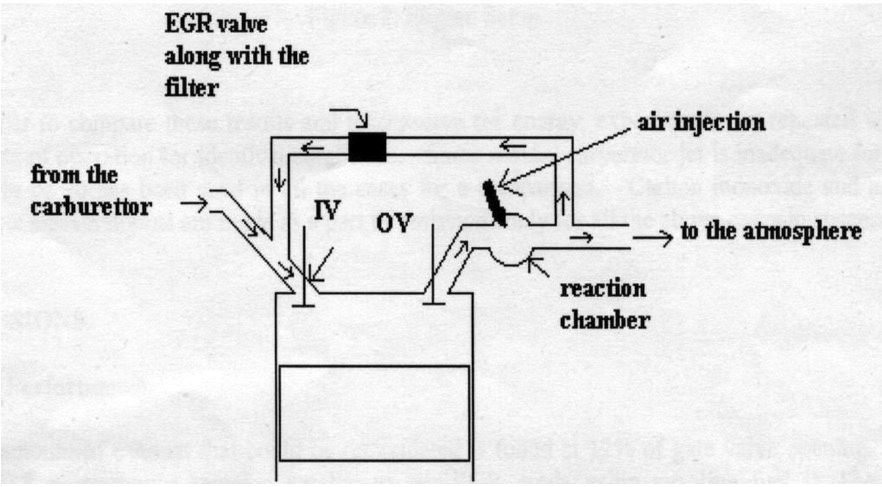

Fig. 1 Schematic of an EGR system

EXPERIMENTAL PROGRAMME

A vertical single cylinder air cooled four stroke cycles Enfield spark ignition engine of 350cc capacity developing 13.5kW at 5625 rpm (commonly noticed in two wheelers) has been mounted on a frame supported by concrete base along with transmission unit to include clutch and gear box. A chain driven wheel acts like an absorption belt friction brake dynamometer to load the engine for a performance test. A flask with graduated burette measures fuel consumption for a definite volume. An EGR system is incorporated in the test set up as shown in the Fig. 2 [9]. To prevent starting difficulties, a lead acid storage battery is used in the programme. A 2-gas analyzer (Manatec Instrumentation) measures carbon monoxide in percent and unburned hydrocarbons in ppm.

Experiments are conducted without EGR system for a performance study at cruising engine speed of 3500rpm equivalent to a road speed of 60 kmh^{-1}. Time required for the flow of known volume of gasoline is found on a set of loads ranging from 0 to15 percent of the safe load of the engine this enables to compute specific energy consumption, brake power and thermal efficiency. The performance is continued for EGR operation maintaining the same conditions as that of Non-EGR mode. The manually controlled mechanical valve functions to allow 2.4, 4.8 and 7.2 percent of exhaust gas to be recirculated. For the above identical conditions, experiments conducted in the last series refer to neat ethanol operation.

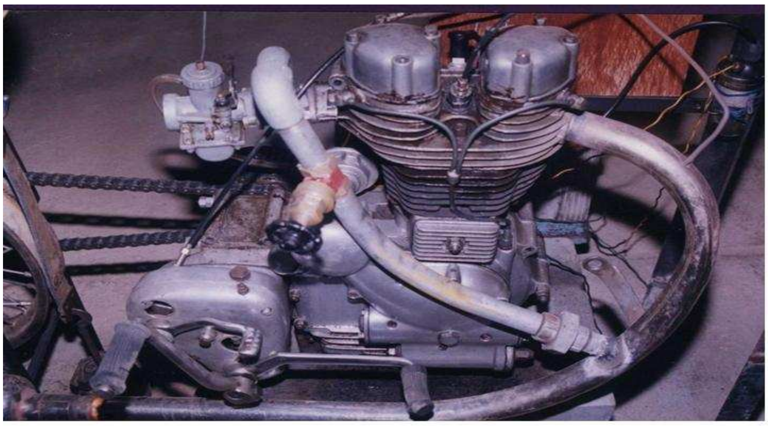

Fig. 2 Engine Setup [9]

In order to compare this energy conservation study with gasoline operation, oversize carburettor jet (number 90) is used in all the cases since normal carburettor jet is inadequate for ethanol mode of operation. Finally carbon monoxide and unburned hydrocarbons measurements are made as a part of emission study for all the above cases in succession.

RESULT AND DISCUSSIONS

Performance Study

Engine performance without EGR facility is optimum at 60N loads (11 percent of engine load) with a fuel consumption of 0.94kghr^{-1}. The effect of exhaust gas re-circulation remains parallel to non-EGR mode for 2.4 percent by volume of recirculated exhaust gas. The percentage volume of gas that could be recirculated was limited to a maximum of around 7.5 per cent, above which the mixture became too lean to continue operation. From Table 1, it is noticed that at a recirculation of 4.8 percent, the required mixture is much leaner under the same conditions. As such, more amount of heat energy is converted into useful work. (Fig. 3 and 4)

Ethanol, the most preferred substitute for gasoline was also tried to check its suitability as a fuel in this system. This study showed that ethanol stalled engine when the EGR facility was turned on. Since the heating value of ethanol is 40 to 45% less than that of gasoline, the system (carburettor) requires over size jet which increases two to three times more fuel consumption than gasoline particularly at part throttle conditions. However, at wide open throttling, the consumption is marginally (3%, say) higher.

Table -1 Performance Data at a Constant Engine Speed of 3500 rpm

Load N	Gasoline Operation								Ethanol Operation	
	Non-EGR		2.4% EGR		4.8% EGR		7.2% EGR			
	SEC	η	SEC	η	SEC	η	SEC	η	SEC	η
0		0		0		0		0		0
15	0.32	1.1	0.232	1.54	0.238	1.51	0.261	1.37	0.355	1.01
30	0.137	2.6	0.113	3.16	0.150	2.39	0.138	2.59	0.169	2.12
45	0.090	4.0	0.079	4.53	0.069	5.18	0.092	3.88	0.123	2.92
60	0.059	6.0	0.059	6.00	0.055	8.50	0.064	5.58	0.098	3.66
75	0.056	6.3	0.061	5.84	0.053	8.49	0.061	5.84	0.096	3.72

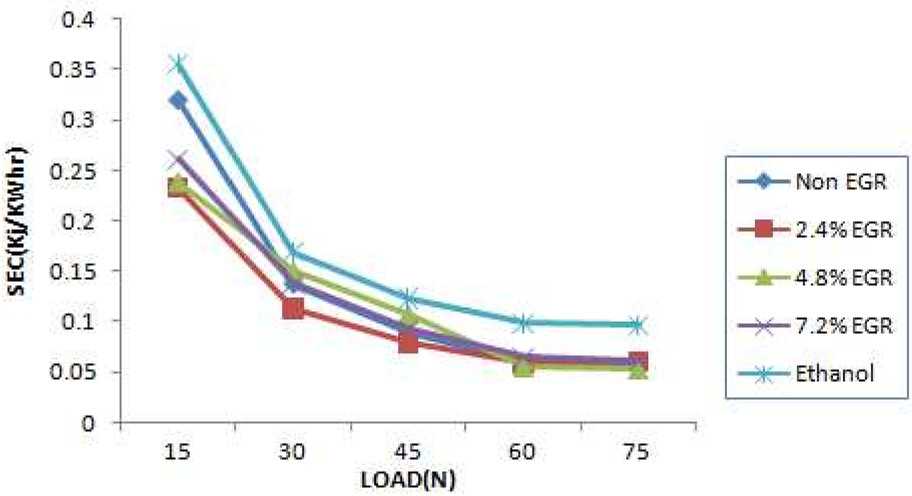

Fig. 3 Specific Energy Consumption Chart

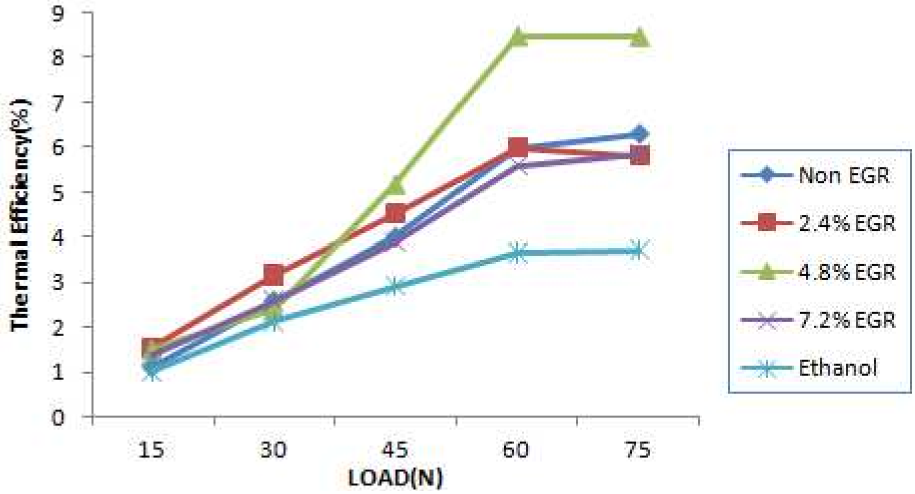

Fig. 4 Thermal Efficiency Chart

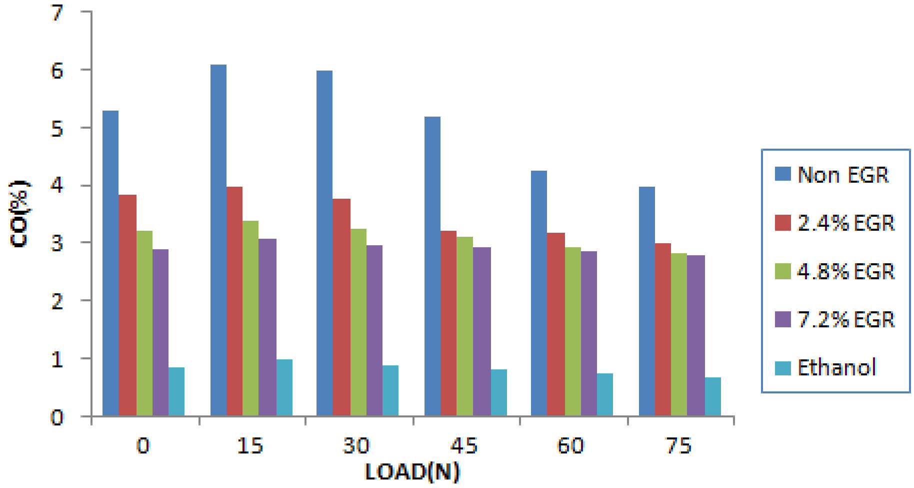

Fig. 5 CO Level Chart

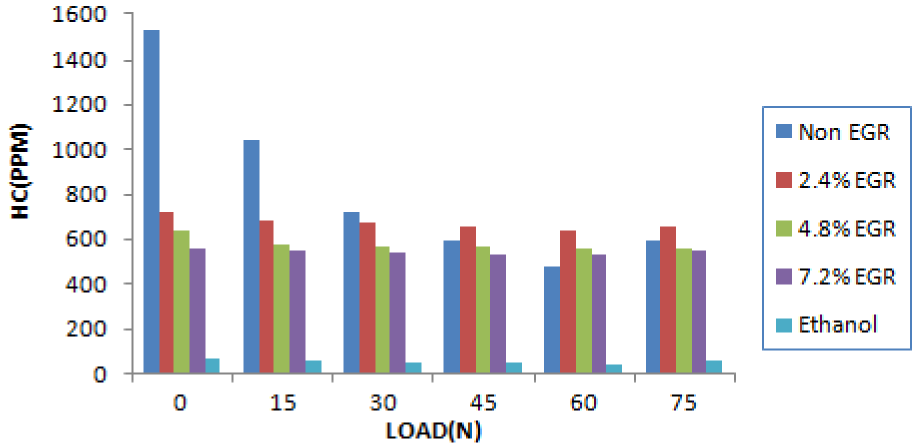

Fig. 6 HC Level Chart

Emission study

Spark Ignition engine constitutes chiefly oxides of carbon, nitrogen and sulphur in addition to unburned hydrocarbons and particulate matters. Since the experimental engine is a spark ignition engine, the emission constituents of Carbon monoxide and unburned Hydro carbon are predominant. Hence, the discussion is restricted to measure CO in percent (Fig. 5) and HC in ppm (Fig. 6). EGR-valve facility shows better emission characteristics (about 40%) than Non-EGR system under gasoline mode of operation. Least values of CO and HC are found when 7.2 percent of exhaust gas was allowed for recirculation

Ethanol operation on the other hand brings down the values of CO and HC by 80 to 95% less than gasoline with or without EGR facility. Provision of catalytic packages can absorb toxic contents so that ethanol can be good substitute to conventional gasoline fuel

CONCLUSION

- Gasoline consumption with EGR facility is reduced from 5% to 27% for wide throttling to part throttling when compared to normally aspirated engine.
- EGR at 4.8 percent recirculation is better than other two opening positions so that thermal efficiency of the engine is enhanced by 35%.
- Gasoline operated EGR system produces CO and HC emission contents about 46% and 58% respectively less than the normally aspirated Non-EGR engine.
- Ethanol operation stalls the engine with EGR facility.
- Ethanol operation reduces CO by 85% and HC by 95% when compared to gasoline operation.
- Ethanol exhaust containing toxic contents like aldehydes and ketones can be absorbed by means of catalytic converter fitted to the exhaust region of the engine.
- Ethanol consumption is 78% at part throttle and 3% at wide open throttle higher than gasoline consumption. But it is a renewable source of energy hence, government (Budget 2002/03) granted fiscal incentive to oil companies with the reduction of surcharge on ethanol doped gasoline system by 75 Paise on a litre.

Nomenclature/ Abbreviations

EGR : Exhaust Gas Recirculation
SEC : Specific Energy Consumption (kJ/kW.hr)
ppm :Parts per million
CO : Carbon monoxide (%)
HC : Unburned hydrocarbons (ppm)
η : Thermal efficiency (%)
NO_x : Oxides of Nitrogen
N : Load in Newton
CO_2 : Carbon dioxide

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