Improving Mechanical and Brake Thermal Efficiency by Using Zeolite Catalyst in IC Engine

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Abstract -- Due to the advancement of energy markets, emission norm satisfaction, meeting energy crisis and environmental protection requirements new challenges arise for the existing engineering designs. The objective of this project work is to increase the performance of the diesel engine and control its undesirable emission during the combustion. For that we made a little modification in diesel engine's air inlet arrangement system. That is the installation of zeolite air filter for oxygen enrichment. Chemically treated adsorbent zeolite act as a catalyst that trapping nitrogen molecule in inlet air and increase the concentration of oxygen content. Oxygen enriched atmospheric air is given to diesel engine that serves the function of increasing the combustion efficiency of the engine and reduce the hazardous exhaust emission particles.

Indexed Terms — zeolite, absorbent, fuel combustion, oxygen enrichment, zeolite air filter, crystal structure, fabrication, thermodynamics test

I. INTRODUCTION

To improve the performance characteristic of diesel engines [2] several researches was conducted. They are based on inlet air oxygen enrichment [2] through catalyst or using separate oxygen supply. The oxygen content of standard atmospheric air[7] is about 21% (by volume); oxygen enrichment technique increases this percentage to 22.5% (by volume). And result in more efficient combustion. This project work deals with the fabrication of such oxygen enrichment device called zeolite filter[4].

Zeolite is a adsorbent compound having cage like structure serve as a catalyst to trap's the nitrogen molecules from inlet atmospheric air and increase the oxygen concentration, [12] Thus it makes zeolite air filter is one of the improved method for oxygen enriched air supply for diesel engine. The present work is carried out in following phases.

1. Adsorbent Selection
2. Analysis of zeolite property
3. Preparation of zeolite air filter
4. Performance and Emission characteristics with and without zeolite air filter.

1.1 Necessity of This Project

The country has made significant strides during the last three decades, in renewable energy applications [11]. High energy needs are the root cause of these happenings. Now it's the situation for using the energy in a proper way to attain the maximum level of performance. Internal combustion engines [3],[6],[8] are 34% efficient, efficient means that 66% of whatever we spend of fuel is wasted, and nobody is doing anything about it. This project is an attempt to minimize the wastages of fuel. The Engines performance is based on many design and operating variables. Incomplete combustion in engines creates several performance-oriented problems. Supplying sufficient oxygen to the engine can rectify incomplete combustion occurrences. This project deals with increasing the oxygen content as well as the performance of the engine, which can be attained by the complete combustion [1],[5],[10].

The increased performances of an existing engine are attractive features in the market place in terms of

- Reduced operating costs
- Reduced fuel combustion
- Reduced capital cost
- Reduced emissions

1.2 Condition For Combustion In Ic Engine

Three elements are necessary for combustion. They are

- Combustible materials such as Fuel.
- Ignition source like Igniter.

- Inlet Oxygen supply

1.3 Effects of Oxygen Enrichment

- Increasing the oxygen content with the air leads to faster burn rates and the ability to control Exhaust Emissions.
- Added oxygen in the combustion air offers more potential for burning diesel.
- Oxy-fuel combustion reduces the volume of flue gases and reduces the effects of greenhouse effect also.
- Efficiency of engine was increased by complete combustion.

1.4 Adsorbent Selection

Adsorption can perform many separations that are impossible or impracticable by conventional technique such as absorption, distillation and even membrane-based system. The component used for adsorption is known as adsorbent. Inorganic materials such as alumina, silica and zeolite [4],[11]are the example for adsorbent.

1.5 Zeolite Adsorbent

Zeolites are aluminosilicates compound having stoichiometric blends of the two adsorbents silica and alumina. Internally zeolites are inherently crystalline and exhibits micro pores within those crystals that have uniform dimension. This fine crystal held together by binder.

II. CRYSTAL STRUCTURE AND MOLECULAR SIEVE

- The basic formula for zeolite molecular[13] sieves is $M_{2/n}O{\bullet}Al_2O_3{\bullet}_xSiO_2{\bullet}_yH_2O$. Where M is a cation of n valence.
- The fundamental building block of the molecular sieve crystal structure is a tetrahedral with four oxygen anions Surrounding a smaller silicon or aluminum cation. Sodium ions or other cations make up the positive charge deficit in the alumina tetrahedral, and each of the four oxygen anions is shared, in turn, with another silica or alumina tetrahedron to extend the crystal lattice in three dimensions.

The crystal structure of zeolite molecular sieves is honeycombed with relatively large cavities. Each cavity is connected through apertures or pores. The water of hydration is contained within these cavities. For the testing purpose Zeolite Na-Y type was selected. Fig 1 shows the Crystal structure of the Zeolite

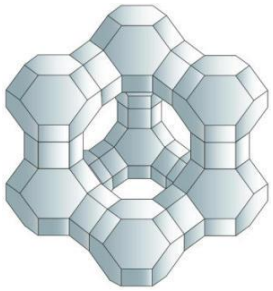

Fig 1: Zeolite Crystal Structure

2.1 Ion-Exchange Process of Zeolite

- The zeolite used for oxygen enrichment is shaped like a die with holes drilled on each face to form an internal cage. The corners of the die (providing the framework) are SiO_2 and AlO_2 units [4],[11]. Cations (either Na or K) are exposed throughout the crystal lattice.
- When nitrogen is in close proximity to the exposed cations of the zeolite crystal, a charge induced dipole forms and the nitrogen is attracted into the zeolite crystal. Nitrogen is more polarizable than oxygen.
- The internal surface area of zeolite is extremely large and so provides a high degree of adsorption per volume of zeolite.
- The cage like structures of zeolite have been carefully designed to allow only nitrogen to pass to their inside and to exclude the larger oxygen molecules. Fig 2 indicates Na cations

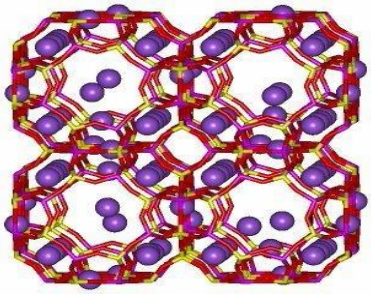

Fig 2: Na Cations Exposed in the Crystal Lattice

2.2 Preparation of Zeolite Air Filter:

Fig 3 consists of

1. card board
2. Plywood box
3. Steel bar
4. Spring hose
5. Adsorbent materials such as zeolite, silica powder and starch

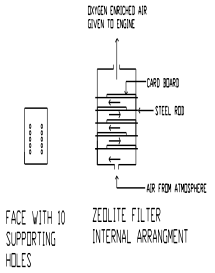

Fig 3 : Components of Zeolite

III. FABRICATION PROCEDURE

Let's take a square plywood box which internally covered with sheet metal. Square wood box having 4 faces, two opposite faces for supporting holes, other two opposite faces for ports.

Drill 5 X 2 metrics structure supporting holes on one set of opposite face.

- Each face having 10 supporting holes of 6mm diameter.
- Totally 20 holes are drilled on one set of opposite faces.
- Holes are connected by the steel bars to make a support for chemically treated cardboard.
- Totally ten supports are created, each support having one steel bar, two holes.
- Insert chemically treated cardboard in supports to form layer.
- One layer formed with two supports and one cardboard.
- Cardboard length is ¾ times to steel bar length.
- Totally 5 layers are created. Distance between the two adjacent layers is 4cm, the layers are arranged to make a zigzag air flow.
- Inlet, Outlet ports are created on other set of opposite faces.
- Inlet port of 2cm diameter is opened for air flow.
- Outlet port of 6cm diameter is connected to the orifice of air box through PVC pipe.
- Outlet port face of the wood box is easy to open and close.

3.1 Mixing of Chemicals

Proportion of chemicals:

- Silicon powder : 60%
- Zeolite powder : 25%
- Starch : 15%

Silicon and zeolite powders are mixed in 3:1 ratio, and then starch is mixed to convert powder form to gel form [4],[12]. Fig 4 explains the experimental setup of Zeolite.

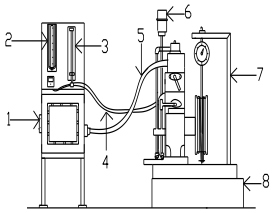

Fig 4: Experimental Setup

a. Orifice meter
b. Manometer
c. Fuel Measuring System
d. Diesel Tube
e. Inlet Air Tube
f. Exhauster
g. Pulley Brake Arrangement
h. Base

IV. PERFORMANCE TESTS ON IC ENGINE

Engines are tested to check the performance[11] under various operating conditions. Tests are two types. They are

- Commercial tests
- Thermodynamic tests

4.1 Purpose of Commercial Test

- To find the output power under certain operating conditions.
- To find fuel consumption in kg/kw-hr.
- To find various efficiencies of the engine in percentage.

4.2 Purpose of Thermodynamic Tests

They are carried out to compare the actual results with theoretical (designed) results. These tests are essential for the improvement of heat engine performance [13]. Measurement of the following is necessary during the thermodynamic test:

- Indicated Power (I.P)
- Brake Power (B.P)
- Rate of fuel consumption

4.3 Measurement of Indicated Power (I.P)

The Total power developed by combustion of fuel in the combustion chamber called as Indicated Power. That is measured by INDICATORDIAGRAM (Fig 5)

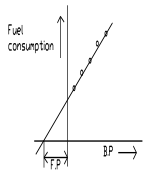

Fig 5: Willam's Line Method

V. ENGINE PERFORMANCE PARAMETERS

The Engine performance is indicated by the term efficiency. In Our Project Concentrating on Mechanical efficiency

i. Mechanical efficiency
ii. Volumetric efficiency

5.1 Indicated Thermal Efficiency:

Indicated thermal efficiency[1],[5] is the ratio of energy in the indicated power to the input fuel energy in appropriate units.

η_{ind} = Indicated power / Input energy

= Indicated power / (Mass of fuel per sec x Calorific value)

5.2 Mechanical Efficiency

Mechanical efficiency is defined as the ratio of brake power (delivered power) to the indicated power (power provided to the piston).

η_{mech} = Brake power / Indicated power

5.3 Volumetric Efficiency

Volumetric efficiency is defined as the ratio of actual volume of air taken to the theoretical volume air taken in the engine. It is the breathing ability of the engine.

$\square_{vol}$ = Actual volume of air taken / Theoretical volume of air taken.

5.4 Formulas :

1) Fuel consumption (m_f) = $(10 \times 10^{-6} \times \rho_{oil}) / t_f$ in Kg/sec

t_f = Time taken for 10cc of fuel consumption

ρ_{oil} = density of oil = $S_{oil} \times \rho_{water}$

2) Input Power = $m_f \times LCV$ in KW

3) Brake Power (B.P) = $(2 \times \pi \times N \times T) / 60000$ in KW

N = Engine Speed in rpm

T = Torque developed in NM = m x g x R

$R = (d_1 + d_2) / 2$

4) Frictional Power (F.P) from the graph in between Brake Power in X axis and Fuel Consumption in Y axis. This method of finding out F.P is known as Willan's line method

5) Indicated Power (I.P) = Brake Power + Frictional Power in KW

VI. COMPARISON OF PERFORMANCE RESULTS

6.1 Comparison of Load and Mechanical Efficiencies

Load (m)	η_{mech} (with apparatus)	η_{mech} (without apparatus)
Kg	%	%
0	-	-
1	15.60	13.47
2	25.51	22.70
3	32.15	30.30
4	40.36	36.60
5	45.60	41.80

Table 1 : calculated Value

Comparison of Load and Volumetric Efficiencies

Load (m)	η_{vol} (with apparatus)	η_{vol} (without apparatus)
Kg	%	%
0	70.83	70.83
1	71.58	71.90
2	71.95	72.13
3	72.52	72.90
4	73.10	73.69
5	73.59	74.19

Table 2 : calculated Value.

VI. CONCLUSION

The Zeolite adsorbent air filter is mainly designed and fabricated to provide the enriched oxygen supply to the diesel engine. The factors like input power, mechanical efficiency and volumetric efficiency of the diesel engine are increased considerably. Through oxygen enrichment we can obtain complete combustion. Oxygen enriched combustion reduces Smoke, Hydro Carbon and Carbon Monoxide emission considerably. This technology leads to slight increase in Oxides of Nitrogen emission but this problem is solved with exhaust gas recirculation system. Indicated thermal efficiency, Indicated power and Brake thermal efficiency are decreases due to the improper design of zeolite air filter. They can be improved by using a bigger size zeolite air filter than the existing one. As a conclusion Zeolite air filter can be consider as a device for reducing exhaust emission and improving the performance of the diesel engine considerably.

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