

INVESTIGATIONS ON OXY-HYDROGEN GAS AND PRODUCER GAS, AS ALTERNATIVE FUELS, ON THE PERFORMANCE OF TWIN CYLINDER DIESEL ENGINE

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ABSTRACT

Presence of carbon element in the conventional fuel like petrol and diesel leads to emission pollutions which are associated with the combustion process in traditional internal combustion engine loaded on automobiles. Increasing stringency in pollution norms is forcing the researchers to work on methods to reduce these emissions especially in the field of alternative fuels. Oxy hydrogen gas, which is enriched mixture of hydrogen and oxygen bonded together molecularly and magnetically and producer gas are emerging as best alternative fuels in the recent past. In this study methods to produce oxy hydrogen gas are discussed in detail with their comparison. Also discussions are made on the process of generating producer gas from biomass through pyrolysis process from coconut leaves which are available on the west coast of India, especially the Konkan region. Finally the effect of these two alternative fuels on the performance of the diesel engine is tested when sent inside combustion chamber of twin cylinder diesel engine in blend with the diesel. Both alternative fuels improves the performance of diesel engine in terms of reduced values of brake specific fuel consumption and improved values of brake thermal efficiency. Amongst both fuels oxy hydrogen is observed to be the best option to improve efficiency of diesel engine.

Keywords: Oxy-hydrogen gas, Brown gas, Producer gas, Pyrolysis, Alternative fuels

1. INTRODUCTION

By products from conventional hydrocarbon fuels like hydrocarbon, nitrogen oxides, carbon monoxides and carbon dioxides are responsible for the global warming which is one of the major problems the scientific community is facing today. Major pollutants causing acid rains are the byproduct of combustion process in the combustion chamber of an internal combustion engine. HC refers to Hydrocarbon which is another term for the unburnt fuel that makes its way through the engine and out the exhaust is main reason for the smog coming out from engine. High compression ratio engines especially CI engines emits NO_x refers to nitrogen oxides which is bad emission to breath at high levels. CO and CO₂ refer to carbon mono-oxides and carbon dioxides causes' headache and eventually death by hold up O₂ from human body, if it exists in large quantities. Also both contribute to green house effect as well [1]. Catalytic convertor loaded in the exhaust pipe can reduce majority of the emissions but not to sufficient levels. Amongst all, hydrocarbons are usually the worst problems for the automobile power plants. How much we try to compensate with alternative options like cars

working with electric motors, solar panels but the bottom line is that we are still lagging behind in the technical aspect compared to petroleum fuels. So not to compete with petroleum fuels but to help petroleum fuels to exist longer life in turn help to survive this ever demanding automobile industry. So in order to conserve petroleum fuels for future and to eliminate the above limitations there is a need of alternative and innovative fuel. Amongst many alternative fuels available oxy hydrogen gas and producer gas are under study in this research work. Electrolysis of water can give us hydrogen in form of Brown's gas (HHO gas) [2] or oxy-hydrogen gas, which can be used as an alternative fuel for any internal combustion engine. Various methods for the generation of oxy-hydrogen gas are discussed in the coming paragraphs. An agricultural waste like rice husk, wood dust, and dried coconut leaves etc can also be used as an alternative fuel for S.I or C.I engines. The thermo-chemical conversion of solid biomass into gaseous fuel called Gasification produces producer gas which can be used as a fuel for internal combustion engines. In this research work the producer gas is produced by pyrolysis process from a coconut leaves which are available in ample amount on the west coast of India especially Konkan region.

2. PROPERTIES OF OXY-HYDROGEN GAS & PRODUCER GAS

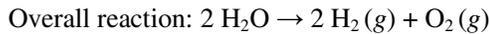
Oxy-Hydrogen is an enriched mixture of hydrogen and oxygen bonded together molecularly and magnetically. Oxy-Hydrogen Gas is produced in a common-ducted electrolyser & then sent to the intake manifold to introduce into combustion chamber of the engine. Oxy-Hydrogen gases will combust in the combustion chamber when brought to its auto-ignition or self ignition temperature. For a stoichiometric mixture at normal atmospheric pressure, auto-ignition of oxy hydrogen gas occurs at about 570°C (1065°F). The minimum energy required to ignite such a mixture with a spark is about 20 micro joules. At normal temperature and pressure, Oxy-Hydrogen gas can burn when it is between about 4% and 94% hydrogen by volume. When ignited, the gas mixture converts to water vapour and releases energy. The amount of heat released is independent of the mode of combustion, but the temperature of the flame varies. The maximum temperature of about 2800°C is achieved with a pure stoichiometric mixture, about 700°C hotter than a hydrogen flame in air. Oxy-hydrogen gas has very high diffusivity. This ability to disperse in air is considerably greater than gasoline and it is advantageous in mainly two reasons. Firstly it facilitates the formation of homogeneous air fuel mixture and secondly if any leak occurs it can disperse at rapid rate. Oxy hydrogen gas is very low in density. This results in a storage problem when used as a fuel in an internal combustion engine which is loaded on automobile.

Producer gas is the gas generated when wood, charcoal or coal is gasified with air and it consists of around 45-50% combustible gases, N₂, CO₂ and water vapour. The gas contains condensable oily substances, acids and dust as well. The main aim of the gasifier system is to generate a gas with a high proportion of combustible components and a minimum of impurities. There are different methods to produce the gas, three different types of arrangements can be used viz. Updraft Gasifier, Downdraft gasifier, Cross draft gasifier but the problem with all these type of arrangements while producing gas is presence of tar content in them, which when introduced in engine can damage the cylinder lining as well as can cause knocking problem [3, 4, 5]. In this research work instead of using conventional processes a Pyrolysis method is used for the production of producer gas. Exact analysis of the gas produced is carried out and is mentioned in the coming paragraphs.

3. METHODS OF OXY HYDROGEN GAS GENERATION AND COMPARARISON BETWEEN THEM

There are two general methods which are used in this research work for the generation of oxy-hydrogen gas. The first method [6] makes use of the basic principle of faradays law. AN electrolytic cell is used for the decomposition of distilled water (H₂O) in to HHO. Heat is

generated due to this electrolysis process, so KOH / NaHCO₃ may be added gradually to accelerate the decomposing of H₂O in to HHO and assure control of the heat generation. An electrical power source is connected to two electrodes, or two plates typically made from some inert metal such as platinum or stainless steel which is placed in the water. In a properly designed cell, hydrogen will appear at the cathode (the negatively charged electrode, where electrons enter the water), and oxygen will appear at the anode (the positively charged electrode). Assuming ideal faradic efficiency, the amount of hydrogen generated is twice the number of moles of oxygen, and both are directly proportional to the total electrical charge conducted by the solution. Following are the reactions normally take place at cathode and anode:



In the second method [7, 15, 16, 17] the resonance is produced inside water molecules between the electrodes by DC pulses (typically square wave output). This alteration at natural frequency of water causes enormous electrical force to break the bond between the hydrogen and the oxygen and they freed as gas molecules, which are magnetically coupled to each other.

Need less to say in both the methods we have used an electrolyser for the generation of the oxy-hydrogen gas. Two different types of electrolysers were tested with the first method of obtaining oxy hydrogen gas. In the first design the electrodes are made up of 216 Stainless Steel plates with width = 100 mm, length = 160 mm and thickness = 1 mm. The plate array is supported with the help of two carbon rods one at the top and other at the bottom. The plates are separated with the help of Teflon washers with a gap 1.6 mm between them as shown in figure 1. It has been observed that if the gap between electrodes is more than this then the gas generation rate decreases and if the gap between the electrodes is less than this then there are chances of current to jump across the electrodes giving spark which is dangerous and may result in blast of electrolyser. The assembly of the electrodes is placed in the plastic container. The container is filled with the electrolytic solution which consists of distilled water and potassium hydroxide. Distilled water will keep the electrodes clean during the process of gas generation and KOH is added to make the distilled water conductive.

In the second design two changes were made. Instead of using plastic container a 304 Stainless Steel container of same capacity is used which itself is acting as a cathode during the process of electrolysis. The anodes are also changed from the first design; they are of 304 Stainless Steel plates. Reason opting for 304 SS is that 304 SS is having more resistance to corrosion as compared to 216 SS. Also as the container itself is becoming cathode the cathode area is increased, which gives larger gas generation compared to first design. Also this design minimises the chances of accidents due to explosion of oxy hydrogen gas. The electrolytic solution remains the same as used in first design. Refer figure 2 for the constructional detail of electrolyser.

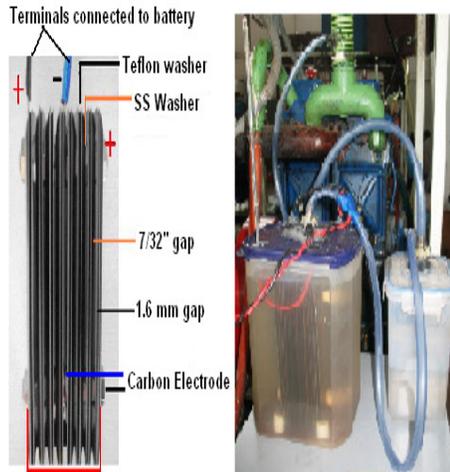


Figure 1 Arrangements of Electrodes in first design of Electrolyser



Figure 2 Arrangements of Electrodes in second design of Electrolyser

In the second method of oxy hydrogen gas generation, dielectric breakdown of water molecules is carried out by creating resonance of 42 MHz which is equal to natural frequency of water in water by electrical circuit consisting of resistors, timer circuits, bifilar inductors and mosphates to produce pulsating DC output. The pulsating DC output is given to set of 9 tube in tube electrodes made up of 316 SS with a radial gap of 0.6615 mm. More the gap lesser will be the generation rate and vice versa. The array of electrodes is kept in a container of same size used in first method. There is no need of electrolyte in this method also no current is admitted to the water; hence we can even use tap water in this method for generation of oxy hydrogen gas. Refer figure 3 for the arrangement.

Comparison between the methods has been done on four factors, first the rate of generation of oxy hydrogen gas, second is the increase of temperature during the generation; third factor is safety of oxy hydrogen generator and fourth factor is its implementation on internal combustion engine.

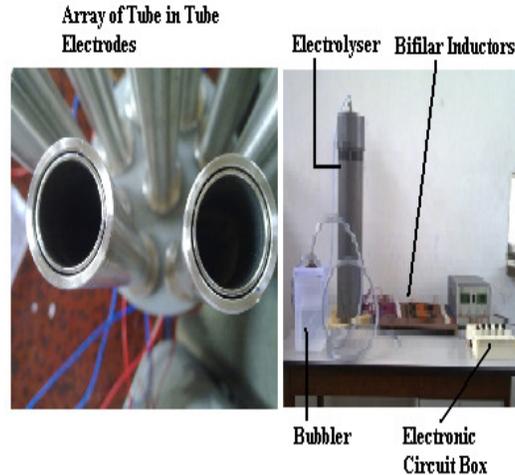


Figure 3 Arrangements of Electrodes in second method of Electrolyser and other components

As far as rate of gas generation is concern the second design in first method is proven to be the best amongst all designs. The reason for that is the increased cathode area during the process of generation, which draws more current from the source (mainly a 12 volt battery) leading to more gas generation. The generation rate in the second method is observed to be least amongst all. As far as increase in temperature of gas generator is concern the second method i.e. generation by resonant DC principle registered least increase in the temperature of generator. The method which is giving large rate of gas generation gives highest rate of temperature rise, which makes it difficult to handle. As far as safety of gas generator is concern the second method is safest and the first method is bit risky. However the second design of first method takes care of safety of gas generator by itself. As far implementation of generator to any engine is concern, all the designs are easy to connect to any engine, petrol or diesel.

4. METHOD OF PRODUCER GAS GENERATION BY PYROLYSIS

Pyrolysis is the thermal decomposition of materials in the absence of oxygen or when significantly less oxygen is present than required for complete combustion. It is important to differentiate pyrolysis from gasification. Gasification decomposes biomass to syngas (gas mixture that contains varying amounts of carbon monoxide and hydrogen) by carefully controlling the amount of oxygen present. Pyrolysis is difficult to precisely define, especially when applied to biomass. The older literature generally equates pyrolysis to carbonization, in which the principal product is a solid char. Today, the term pyrolysis often describes processes in which oils are preferred products. The time frame for pyrolysis is much faster for the latter process i.e carbonization. The general changes that occur during pyrolysis are enumerated below:

- (1) Heat transfer from a heat source, to increase the temperature inside the fuel
- (2) The initiation of primary pyrolysis reactions at this higher temperature releases volatiles and forms char
- (3) The flow of hot volatiles toward cooler solids results in heat transfer between hot volatiles and cooler un-pyrolyzed fuel
- (4) Condensation of some of the volatiles in the cooler parts of the fuel, followed by

secondary reactions, can produce tar

(5) Autocatalytic secondary pyrolysis reactions proceed while primary pyrolytic reactions (item 2, above) simultaneously occur in competition

(6) Further thermal decomposition, reforming, water gas shift reactions, radical's recombination, and dehydrations can also occur, which are a function of the process's residence time/temperature/pressure profile.

Pyrolysis processes may be conventional or fast pyrolysis, depending on the operating conditions that are used [8]. Conventional pyrolysis may also be termed slow pyrolysis. The terms "slow pyrolysis" and "fast pyrolysis" are somewhat arbitrary and have no precise definition of the times or heating rates involved in each. Many pyrolysis have been performed at rates that are not considered fast or slow but are conducted in a broad range between these extremes. Conventional slow pyrolysis has been applied for thousands of years and has been mainly used for the production of charcoal. In slow wood pyrolysis, biomass is heated to 500 °C. The vapour residence time varies from 5 min to 30 min. Vapours do not escape as rapidly as they do in fast pyrolysis. Thus, components in the vapour phase continue to react with each other, as the solid char and any liquid are being formed. The heating rate in conventional pyrolysis is typically much slower than that used in fast pyrolysis. A feedstock can be held at constant temperature or slowly heated. Vapours can be continuously removed as they are formed. Vacuum pyrolysis at slow or fast heating rate is another variant. The definition of a "slow" heating rate versus a "fast" heating rate is arbitrary in many respects. Fast pyrolysis is a high-temperature process in which biomass is rapidly heated in the absence of oxygen [9]. Biomass decomposes to generate vapours, aerosols and some charcoal-like char. After cooling and condensation of the vapours and aerosols, a dark brown mobile liquid is formed that has a heating value that is about half that of conventional fuel oil. Fast pyrolysis processes produce 60-75 % wt. of liquid bio-oil, 15-25 wt. % of solid char, and 10-20 wt. % of non-condensable gases, depending on the feedstock used. No waste is generated, because the bio-oil and solid char can each be used as a fuel and the gas can be recycled back into the process. Fast pyrolysis uses much faster heating rates than traditional pyrolysis. Advanced processes are carefully controlled to give high liquid yields. There are four essential features of a fast pyrolysis process [8]. First, very high heating and heat transfer rates are used, which usually requires a finely ground biomass feed. Second, a carefully controlled pyrolysis reaction temperature is used, often in the 425-500°C range. Third, short vapour residence times are used (typically <2 s). Fourth, pyrolysis vapours and aerosols are rapidly cooled to give bio-oil. Heating rates of 1000°C/s, or even 10000°C/s, at temperatures below 650°C have been claimed. Rapid heating and rapid quenching produced the intermediate pyrolysis liquid products, which condense before further reactions break down higher-molecular-weight species into gaseous products. High reaction rates minimize char formation. Under some conditions, no char is formed [8]. At higher fast pyrolysis temperatures, the major product is gas.

5. EXPERIMENTAL SET UP AND PROCEDURE

No hardware modification in the engine is required for the supply of Oxy-Hydrogen gas. Only an inlet is to be given for the entry of the gas into the combustion chamber. This entry is provided S.I engine and after air cleaner in case of diesel engine, so that the Oxy-Hydrogen gas will get sufficient time to adhere the fuel molecules. Thus the oxy hydrogen gas is brought inside the combustion chamber just because of engine suction pressure. Thus the Oxy-Hydrogen usage is compatible with any of the running engine. To make the complete Oxy-Hydrogen gas unit, components required are the Oxy-Hydrogen Generator or Electrolyser, Bubbler & Post Air Cleaner Joint [10, 11, and 12]. Oxy-Hydrogen Generator generates Oxy-Hydrogen gas as discussed earlier. Terminals of electrolyser are connected to

the car battery by means of two insulated wires. Insulated wires are attached to the plates by means of hard soldering. Soft solder should be avoided as due to the rise in temperature there are chances that the solder may melt and the wires come in contact with adjacent plate leading to generation of spark & thus causing explosion of the generator / electrolyser.

Bubbler is component used for the safety purpose in case of backfire from engine. It is filled with water, through which Oxy-Hydrogen gas is allowed to pass; also if steam is generated in the generator is condensed inside the bubbler. Thus it allows only pure gas to enter the engine. As its purpose is just to act as a safety device plastic bottle is sufficient it also reduces the cost and even if back fire occurs the plastic bottle will tear off quickly & avoid strong blast of it. It does not allow the ignited gas to reach the generator as the water present in it extinguishes the ignited gas.

Refer figure 4 for more constructional details of the assembly and flow of Oxy-Hydrogen gas through the circuit.

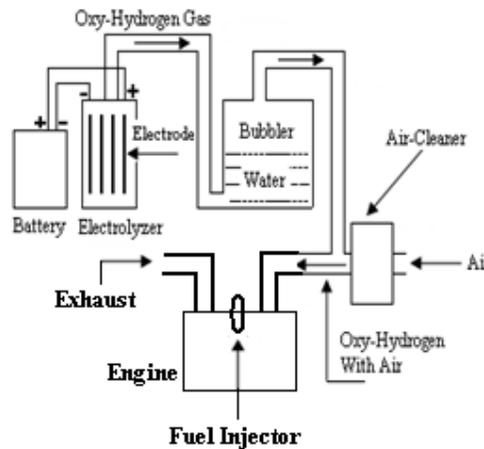


Figure 4 Block Diagram of Oxy-Hydrogen unit mounted on engine

The unit used in this research work for the generation of producer gas consists of a stainless steel body having geometry like a cylinder with a flange for fixing the head of cylinder having same flange [5]. The head of Pyrolyser unit has provision for introducing biomass and removal of gas produced in the unit. It also has two thermocouples, a long and a short one the long thermocouple measures the core temperature whereas the short thermocouple measures the temperature of the gas produced at top inside the unit. Heating coils are fixed circumferentially to the pyrolyser unit from outside and insulation is provided over the unit circumferentially from outside. Scrubber tank is used to clean the gas and also to condense the condensable. It is partially filled with water; gas comes from top of the tank which is taken to the bottom of water through pipe so that it passes through water. There is an outlet for removal of gas. Also there is a provision for flushing out the water from the tank. Control unit is the unit from which we can set the temperature and also control the heating. From 150⁰C to 400⁰C of inner core there is continuous production of the gas. It requires 70 to 75 minutes to produce 700 gm of gas. Figure 5 below demonstrates the constructional details of producer gas unit.

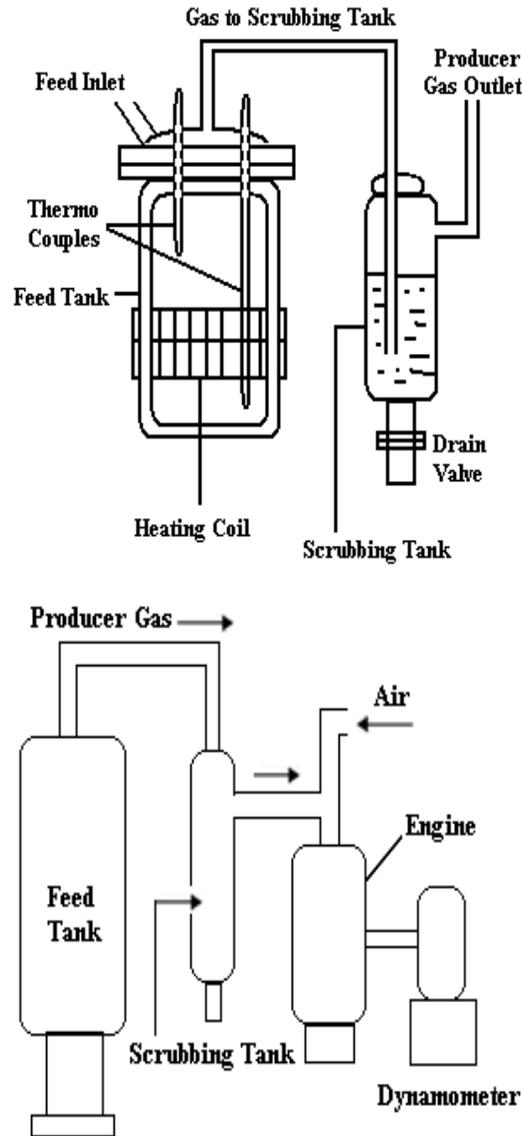


Figure 5 Producer Gas Unit – Constructional details and supply

6. ANALYSIS OF PRODUCER GAS PRODUCED FROM PYROLYSIS OF COCONUT LEAVES

In order to find out the constituents of producer gas from the pyrolysis process, a gas chromatography was carried out at ENMOS Company Pvt. Ltd., Ratnagiri. Table number 1, 2 and 3 gives the contents of the gas and its calorific value.

Table 1 Average composition of two samples in % V/V from gas of coconut waste

Components	%	Components	%
Methane	10.43	Ethylene	0.73
Carbon monoxide	24.31	Ethane	1.48

Nitrogen	11.24	Carbon dioxide	38.50
Oxygen	3.08	Hydrogen	10.2

Table 2 Calculation of wt. of gas in 100cu.ft from coconut waste

Component	Empirical relations [13]	Mass (lbs.)	% mass
Hydrogen	$0.0056 \times \%H_2$	0.05712	0.6753
Methane	$0.0447 \times \%CH_4$	0.46621	5.51
Carbon monoxide	$0.0781 \times \%CO$	1.89861	22.41
Nitrogen	$0.0784 \times \%N_2$	0.88121	10.41
Oxygen	$0.0893 \times \%O_2$	0.27504	3.25
Carbon dioxide	$0.1227 \times \%CO_2$	4.72395	55.85
Ethylene	$0.0784 \times \%C_2H_4$	0.05723	0.6766
Ethane	$0.0689 \times \%C_2H_6$	0.104039	1.23
	TOTAL	8.4581	

Table 3 Calculations for calorific value of gas from coconut waste

Component	Empirical relationship [13]	Calorific value in C.U.
Hydrogen	$C.V \times \% \text{ mass of } H_2$	0.6753×29300
Methane	$C.V \times \% \text{ mass of } CH_4$	5.51×12000
Ethylene	$C.V \times \% \text{ mass of } C_2H_4$	0.6766×10400
Carbon monoxide	$C.V \times \% \text{ mass of } CO$	22.41×2400

Ethane	C.V x % mass of C ₂ H ₆	1.23 x 14955.11
	TOTAL	165121.71

The components obtained during the gas chromatography resembles the constitution of producer gas, the amount of tar was very negligible. Generally calorific value of a producer gas is 7000 to 9000 kJ/kg. The gas obtained during the pyrolysis was having calorific value 6918.26 kJ/kg. While producing the gas, if we used 1 kg of biomass almost 400 – 450 gm of gas along with remaining amount of charcoal is also obtained. Coal is obtained as by-product of the Pyrolysis process. Testing of coal had been done on bomb calorimeter in laboratory of ENMOS Private Limited Company. The calorific value came out to be 2045.1426 cal/gm, which is good for domestic purpose.

7. INVESTIGATION OF ENGINE PERFORMANCE

To check the rate of oxy hydrogen gas generated with respect to rate of current rise, a loss of weight of electrolyser is noted for given period of time and current. Current passing through electrodes is increased from 1 ampere to 3 ampere in step of 1 ampere. Figure 6 shows that with increase in the time for which the current is flowing through electrolyser, weight of electrolyser decreases. Larger the weight loss larger is the gas generation weight. Also with increase in amplitude of current the rate of generation increases. For larger gas generation it is possible to increase the amplitude of current as well. As the engine keeps on consuming the oxy hydrogen the level of electrolytic solution in the electrolyser decreases which further decreases the weight of the electrolyser.

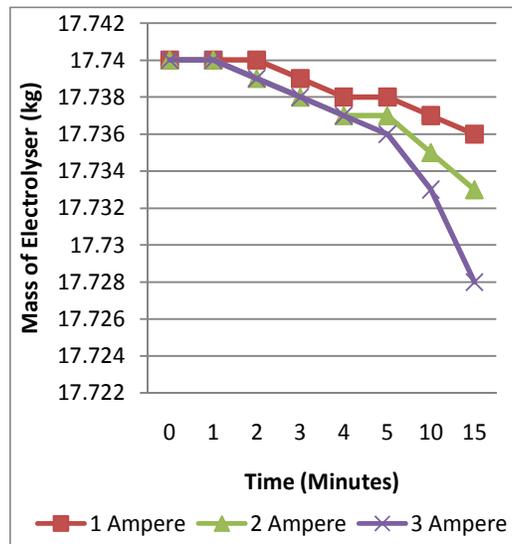


Figure 6 Time rate of gas generation with decreased weight of Electrolyser

All the designs of electrolyzers were tested on twin cylinder four stroke diesel engine, technical specifications of which can be seen in table 4. All of them showed the improvement in the operating characteristics of engines when blend of oxy hydrogen is send with conventional fuel. Whichever may be the generation method used for production of oxy hydrogen gas, there is little effect of it as far as change in the improved performance of the engine is concern.

Table 4 Technical Specifications of engine

Configuration	Inline twin cylinder
Type	Direct Injection
Stroke	100 mm
Bore	87.5 mm
Maximum Power	13 BHP @ 1500 RPM
Compression Ratio	18:1
Firing Order	1,2
Cooling System	Water Cooled

In order to investigate the performance variation between oxy hydrogen gas and producer gas, amongst the various methods for oxy hydrogen gas generation, second design of first method is used. The reason for this is the very high rate of oxy hydrogen gas generation. To make comparison between both the alternative fuels discussed earlier, load tests are carried out the same twin cylinder diesel engine. Brake Specific Fuel Consumption, Brake Thermal Efficiency, Speed and Load are the parameters which were kept under observation during the tests. Following graphs are used to discuss the comparison. Figure 7 shows the variation of brake specific fuel consumption with increase in load for both the alternative fuels.

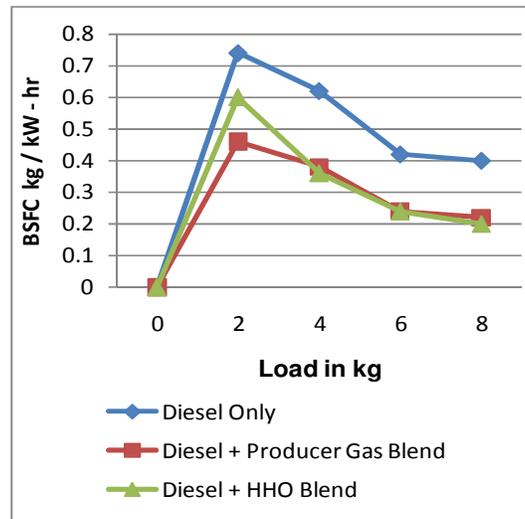


Figure 7 Variation of Brake Specific Fuel consumption in kg/kW-hr v/s load in kg

From the trend of the variation shown in graph, it is very clear that BSFC of the engine reduces when both the alternative fuels are used in blend with diesel instead of only diesel. The reduction in BSFC is due to uniform mixing of oxy hydrogen gas with air due to its high diffusivity. At high speed the diesel is hard to burn completely at lean condition due to the increased residual gas fraction and poor mixing. Since HHO gains a high flame speed and

wide flame mobility, the addition of hydrogen would help the fuel to burn faster and more completely. Lesser values of BSFC are also because some amount of diesel is replaced by oxy hydrogen gas during the process of combustion. So some amount of required input energy is supplied by oxy hydrogen gas and the amount of diesel required to produce the equivalent energy is saved.

Same is the reason for the lower values of BSFC in case of producer gas and diesel blend. Almost 11% of Hydrogen in the producer gas makes it possible again. Amongst both the alternative fuels the oxy hydrogen gas has shown larger decrease in the values of BSFC especially when the load increases. At the maximum load of 8 kg during testing almost 200 grams of less fuel is required to produce same power hour, with both alternative fuels, oxy hydrogen gas is having little more edge on the producer gas. Figure 8 shows the variation of brake thermal efficiency with increase in load for both the alternative fuels.

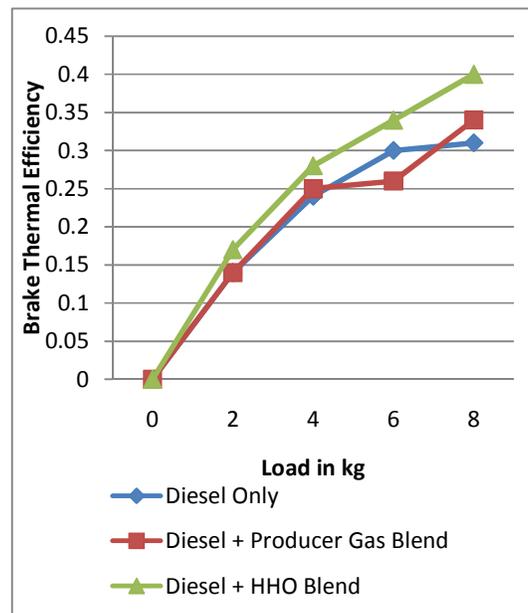


Figure 8 Variation of Brake Thermal Efficiency in % v/s Load in kg

From the graphs of Brake Thermal Efficiency v/s load it is clear that as the load on the engine increases, brake thermal efficiency further increases for the blend of both alternative fuels and diesel compared to only diesel. Presence of hydrogen releases greater energy during the process of combustion. That increases the brake mean effective pressure inside the combustion chamber. More work is done onto the piston which increases brake power of the engine as well. Increase in brake power increases the thermal efficiency of the engine. An increase of almost 10% in the efficiency is observed with the oxy hydrogen and diesel blend, compared to only diesel and an increase of almost 5% is observed with the producer gas and diesel blend, compared to only diesel.

Figure 9 shows the variation in the speed of the engine with increasing load for both the alternative fuels. Graph of Speed v/s Load shows same trend discussed earlier. At the same load condition the RPM of the engine increases for both the blends compared to only diesel. As power developed by engine is directly proportional to the engine RPM, it is natural that with the blends power produced by the engine increases.

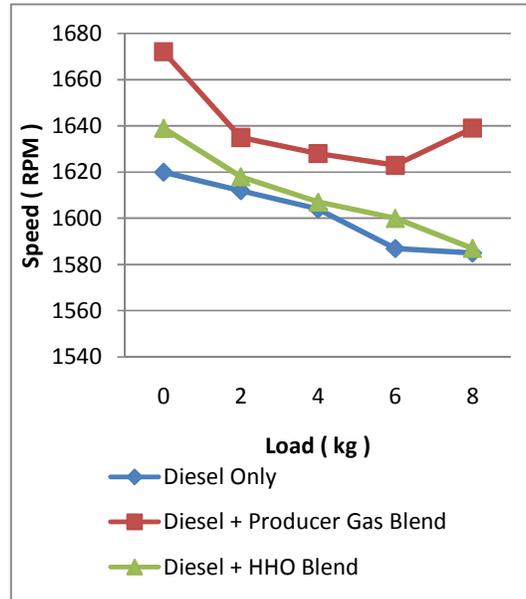


Figure 9 Variation of Speed in RPM v/s Load in kg

8. CONCLUSION

Experimental tests to investigate the comparison between oxy hydrogen gas and producer gas are carried out on twin cylinder diesel engine. Oxy hydrogen gas has been generated by electrolysis process and producer gas by pyrolysis. Both the alternative fuels mixed with fresh air before entering the combustion chamber. BSFC, Brake thermal efficiency, speed and load are the performance parameters kept under observation. The following conclusions are drawn:

1. It is very easy to integrate both the alternative fuels with existing engine. No major hardware modification is required.
2. Combustion efficiency increases with both alternative fuels due to presence of hydrogen in the blend. Since hydrogen is present in larger quantity oxy hydrogen gas compared to producer gas, the oxy hydrogen and diesel blend has shown best combustion efficiency as a result of which larger values of BSFC and brake thermal efficiency are obtained for the same engine.
3. Presence of extra oxy in both alternative fuels helps to improve the combustion efficiency further more. Water vapour is one of byproduct of combustion process with oxy hydrogen and diesel blend. This decreases the combustion chamber temperature and thus decreases the chances of engine detonation. Very less amount of oxygen is available with producer gas and diesel blend hence it is not the case with this combination.
4. Cost of the producer gas generation is more compared to oxy hydrogen gas generation. Three phase AC power source is required for the generation of producer gas using pyrolysis process. Oxy hydrogen gas module requires only 12 V DC supply from the battery.
5. As far as implementation of both the alternative fuels with engine on automobiles is concern, oxy hydrogen gas is best suitable compared to producer gas. The size of the oxy hydrogen gas generation module is less and easy to install under hood of automobile engine. The size of the producer gas generation module is very large and nearly impossible to fit on automobile engines, hence best suitable for the stationary engines application like pump, generators etc. Coal is coming as one of the byproduct of the pyrolysis process, can be used for domestic purpose, and hence an added advantage.

6. Presence of oxy hydrogen gas during the process of combustion decreases the hydrocarbon emissions from diesel engine [14]. Reduction in HC is observed because of short quenching distance and wide flammability range of hydrogen present in large quantity in oxy hydrogen and diesel blend. Also an increase in turbulence intensity mixing process of burnt and unburnt gases increases the oxidation rate of HC thereby decreasing the HC emission from engine. More percentage of unburnt gases in producer gas diesel blend helps in the reduction of NO_x from the diesel engine same as the exhaust gas recirculation (EGR) methods.

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