# Efficiency Improvement of Diesel Engine Pump sets through Oxygen Enrichment by Vacuum Swing Adsorption Method-A Overview

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***ABSTRACT :*** *It is estimated that there are approximate 10 million diesel pumps that are in use nationwide. The population of stationary diesel engine is expected to continue to grow.Normally in diesel engines lots of power lost is take place because of friction loss, heat loss and due to incomplete combustion of fuel. There is no efficient way of reduction in power loss due to incomplete combustion of fuel. Complete combustion of fuel can be achieved by supplying sufficient amount of oxygen. One of the best solutions to increase efficiency of the engine by complete combustion is Oxygen enrichment by Vacuum Swing Adsorption Method. Oxygen enrichment in diesel engine i.e. increased amount of oxygen in the air is to be supply to the engine intake. Hence rise in the amount of oxygen will increase the power developed by engine.*

***Keyword-*** *Complete Combustion, Diesel Engine, Efficiency, Oxygen enrichment, Vacuum Swing Adsorption.*

## I. INTRODUCTION

Diesel engines provide important fuel economy and durability advantages for stationary diesel pump set. The diesel-powered pumping plant should be viewed as a system of at least FOUR components:

1. The power source
2. The transmission system (gear drive, line shaft, v-belts, close-couple)
3. The pump itself
4. The management of the system

Water is the primary source of life for mankind and one of the most basic necessities for rural development. The rural demand for water for crop irrigation and domestic water supplies is increasing. At the same time, rainfall is decreasing in many arid countries, so surface water is becoming scarce. Groundwater seems to be the only alternative to this dilemma, but the groundwater table is also decreasing, which makes traditional hand pumping and bucketing difficult. As these trends continue, mechanized water pumping will become the only reliable alternative for lifting water from the ground. Diesel, gasoline, and kerosene pumps (including windmills) have traditionally been used to pump water. However, reliable solar (photovoltaic [PV]) and wind turbine pumps are now emerging on the market and are rapidly becoming more attractive than the traditional power sources. These technologies, powered by renewable energy sources (solar and wind), are especially useful in remote locations where a steady fuel supply is problematic and skilled maintenance personnel are scarce. Although they are often the power plant of choice for stationary applications, they have the disadvantage of emitting significant amounts of particulate matter (PM) and oxides of nitrogen (NOx), and lesser amounts of hydrocarbon (HC), carbon monoxide (CO), and toxic air pollutants.

### (A) Introduction to Oxygen Enrichment

Oxygen enrichment is process of increasing the proportion of oxygen in air. In air 23% oxygen, 73% nitrogen and 4% other gases are available. Oxygen can be produced by separating oxygen and nitrogen from air and also by separating hydrogen and oxygen from water.

### (B) Different Methods For Oxygen Enrichment

(I) Method of oxygen cylinder: - In this method cylinder filled with compressed oxygen is directly inserted to the air. Here pure oxygen is filled in the cylinder as a result in this method we don't require to produce the pure oxygen at the place of utilization. Limitation of this method is that we have to refill or replace the cylinder frequently, it is very heavy and bulky and it is not financially viable.

(II) Adsorption method: Adsorption processes are based on the ability of some natural and synthetic materials to preferentially adsorb nitrogen. In the case of zeolites, non-uniform electric fields existing void spaces of the material, causing preferential adsorption of molecules, which are more polar sable as those that have greater electrostatic Quadra polar moments. Thus, in air separation, nitrogen molecules are more strongly adsorbed than oxygen molecules, **A.R Smith et. al. [1]** . More than 90% pure oxygen can be produced and mixed with air to produce oxygen enriched air. There are three types of adsorption methods to separate oxygen from air which are as below.

(a) Pressure swing adsorption (PSA) method: - In this method pressurised air is pass through the adsorbents, where nitrogen molecules are adsorbed and pure oxygen can be generate. For PSA compressor is necessary to supply pressurised air. In this method complicated valve mechanism is used to operate the flow of air, nitrogen and oxygen.

(b) Vacuum swing adsorption (VSA) method: In this method vacuum is created inside the adsorbent bed which is connected to the air and air pass through the bed where nitrogen will adsorbed and oxygen molecules will pass out. For VSA vacuum pump is utilize to create vacuum. No complicated valve mechanism required, simple valve can operate the flow of oxygen and nitrogen.

**(C) Effect on Combustion Parameter**

Oxygen enrichment affects so many parameters of the combustion process which are as below,

(I) Ignition Delay**:** Oxygen enriched air have revealed large decrease of ignition delay stated by Rakopoulos National Technical University of atherns [7]. From the literature it was clear that reduction in ignition delay can be achieved with oxygen enrichment. The ignition delay can be divided in to two part i. Physical delay ii. Chemical delay. Effect of oxygen enrichment does not influence physical delay but it has greater influences on chemical delay. This is due to more oxygen molecules present in the air helps the rate of chemical reaction in fast manner. From that it was clear that oxygen enriched combustion plays a considerable role in decreasing the ignition delay period.

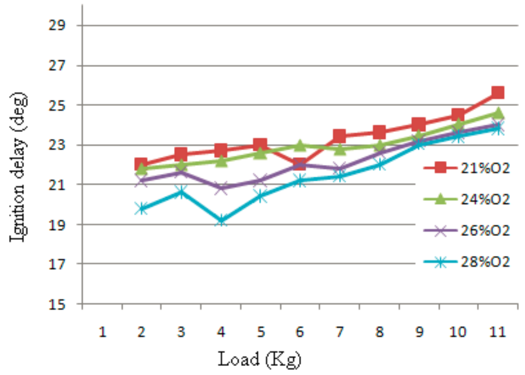


Fig 1.1 Ignition delay VS load on engine for different oxygen enrichment level

(II) Combustion duration: Fuel oxygen enrichment results in an increase of brake specific consumption and a reduction of combustion duration [8].

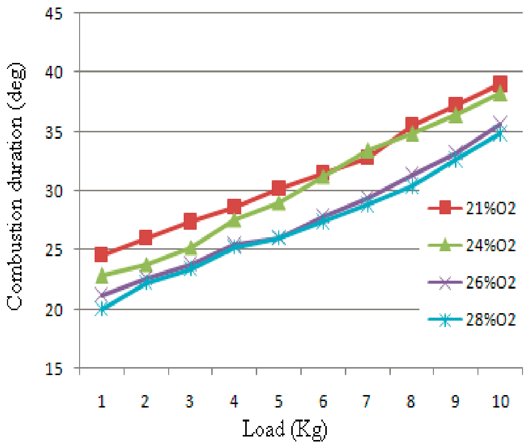


Fig.1.2 Combustion duration VS load for various oxygen percentages

(III) Heat Release: In a diesel engine, combustion occurs via a flame. Hence at any point in time, only a fraction of the total fuel is burning. This results in low peak pressures and low energy release rates. In oxygen enriched combustion the fuel/air mixture ignites and burns in a fast rate resulting in high peak pressures and high energy release rates. Rates of heat release from fuel combustion are closely related to peak combustion temperature hence high combustion temperature leads to maximum rate of heat release.

### (D) Effect on Power Production

A constant oxygen-to-fuel ratio was used as the basis to compare engine performance under different levels of oxygen enrichment in the intake air. The mass of fuel injected per cylinder per cycle was increased proportionally to the oxygen level in the intake air to maintain a constant oxygen-to-fuel ratio. The gross brake power, bsfc, bmep, and peak cylinder pressure obtained when oxygen levels ranged from 21% to 35%. The model predictions indicate that cylinder brake power significantly increases when the intake air oxygen concentration increases from 21% to 35%. A substantial output improvement can be achieved as the result of a relatively small increase in oxygen content to 23% by volume; while up to 90% improvements can be achieved when the oxygen content is increased to 35%. When the intake oxygen content was increased from 23% to 35%, the cylinder brake output increased from about 10% to 90%. At lower oxygen level the cylinder output increased even more, by approximately 12% and 110% at oxygen-enrichment levels of 23% and 35%, respectively. The enhanced power output resulting from oxygen enrichment was accompanied by higher bmep and lower bsfc. The implied thermal efficiency improvements are attributed to faster bum rates, particularly during the diffusion phase of combustion by **Assanis, D.N. *et al.*,[9]**. Despite the advantages of lower bsfc, higher cylinder output, and higher bmep, the peak cylinder pressures were higher by about 3% to 35% when the intake air oxygen level was increased from 23% to 35%, respectively, over ambient air. However, the increase in peak cylinder pressure was smaller than the increase in cylinder output. This feature of the oxygen-enriched engine is attractive, particularly because some of the other techniques for increasing power output (increased compression ratio, high boost turbo charging) typically yield power improvements proportional to peak pressure increases by **Ramesh B. Poola *et al.*,[2]**.

### (E) Effect on Emission

Carbon monoxide: CO is generally produced due to incomplete combustion of a carbon containing fuel. Generally a combustion system operated with high excess air leads to complete combustion and to minimize CO emissions compared with conventional system, due to more complete combustion. When using high levels of oxygen enrichment causes thermal dissociation, Hence CO is converted to $CO_2$ at high temperatures. With Oxygen enriched combustion, the engine-out hydrocarbon, CO and smoke emissions throughout the whole start-up process were all reduced considerably **Xiao *et al.*,[10].**

Carbon Dioxide: The CO2 emissions increased with load for all the fuel modes. Higher percentage of CO2 in the exhaust indicated higher oxidation of fuel at the constant engine speed and release of more heat for power conversion. It also indicated better combustion as more fuel was converted from CO-CO2. An average of 5-21% increase in CO2 was obtained for the enrichment level of 1LPM. A maximum of 29% increase 33% increase in CO2 was obtained for enrichment level of 2LPM and 3LPM respectively. When comparing with percentage reduction of CO, the increase in CO2 percentage was less. It was concluded that oxygen enriched combustion increases CO2 emissions slightly, **K.Rajkumar *et al.*,[6].**

$NO_x$ Emission: $NO_x$ There are three accepted mechanism for NOx production. Thermal NOx is produced by the high temperature reaction of nitrogen with oxygen.($N_2 + O_2 = NO, NO_2$). Prompt NOx is formed by the relatively fast reaction between nitrogen, oxygen and hydrocarbon radicals ($CH_4 + O_2 + N_2 = NO, NO_2, CO_2, H_2O$). Prompt NOx is generally an important Mechanism at lower-temperature processes. Fuel NOx is formed by the direct oxidation of Oregano nitrogen compounds contained in the fuel ($RxN + O_2 = NO, NO_2, CO_2, H_2O$). Higher post-flame temperature and oxygen concentrations during the combustion process result in high No formation rates. Oxygen enriched combustion yields higher $NO_x$, **Xiao *et al.*[10]**.

## II. PRINCIPLE AND OPERATION

Fig. 1.3 shows four bed vacuum swing adsorption method for the oxygen enrichment. In this system four cylinder of identical size are filled with adsorbing material like zeolite sieve. One end of all the cylinders is open to the atmosphere and other end of the cylinders is connected to the vacuum pump through valve.

When engine starts, vacuum pump or air blower which is coupled with the engine shaft will creates vacuum inside the adsorbing bead. So that air enters from the atmosphere to the cylinder A. As air passes through the sieve bed, nitrogen, HC and other molecules are adsorbed while oxygen passes out to the mixing chamber. After few seconds sieve bed A will become saturated by nitrogen molecules. At that time air starts to flow through cylinder B, while adsorbed nitrogen in cylinder A is desorbed to the atmosphere in the form of gas. These processes continuously run in one by one in four cylinders.

Oxygen from the cylinders is mixed with the air in desired proportion and it is maintained constant. Due to addition of oxygen in the air, we get oxygen enriched air. This enriched air is supplied to the intake of engine.

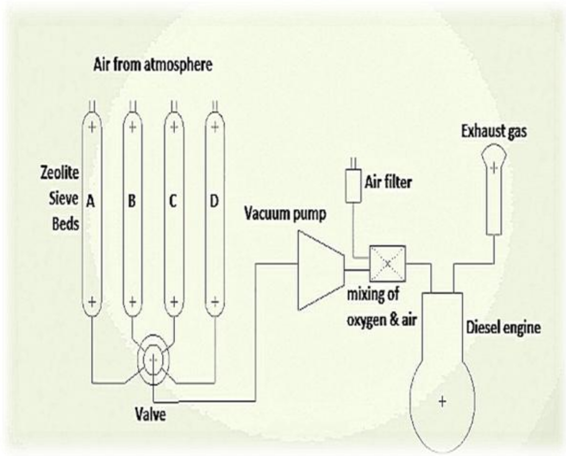


Fig.1.3 Proposed Model of VSA System with Experimental setup

It will provide more oxygen to complete the combustion of fuel. Hence due to complete combustion more power produces and brake specific fuel consumption will decrease. It will also reduce the emission of unburned HC and CO.

## III. COMPONENTS PROPOSED MODEL EXPERIMENTAL SETUP

1. Diesel Engine – A single cylinder diesel engine can be used for the testing Oxygen enrichment setup. Component for the enrichment system are as given below. Specification of the engine is as below.

- Turning speed: 1500 rpm
- Stroke length : 85mm
- Compression ratio: 16.7:1

2. Zeolite Bed – In zeolite bed the cylinders are partially filled with zeolite MS 5A which we are using as adsorbent material. We are using four bed adsorption method. For that we require 4 bed of zeolite which are connected with the engine intake. For the adsorption vacuum is required to produce inside the cylinder bed.

Fig.1.4 Zeolite MS5

3. Vacuum Pump- vacuum pump to produce vacuum inside the four cylinders. vacuum pump is utilized to create required vacuum in zeolite beds to adsorb the nitrogen. Oxygen from these beds is pass through pump to the engine. Vacuum pump is directly coupled to the engine.

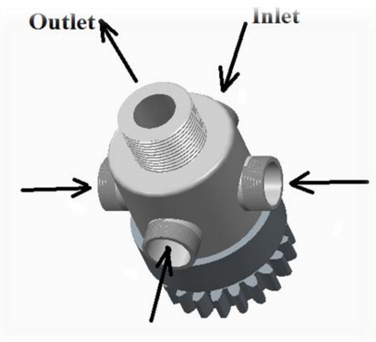


Fig.1.5 Four way centre bore valve

4. Valve - Four ways center bore valve is used to connect four cylinders to the vacuum pump. This valve connects any one cylinder with the vacuum pump at a time. This valve will rotate by engaging with the engine shaft though gearing.

5.Mixing Chamber- Air from atmosphere though air filter and oxygen from zeolite bed is mixed at here. Percentage of Oxygen and air mixer cab be control by using valve, like throttle valve inside. This mixture then supplied to engine intake.

## IV. CONCLUSION

Following are the major consideration:

1. Oxygen enrichment is one of the best solutions to increase efficiency of the engine by complete combustion.

2. Vacuum swing adsorption (VSA) Method play dominant role to increase efficiency by Oxygen enrichment in diesel engine i.e. increased amount of oxygen in the air is to be supply to the engine intake.

3. High Engine efficiency can be expected from Vacuum swing adsorption (VSA) Method.

## V. Acknowledgements

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## REFERENCES

1. A.R. Smith, J. Klosek , "A review of air separation technologies and their integration with energy conversion processes" *Air Products and Chemicals, Inc., Allentown, PA 18195, USA.*
2. Ramesh B. Poola , Raj Sekar, et al. "Study of Using Oxygen-Enriched Combustion Air For Locomotive Diesel Engines".
3. KuppusamyRajkumar and PalanisamyGovindarajan "Impact of Oxygen Enriched Air Intake on the Exhaust of a Single Cylinder Diesel Engine" *American Journal of Environmental Sciences 7 (2): 136-140, 2011*
4. WaleedMomani, "The Effects of Excess Oxygen to Mixture on the Gasses Emissions of a Gasoline Engine "*American Journal of Applied Sciences 6 (6): 1122-1125, 2009.*
5. Kamalakkannan.K1, Bharath.P2, " Analysis of Fuel Consumption And Oxides Of Nitrogen Using Oxygen Enriched Air In Compression Ignition Engine" *Ijret Eissn: 2319-1163 | Pissn: 2321-7308*
6. KuppusamyRajkumar and PalanisamyGovindarajan "Experimental Investigation of Oxygen Enriched air intake on Combustion Parameters of a Single Cylinder Diesel Engine" *International Journal of Engineering Science and Technology Vol. 2(8), 2010, 3621-3627*
7. C.D.Rakopoulos et al., Operational and environmental evaluation of diesel engines burning oxygen-enriched intake air; A review SAE Transactions 113(2004) 1723-1743.
8. Theodoros C et al., DI Diesel Engine Performance and Emissions from the Oxygen Enrichment of Fuels with Various Aromatic Content, Internal Combustion Engines Laboratory, National Technical University of Athens
9. Assanis, D.N., R.R. Sekar, D. Baker, C.T. Ciambekos, R.L. Cole, and T.J. Marciniak, *Simulation Studies of Diesel EnginePerformance with oxygen Enriched Air and Water EmulsifiedFuels,* ASME Paper *90-ICE-1* 7, 1990
10. Xiao, G.F., X.Q. Qiao, Z. Huang and Z.P. Chen, 2007. Improvement of startability of direct-injection diesel engines by oxygen-enriched intake air. Proceed. Instit. Mech. Eng., Part D: J. Autom. Eng., 221: 1453-1465. DOI: 10.1243/09544070JAUTO541
11. Najafi, G., B. Ghobadian, T.F. Yusaf and H. Rahimi,2007. Combustion analysis of a CI engine performance using waste cooking Biodiesel fuel with an artificial neural network aid. Am. J. Applied Sci., 4: 759-767. DOI:10.3844/ajassp.2007.759.767