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*Research Paper*

# PERFORMANCE AND EMISSION CHARACTERISTICS BY USING OXYGEN ENRICHED COMBUSTION

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The internal combustion engine is one of the most widely used applications produced by engineering development. However, it is a very limited machine: it has an effective efficiency of 30-35%. This means that almost 70% of the chemical energy contained in the fuel is lost in the coolant, in the exhaust gases, as incomplete combustion of fuel and as radiation. Utilization of oxygen-enriched air in diesel engines holds potential for low exhausts smoke and particulate emissions. The majority of the oxygen enriched-air combustion-related studies so far are experimental in nature, where the observed results are understood on an overall basis. This paper deals with the fundamental considerations associated with the oxygen-enriched air-fuel combustion process to enhance understanding of the concept. The increase in adiabatic flame temperature, the composition of exhaust gases at equilibrium, and also the changes in thermodynamic and transport properties due to oxygen-enrichment of standard intake air are reviewed. The notion of oxygen-enrichment of standard intake air as being akin to leaning of the fuel-air mixture is refuted on the basis of the fundamentally different requirements for the oxygen-enriched combustion process.

Keywords: Oxygen enriched combustion, Adiabatic flame temperature

## INTRODUCTION

The purpose of IC engine is the production of mechanical power from the chemical energy contained in the fuel. In IC engines, as distinct from external combustion engines, burning or oxidizing the fuel inside the engine releases this energy. The air fuel mixture before combustion and the burned gases after combustion are actual working fluids. The work transfer which provides output occurs directly between these working fluids and the mechanical components of the engine.

There has been a great concern, in recent years, that the internal combustion engine is

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responsible for too much atmospheric pollution, which is detrimental to human health and environment. Thus it is required to think something in the direction of reducing emission without sacrificing power and fuel consumption.

The principal challenge to continuing success is control of its emission to conform the tightening legislations to protect the environment. If limits of diesel emissions become too stringent, the automotive diesel, for both commercial and private use, may have a very uncertain future and the inherent benefits of the good fuel efficiency is wasted. If not most serious, certainly the most conspicuously annoying feature of the diesel engine is its exhaust smoke. It is often regarded with far more hostility than the relatively invisible engine exhaust.

Most of the diesel engines are now sold with retarded fuel injection timing and a re-optimized lower swirl combustion system to keep NOx levels low. These remedies, however, are reaching their limit of effectiveness. Some diesel engines use EGR to further reduce NOx, particularly for passenger use. Another method of NOx reduction is by utilizing water. Numerous studies are now under way on emulsified fuels and water injection into the air intake pipe or directly into the cylinder. Increasing the concentration of oxygen in the combustion chamber is one method which will reduce HC, CO and smoke and could also improve the brake thermal efficiency. It will also affect the formation of NOx directly and indirectly.

The concept of oxygen enrichment aims at limited substitution of the nitrogen in air by oxygen to achieve low emission levels. Because of the increased oxygen content, additional fuel is burned. The resulting increase in power output is a beneficial offshoot, though it is not attempted for its own sake. Oxygen-enrichment of combustion air provides an opportunity to achieve ignition with minimum amounts of premixed fuel because it reduces the ignition delay period under all operating conditions.

Studies of the effects of oxygen enrichment on direct injection (DI) diesel engine have been carried out with the objective to reduce smoke emissions carried out by Dr R Anand and Dr Mahalakshami. It was found that 25% oxygen enrichment in the inlet air results 10% oxygen flow in the optimum performance and emission characteristics (Anand and Mahalakshami, 2006).

Increasing the oxygen content with the air leads to faster burn rates and the ability to burn more fuel at the same stoichiometery. Added oxygen in the combustion air leads to shorter ignition delays and offers more potential for burning diesel (Rajkumar and Govindrajan, 2010).

Cold-phase emissions was reduced by using oxygen-enriched intake air containing about 23% and 25% oxygen (by volume) in a vehicle powered by a spark-ignition (SI) engine. The experiment was carried out by R. Poola, R. Sekar and

C. Colluci. Test results indicate that the engine-out CO emissions during the cold phase were reduced by about 46 and 50%, and HC by about 33 and 43%, using nominal 23 and 25% oxygen-enriched air compared to ambient air (21% oxygen by volume), respectively. However, the corresponding oxides of nitrogen ($NO_3$ emissions were increased by about 56 and 79%, respectively (Poola *et al.*, 1995).

The increase in adiabatic flame temperature, the Composition of exhaust gases at equilibrium, and also the changes in thermodynamic and transport properties due to oxygen-enrichment of standard intake air are computed. The effects of oxygen-enrichment on fuel evaporation rate, ignition delay, and premixed burnt fraction are also evaluated. Appropriate changes in the ignition delay correlation to reflect the effects of oxygen-enrichment are proposed by Lahiri and Mehta. There is a considerable increase in thermal conductivity of gases with increase in oxygen enrichment and increase in maximum adiabatic temperature and considerable reduction in ignition delay (Lahiri and Mehta, 1997).

The effects of excess feeding oxygen to the fuel-air mixture on air and fuel mass flow rates and also on air-fuel ratio were investigated here experimentally by Momani *et al.* This study concerned with the effects of injecting pure oxygen quantity to the mixture of fuel and air before interring the combustion chambers. It is found that the mass flow rate of fuel with the oxygen feeding is less than that of with no oxygen feeding at some specific values of engine speeds and the same thing was found for air mass flow rate. The air-fuel ratio also is less with considerable values in the case with oxygen feeding than that with no oxygen samples (Momani *et al.*, 2009).

The experiment was carried out by Sekar and Poola (1997) in which direct injection diesel engine was treated as with intake oxygen level of 35%. They concluded that there is an increase in power density potential with increase in oxygen level. Thermal efficiency and fuel consumption is slightly improved with oxygen enrichment. As NOx emission increases with increase in oxygen enrichment, small amount of water is injected to control the NOx emission. Small emulsification of fuel does not affect the engine performance and reduces NOx emission.

## COMBUSTION PROCESS

Combustion processes have been and will be the prime generator of energy to our civilization in the near future. It can be defined as a chemical reaction during which a fuel is oxidized and a large quantity of energy is released, in common, the oxidizer in this process is atmospheric air, specifically the oxygen element in the air, which forms 21% of it. In other words, chemical energy is stored in the fuels, and it's released during combustion process in the form of thermal energy.

The two active elements in fuels are carbon and hydrogen. Ideally, combustion breaks down the molecular structure of the fuel; the carbon oxidizes to carbon dioxide ($CO_2$) and the hydrogen to water vapor ($H_2O$), but an incomplete process creates undesirable and harmful products. Carbon can produce two compounds depending on the availability of the air supply and these two compounds are very helpful in analyzing combustion process as the following:

If enough air is supplied to the fuel during combustion, carbon dioxide ($CO_2$) will appear in the products plus release of heat, and if the supplied air is exactly the theoretical air needed then the exhaust gaseous products consists of 21% carbon dioxide ($CO_2$), about 78% Nitrogen, and 1% of various gases, plus release of heat.

When the air supply is not sufficient the carbon partially is burnt to carbon monoxide (CO) and the full calorific value of the fuel will not released, this is known as incomplete combustion which is one of the combustion process main sources of heat losses.

There are many contributing reasons to why a combustion process becomes incomplete in an actual case. One of the easiest reasons to see is that a lack of oxygen leaves some of the fuel unburned. But also incompletion can be attributed to insufficient mixing between fuel and oxygen in the combustion chamber due to the short time intervals in which these combustions are occurring. Another cause for incompletion is because of a process called hydrogen bonding. Hydrogen bonding is a process in which chemical bonds form between molecules containing a hydrogen atom bonded to a strongly electronegative atom (an atom that attracts electrons). Because the electronegative atom pulls the electron from the hydrogen atom, the atoms form a very polar molecule, meaning one end is negatively charged and the other end is positively charged. Hydrogen bonds form between these molecules because the negative ends of the molecules are attracted to the positive ends of other molecules, and vice versa.

## OXYGEN ENRICHED COMBUSTION

Oxygen Enhanced Combustion (OEC) has become one of the most attracting combustion technologies in the last decade, two developments have increased the significance of it, the first one is the new technology of producing oxygen less expensively and the second one is the increased importance of environmental regulations.

The principle of this technology is to use air with higher oxygen concentration in the combustion process as an intake air, this will reduce the volume of unnecessary nitrogen enters the process. Advantages of oxygen-enhanced combustion include numerous environmental benefits as well as improving energy efficiency and productivity.

## METHODS OF OXYGEN ENRICHMENT IN COMBUSTION PROCESS

There are three commonly used methods to enhance combustion process with oxygen:

**Air Enrichment:** In this method the oxygen is injected into the incoming combustion air supply through a diffuser to ensure adequate mixing. This method may be referred to as low-level $O_2$ enrichment or premix enrichment. Many conventional air/fuel burners can be adapted for this technology by making small modifications. The advantage of this method that it is usually an inexpensive retrofit that can provide substantial benefits. On the other hand, it has a disadvantage; the added $O_2$ will shorten and intensify the flame. However, there may be some concerns if too much $O_2$ is added. The flame shape may become unacceptably short, and the high flame temperature may damage the combustion chamber.

**$O_2$ Lancing:** In this method the $O_2$ is injected directly to the flame describes the process schematically; this $O_2$ injection method is also generally used for lower levels of $O_2$ enrichment. However, oxygen lancing may have several advantages over air enrichment. First, no modifications to the existing chamber design need

Figure 1: Air Enrichment Method

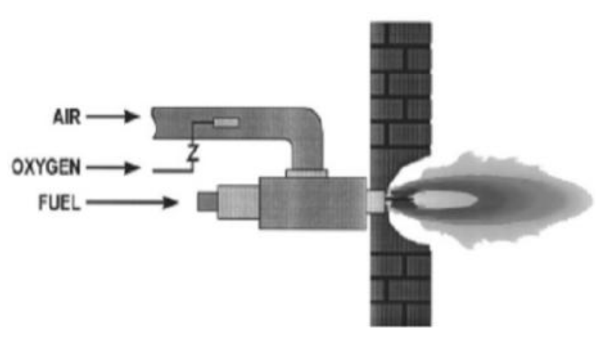
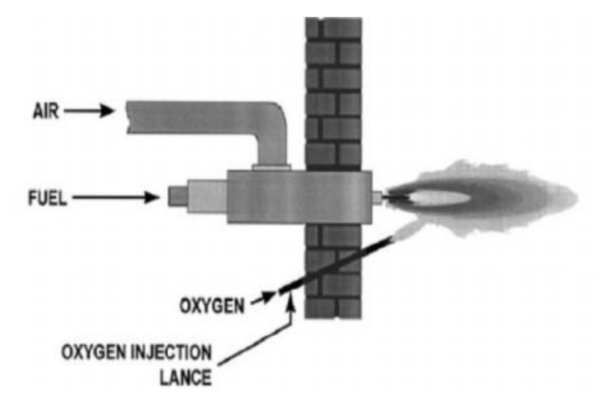


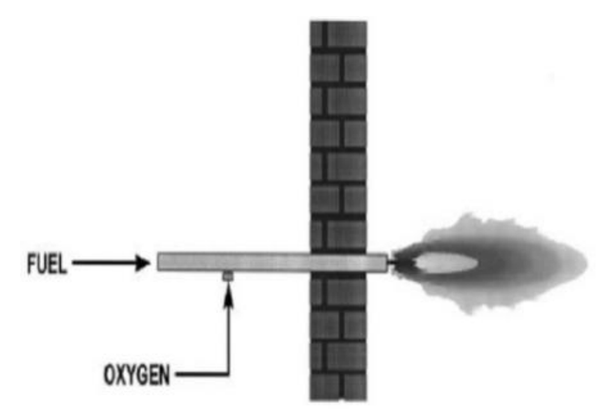
Figure 2: $O_2$ Lancing Method




to be made. Second, the NOx emissions are lower using $O_2$ lancing compared with premixing since this is a form of staging, which is a well-accepted technique for reducing NOx. Third, Depending on the injection location, the flame shape may be lengthened by staging the combustion reactions which improves the heat transfer efficiency.

**Oxy/Fuel:** The third oxygen enrichment method which is mixing $O_2$ with the fuel supply, it is commonly referred to as oxy/fuel combustion. In this method, high-purity oxygen (>90% $O_2$ by volume) is used to combust the fuel and it has the greatest potential for improving a process, but it also may have the highest operating cost.

Figure 3: Oxy Fuel Method

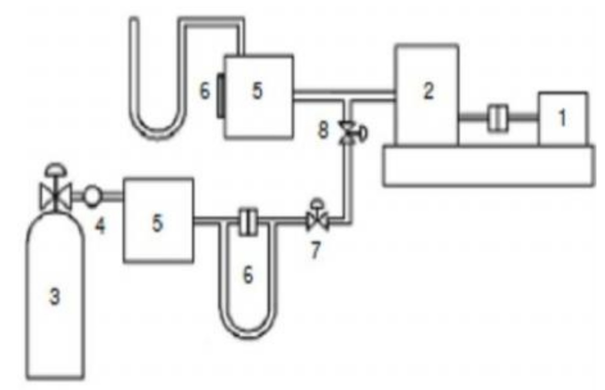



One specific variation of oxy/fuel combustion, known as dilute oxygen combustion, is where fuel and oxygen are separately injected into the combustion chamber. In order to ensure ignition, the chamber temperature must be above the auto-ignition temperature of the fuel.

## EXPERIMENTAL SET UP

To perform this experiment a single-cylinder, 4-Stroke, water-cooled diesel engine of 5 hp rated power is considered. The engine is coupled to a rope brake dynamometer through a load cell. The schematic layout of the experimental set up is shown in Figure 4.

Figure 4: Experimental Set Up

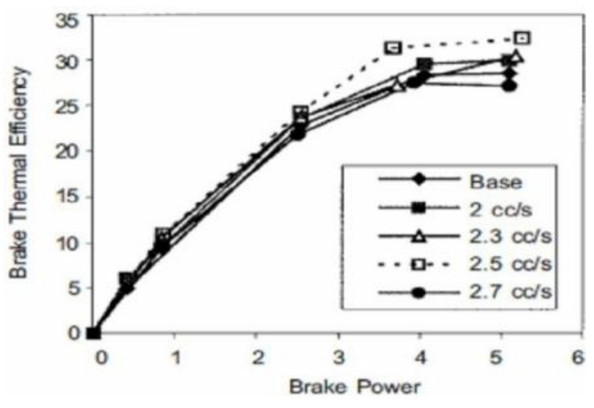



## EFFECT OF OXYGEN ENRICHMENT ON THE ENGINE PERFORMANCE AND EMISSION

### Brake Thermal Efficiency

There is an improvement in the brake thermal efficiency at all loads when the oxygen flow rate is enhanced as shown in Figure 5. This improvement is may be due to better combustion with enhanced oxygen flow rate. However, brake thermal efficiency falls as the oxygen flow rate is increased to 2.7 cc/s (Udaykumar and Meher, 2004).

Figure 5: Variation of Brake Thermal Efficiency with Brake Power




### Specific Fuel Consumption

The variation of Specific Fuel Consumption (SFC) at various power outputs of the base engine is compared with the modified engine at increased oxygen flow rates in Figure 6. There is a fall in the SFC at all loads when the oxygen flow rate is enhanced (Udaykumar and Meher, 2004).

### NOx Emission

NOx emission significantly increases with increase in oxygen level. It raises from 625 ppm for the base engine to 878 ppm with 2.5 cc/s flow rate of oxygen level. CO and HC emission

Figure 6: Variation of Specific Fuel Consumption with Brake Power

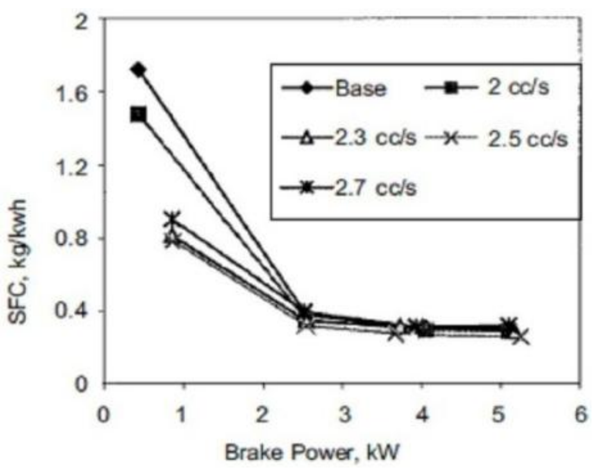
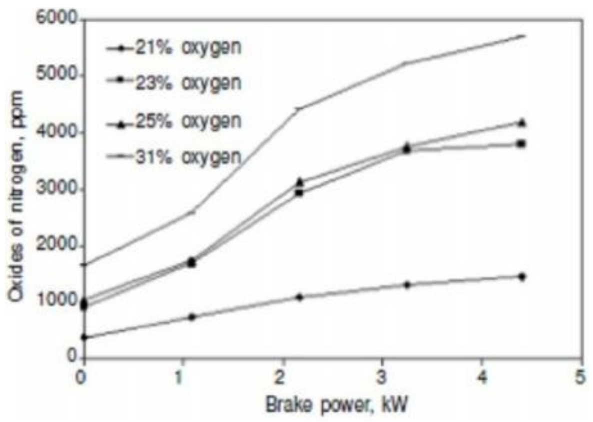



Figure 7: Effect of Oxygen Enrichment on NOx Emission




reduces with increase in oxygen enrichment (Udaykumar and Meher, 2004).

## CONCLUSION

It is obvious from the literature review that by increasing the oxygen level in air the combustion efficiency is improved considerably. By using oxygen enriched air the brake thermal efficiency of the engine is considerably increased and it obviously reduces the fuel consumption and CO, HC, PM emission. The aim of the experiment is to find out the correct concentration of the oxygen in atmospheric air to achieve an optimum engine performance and minimum exhaust emission.

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