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Optimization of IC engines through Rapid Pressure Swing Adsorption

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***Abstract*— The thermal efficiency of heat engines can be improved using Rapid Pressure Swing adsorption technique (RPSA). This technique employs insertion of pure Oxygen into the combustion chamber of IC engines. This air-fuel mixture is similar to stoichiometric mixture. Atmospheric air is removed of its Nitrogen before sending it into the intake manifold using adsorbing materials such as Zeolite, Carbon etc. This technique decreases the amount of fuel supplied for each stroke and hence aiding in fuel consumption. This method also reduces the emission of Carbon Monoxide and Nitrogen Oxides (NOX) thus contributing to a greener environment. This process also ensures complete combustion of fuel.**

***Keywords*— thermal efficiency, Rapid Pressure Swing adsorption, stoichiometric mixture, Zeolite.**

I. INTRODUCTION

Nowadays, IC engines are used in almost every part of our life. The efficiency of these engines plays a vital role in many aspects of our environment. Atmospheric air consists of 78% Nitrogen, 21% Oxygen and 1% remaining gases [1]. Of this composition, only Oxygen is utilized during the process of combustion [2]. The remaining Nitrogen, being inert does not take part in any chemical reaction and consumes unwanted space inside the combustion chamber. Sometimes, this Nitrogen reacts with Oxygen forming harmful Nitrous Oxides (NOX) [9]. This can be eliminated by supplying pure Oxygen to the intake manifold of IC engines. Atmospheric air can be made Oxygen rich using a method known as „Rapid Pressure Swing Adsorption" (RPSA).

II. RAPID PRSSURE SWING ADSORPTION

Pressure Swing Adsorption is a technique used to separate gas species from air or mixture of gases under pressure and adsorbing them. This process takes place in near ambient temperatures and different partial pressures. Adsorption is achieved through adsorptive materials such as Carbon, Zeolite, Polyethylene membranes with each material having affinity towards different species at different temperatures and partial pressures [4].It is currently being used in Oxygen Concentrators [5].

III. PROCESS

- Intake and compression of atmospheric air.
- Cooling of compressed air.
- Separation of Nitrogen from the compressed air.
- Supply of Oxygen rich air to the intake manifold.
- Desorption of Adsorbed gases.

A. Intake and compression of atmospheric air

This is achieved using a turbo charger. A turbo charger is a mechanical device which is used for forced air induction. It is generally used in diesel engines. It is also used to preheat the atmospheric air before entering the combustion chamber. This device is actually an Axial Flow Compressor powered by a Turbine. The Turbine is connected to the exhaust of an engine and is powered by the flow of flue gas. The shaft of the Turbine is connected to that of the compressor which acts as its drive shaft and hence rotating the vanes of the compressor. This compressor in turn would compress atmospheric air and supply this preheated air into the combustion chamber and hence the name „Forced Induction" [3]. For experimental purposes, an electric motor driven reciprocating compressor is used.

B. Cooling of compressed air

The Compressed air cannot be supplied directly to the combustion chamber as it has very high temperature. This cannot be sent directly into the reaction chamber as adsorption takes place efficiently at near ambient temperatures and hence needs to be cooled. This is achieved by passing the tube containing compressed air through the radiator of the engine.

C. Separation of Nitrogen from the compressed air

The cool compressed air from the Turbo charger is forced into a container filled with Zeolite. Zeolite has an affinity towards Nitrogen and so adsorption of Nitrogen onto the Zeolite pellets. The air leaving this reaction chamber is void of Nitrogen. The separation of Nitrogen can also be achieved using Polyethylene membrane cartridges which also follow the same process [6].

D. Supply of Oxygen rich air to the intake manifold

The oxygen rich air is now forced into the combustion chamber through the intake manifold. The purity of Oxygen will be about 75 – 85 %. The amount of fuel injected must be reduced as too much temperature will be produced inside the combustion chamber due to Oxygen rich supply. If not, it might damage the piston, valves and other parts inside the chamber.

E. Desorption of Adsorbed gases

After the gases are Adsorbed by the material, when the pressure reaches ambient conditions the adsorbed gases are automatically desorbed from them and can be removed from the reaction chamber through an outlet pipe.

IV. CALCULATION

Engine Selected for calculation: Hero Honda Splendor
Displacement: 97.2 cc
Maximum Power: 5.5 KW
Maximum Torque: 7.95 Nm at 4500 rpmBore: 50 mm
Stroke: 49.5 mm Compression ratio: 9.9:1
Carburetor: Side draft variable venture type.

Complete Combustion

Combustion of Hydrogen
$2H_2 + O_2 \rightarrow 2H_2O$ By Mass
$4Kg\ H_2 + 32Kg\ O_2 \rightarrow$
$36Kg\ H_2O$ Combustion of
Carbon
$C + O_2 \rightarrow CO_2$
By Mass
$12Kg\ C + 32Kg\ O_2 \rightarrow 44Kg\ CO_2$

Incomplete Combustion

Combustion of Hydrogen
$2H2 + O2 + 79/21\ N2 \rightarrow 2H2O + 79/21\ N2$
$4Kg\ H2 + 32Kg\ O2 + 105.3Kg\ N2 \rightarrow 105.3Kg\ N2 + 36Kg\ H2O$
Combustion of Carbon
$2C + O2 + 79/21\ N2 \rightarrow 2CO + 79/21\ N2$
$24Kg\ C + 32Kg\ O2 + 105.3Kg\ N2 \rightarrow 56Kg\ CO + 105.3Kg\ N2$
Further O2 Supply
$2CO + O2 + 79/21\ N2 \rightarrow 2CO2 + 79/21\ N2$

Element	Percentage weight (%)
Carbon	84
Hydrogen	12
Oxygen	1

Table 1 Composition of atmospheric air by weight

Element	Molecular weight (kg/kmol)
Carbon	12
Hydrogen	1.01
Oxygen	16
Nitrogen	14

Table 2 Composition of Petroleum by weight

Amount of oxygen required for complete combustion of fuel:
Carbon: 0.84 * (32/12) = 2.24 kg
Hydrogen: 0.12*(32/4) = 0.96 kg Total: 3.2 kg

Weight of oxygen supplied = Weight of oxygen needed for combustion – weight of oxygen in fuel.

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Weight of oxygen needed for 1 kg Fuel: 3.2 – 0.01 = 3.19 kg

Weight of air needed for combustion of 1 kg of fuel :

3.19*(100/23) = 13.869 kg

If concentration of oxygen is increased

to 30 %: Weight of air needed:

3.19*(100/30) = 10.6 kg

Calculation of flow rate of oxygen:

Volumetric displacement at idling conditions N = 1500 rpm

V = (3.14/4)*0.05*0.0495*1500*0.5*0.75

V = 0.0547 m^3/ min

Volume flow rate of oxygen for an increase of oxygen concentration by 4%

Volume flow rate of oxygen =

0.04*V Volume flow rate of oxygen

= 0.04 * 0.0547

Vo = 0.0018 m^3/ min

Vo = 1.8 LPM of oxygen

Volume flow rate of air required for the compressor in order to achieve the required flow rate:

Flow rate of compressor = Vo/0.23

Vc = 1.8/0.23

Vc = 7 LPM

V. DESIGN & WORKING

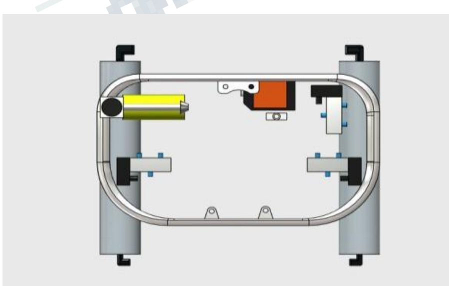

Figure 1 Arrangement of components

The main aspect of the whole setup is ease of installation without compromising the performance of the existing system. Hence the chassis guard of the vehicle is selected as the ideal candidate as it can be easily removed from the vehicle and the necessary mounts can be installed on it.

Figure 2 Modification of chassis guard for retrofit

The compressor is connected to the battery of the automobile and is capable of producing up to 150 psi of pressure. The output of the compressor is connected to a flow control meter which is used to regulate the pressure and flow rate of the atmospheric air. The output of the flow control meter is connected to the input of one of the solenoid valves. From the solenoid valves, air is directed to one of the two sieve beds at any given time using a cyclic Timer circuit which controls all the three solenoid valves. The output from the sieve beds is connected to the intake manifold of the automobile.

Air enters the compressor and is raised from atmospheric pressure to a pressure of 40 psi. At this pressure the air containing 21 % oxygen and 78 % Nitrogen enters the molecular sieve bed. The adsorption pressure of Zeolite is about 40 psi at which it starts adsorbing Nitrogen from Air. The compressed air is sent to one of the sieve beds initially. The nitrogen gets separated and pure oxygen reaches the intake manifold of the vehicle. After 15 seconds of adsorption the compressed air is directed to the second sieve bed and the same process takes place.

In order to switch the supply of compressed air between the two sieve beds, a timer circuit is used. A cyclic timer is used to achieve this goal. The timer used runs on 12v DC supply. Maximum of three valves can be attached to the timer at any given time. It is used to activate a set of solenoid valves at a time interval of 15

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seconds.

VI. ADVANTAGES AND DISADVANTAGES

A. Advantages

There are numerous advantages of improved efficiency of automobile engines. Some of the key advantages are:

- Improved Thermal Efficiency.
- Excludes the use of Nitrogen Oxide Systems thus eliminating harmful Nitrogen Oxides (NOX) which is currently being used as optional oxidizer in automobiles [7].
- Reduces fuel consumption drastically.
- Increase in power output.

B. Disadvantage

- If the amount of fuel is not decreased it may lead to the damage of cylinder bore and other components.

VII. COMPARISONS

There are different materials suitable for the separation of Nitrogen. Polyethylene membranes can be used for getting Oxygen of very high purity. But they cannot be used in IC Engines due to the following reasons:

- High cost when compared to other materials.
- Desorption of adsorbed gases is difficult when compared to Zeolite.
- Vulnerable to wear easily as they are delicate membranes made up of nano-particles.

Zeolites on the other hand are a promising option [8]. There are two types of Zeolites which are capable of adsorbing Nitrogen, they are:

- Zeolite 13X
- Zeolite 5A

Zeolite 13X, has the chemical formula
Na86 [(AlO2)86 (SiO2)106] • H2O.
The second, Zeolite 5A, is represented by the formula
Na12 [(AlO2)12(SiO2)12] •27H2O.
Experimental results show that adsorption isotherm for Zeolite 5A is significantly greater than that of Zeolite 13X at identical temperatures

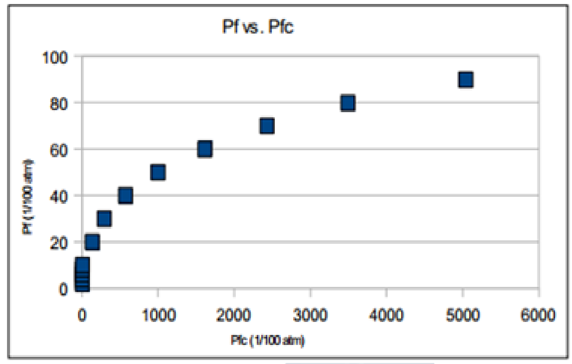

Table 3 Adsorption Isotherm for Zeolite 5A

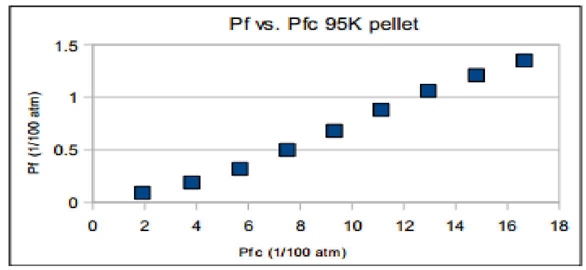

Table 4 Adsorption Isotherm for Zeolite 13X

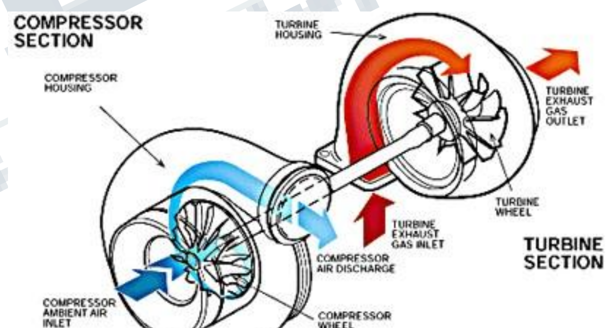

Figure 3 Working of Turbo Charger

VIII. CONCLUSION

The affect of temperature on the performance of the zeolite pellets was unaccounted for which led to random results of various iterations of the experiment. Thus a cooling system comprising of cooling fins which encases the zeolite container must be provided or liquid cooling can be done in case of larger engines with higher flow rates. The concentration of Oxygen in the air decreases as the zeolite adsorption decreases steadily with increase in temperature.

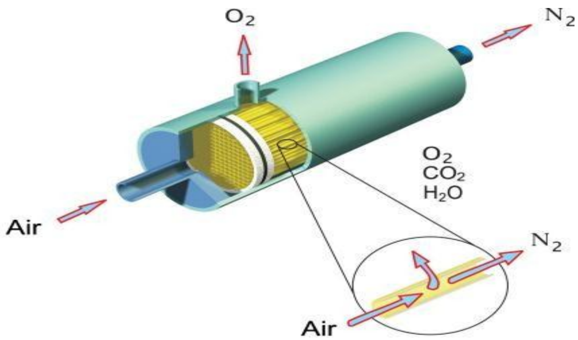

Figure 4 Working of Zeolite

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