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# An Overview of the Vacuum Swing Adsorption Method for Oxygen Enrichment and Efficiency Improvement in Diesel Engine Pump Sets

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**ABSTRACT :** Approximately 10 million diesel pumps are thought to be in operation throughout the country. It is anticipated that the number of stationary diesel engines would keep increasing. In diesel engines, friction loss, heat loss, and incomplete fuel combustion often result in significant power loss. Power loss from incomplete fuel combustion cannot be effectively reduced. By providing a enough quantity of oxygen, fuel may be completely burned. The Vacuum Swing Adsorption Method of oxygen enrichment is one of the greatest ways to boost engine efficiency via full combustion. Diesel engines need oxygen enrichment, which involves supplying the engine intake with more oxygen from the air. Therefore, an increase in oxygen will boost the engine's power output.

**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

One of the most fundamental needs for rural development is water, which is also the main source of life for humans. Water is becoming more and more necessary in rural areas for household water supply and agricultural irrigation. Surface water is increasingly limited as rainfall declines in many desert nations. The only apparent solution to this problem seems to be groundwater, yet conventional manual pumping and bucketing are challenging due to the declining groundwater table. Mechanized water pumping will be the sole dependable option for extracting water from the ground as long as these trends persist. Water has historically been pumped using diesel, gasoline, and kerosene pumps (including windmills). However, dependable wind turbine and solar (photovoltaic [PV]) pumps are only starting to appear on the market and are quickly outperforming the conventional power sources in terms of appeal. These solar and wind-powered technologies are particularly helpful in isolated areas where reliable fuel supplies are difficult to come by and there is a shortage of qualified maintenance staff. They have the drawback of producing large quantities of particulate matter (PM) and nitrogen oxides (NO<sub>x</sub>), and smaller levels of hydrocarbons (HC), carbon monoxide (CO), and harmful air pollutants, while being the preferred power plant for stationary applications.

### (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 athenrs [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.

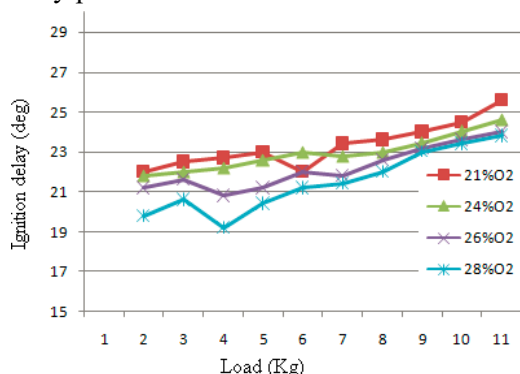


Fig 1.1 Ignition delay VS load on engine for different oxygen enrichment level

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

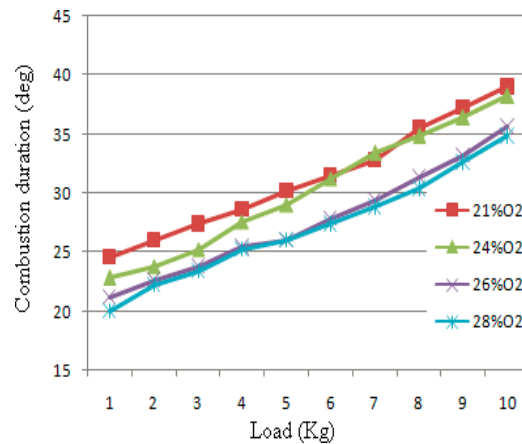


Fig.1.2 Combustion duration VS load for various oxygen percentages

(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.

#### (IV) Effect on Power Production

Engine performance under varying amounts of oxygen enrichment in the intake air was compared using a constant oxygen-to-fuel ratio as the foundation. To keep the oxygen-to-fuel ratio constant, the quantity of fuel injected per cylinder every cycle was raised according to the amount of oxygen in the intake air. Peak cylinder pressure, bsfc, bmep, and gross braking power were measured at oxygen levels between 21% and 35%. According to the model's predictions, as the intake air oxygen content rises from 21% to 35%, cylinder braking power increases dramatically. A very slight increase in oxygen content to 23% by volume may result in a significant gain in production, whereas an increase to 35% can result in benefits of up to 90%. The cylinder braking output rose from around 10% to 90% when the intake oxygen content was raised from 23% to 35%. The cylinder production rose even greater at lower oxygen levels, by around 12% and 110% at 23% and 35% oxygen enrichment levels, respectively. Higher bmep and decreased bsfc were associated with the increased power output brought about by oxygen enrichment. Assanis, D.N. et al. [9] credit the predicted increases in thermal efficiency to quicker burn rates, especially during the diffusion phase of combustion. When the intake air oxygen level was raised from 23% to 35%, respectively, above ambient air, the peak cylinder pressures rose by around 3% to 35%, despite the benefits of lower bsfc, greater cylinder output, and higher bmep. Nevertheless, the rise in cylinder output outweighed the rise in peak cylinder pressure. This oxygen-enriched engine characteristic is appealing, especially because Ramesh B. Poola et al. [2] have shown that various other methods of boosting power output (such as a higher compression ratio or high boost turbo charging) usually result in power gains proportionate to increases in peak pressure.

#### (D) 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<sub>2</sub> 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 .

**Carbon Dioxide:** The CO<sub>2</sub> emissions increased with load for all the fuel modes. Higher percentage of CO<sub>2</sub> 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-CO<sub>2</sub>. An average of 5-21% increase in CO<sub>2</sub> was obtained for the enrichment level of 1LPM. A maximum of 29% increase 33% increase in CO<sub>2</sub> was obtained for enrichment level of 2LPM and 3LPM respectively. When comparing with percentage reduction of CO, the increase in CO<sub>2</sub> percentage was less. It was concluded that oxygen enriched combustion increases CO<sub>2</sub> emissions slightly,

**NO<sub>x</sub> Emission:** NO<sub>x</sub> There are three accepted mechanism for NO<sub>x</sub> production. Thermal NO<sub>x</sub> is produced by the high temperature reaction of nitrogen with oxygen.(N<sub>2</sub> +O<sub>2</sub> = NO, NO<sub>2</sub>). Prompt NO<sub>x</sub> is formed by the relatively fast reaction between nitrogen, oxygen and hydrocarbon radicals (CH<sub>4</sub> + O<sub>2</sub> +N<sub>2</sub> = NO,NO<sub>2</sub>, CO<sub>2</sub>, H<sub>2</sub>O). Prompt NO<sub>x</sub>

is generally an important Mechanism at lower- temperature processes. Fuel NO<sub>x</sub> is formed by the direct oxidation of Oregano nitrogen compounds contained in the fuel (R<sub>x</sub>N+O<sub>2</sub> =NO, NO<sub>2</sub>, CO<sub>2</sub>, H<sub>2</sub>O). Higher post-flame temperature and oxygen concentrations during the combustion process result in high No formation rates. Oxygen enriched combustion yields higher NO<sub>x</sub>,

## 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.

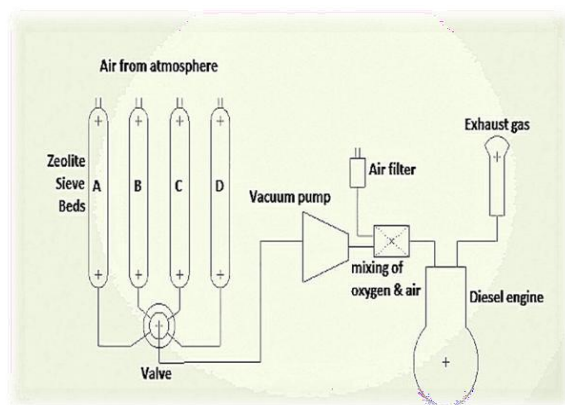


Fig.1.3 Proposed Model of VSA System with Experimental setup

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.

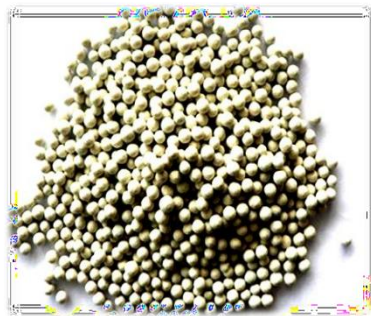


Fig.1.4 Zeolite MS5

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.

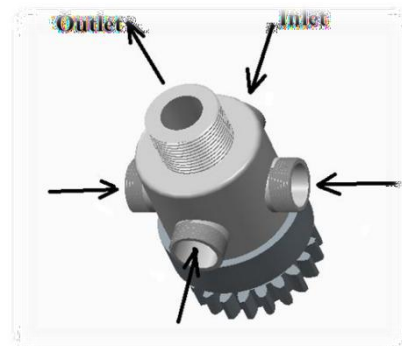


Fig.1.5 Four way centre bore valve

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 through 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

The main factors to consider are as follows:

1. One of the finest ways to boost engine efficiency via full combustion is through oxygen enrichment.
  
2. The vacuum swing adsorption (VSA) method is the main way to boost diesel engine efficiency via oxygen enrichment, which means that more oxygen in the air is supplied to the engine intake.
  
3. The Vacuum Swing Adsorption (VSA) Method is projected to provide high engine efficiency.

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