Abstract – The idea of the automobile engine that people have is of one that is bygone. The automobile engine today is the pinnacle of engineering expertise, implementing the best of technologies and undergoing the best of manufacturing processes to make the closest possible achievement to perfection, from design to combustion. The art of perfection though starts much before the process itself. In case of the automobile engine, the process is the 4-Stroke cycle that most engines go through and the art we are referring to is attaining homogeneity in charge. Homogeneous charge in an Internal Combustion Engine refers to the complete mixture of fuel (Petrol) and air, entering the cylinder. Ideally this would mean the complete dispersion of the atomised fuel in air. This as a result reduces the overall efficiency of the engine. To help achieve the required atomisation, reducing the Surface Tension of the fuel is a potential solution. On reduction of Surface Tension the atomisation is enhanced, possibly reaching the ideal value. This can be achieved by heating the fuel to an operating temperature for which heat can be extracted from a potential source, namely the Exhaust Manifold.

Keywords – Pre-heating, Homogeneity, Internal Combustion Engine, Atomised fuel, Surface Tension, Exhaust Manifold.

I. INTRODUCTION

Energy demands are rising in contrast to its scarcity and rapid depletion. Alternate sources render current infrastructure worth trillions obsolete, disconnecting decades of development. We propose a hypothesis for enhancing the utility of petrol, a major source of energy in sectors of transportation.

The fuel petrol is a mixture of over 200 species of hydrocarbons H-C averaging a molecular weight 105g/mol. based on stoichiometry, 1 part of fuel requires 14 parts of air for complete combustion and liberates CO₂ and H₂O as the only by-products.

2H-C + O₂ + N₂ --> H₂O + CO₂ + N₂ + H-C

However in a real engine,

A. By-products are formed in the form of smog as a result of supplementary reactions such as NOx or the various oxides of nitrogen, the nature of these reaction is endothermic, higher the temperature, greater the emissions of NOx

N₂ + O₂ --> 2 NO (Δh = 175.728kJ)

½N₂ + O₂ -----> NO₂ (Δh = 33.9kJ)

B. Incomplete combustion resulting in the formation of CO or carbon monoxide a highly poisonous and good oxidizing agent. The formation of CO is favoured at lower temperatures contrary to NOₓ

H-C + ½O₂ --> CO + ½H₂O (Δh = -110.527kJ*)

C. Some hydrocarbons are not burnt due to lack of successive collisions between oxygen and fuel.

D. Based on our reading, observation and calculation, we have the following tables

Table 1: Major components in combustion [16,17,18]

<table>
<thead>
<tr>
<th>Sl. no</th>
<th>Component</th>
<th>Density (kg/m³)</th>
<th>Calorific value (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Petrol</td>
<td>700</td>
<td>48,000</td>
</tr>
<tr>
<td>2</td>
<td>CO</td>
<td>1.15</td>
<td>10,150</td>
</tr>
<tr>
<td>3</td>
<td>H-C</td>
<td>700</td>
<td>48,000</td>
</tr>
<tr>
<td>4</td>
<td>NOₓ</td>
<td>1.24</td>
<td>-2,928*</td>
</tr>
</tbody>
</table>

*The negative sign is to indicate that energy is absorbed, thereby inhibiting an equivalent amount of already produced power.

Table 2: Degree of concern [16,17,18]

<table>
<thead>
<tr>
<th>Sl. no</th>
<th>Component</th>
<th>Formation rate (kg/m³)</th>
<th>Fuel burnt</th>
<th>Effective heat lost (kJ/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CO</td>
<td>275.5</td>
<td>2,798,804.5</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>H-C</td>
<td>24</td>
<td>1,153,000</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>NOₓ</td>
<td>18.9</td>
<td>-55,354*</td>
<td></td>
</tr>
</tbody>
</table>
Burning 1 m³ petrol at STP releases 33,600,000kJ of heat, the combined losses contribute to a total of 4,061,512.5kJ to be subtracted from the output, which is 12.08% of the total heat this equals 83.4kg worth petrol. The unused energy alone totals 3950804kJ, which is 11.75% of the total input.

In most modern vehicle engines, fuel is injected into the cylinder towards the end of the compression stroke. More efficient engines have combustion chamber characteristics to facilitate excellent turbulence and swirl for thorough mixing of air and fuel. The fuel is sprayed into the chamber as a fine jet. When the air flows over the droplets of the jet, it makes the droplet smaller by removing its layers one by one. This is illustrated in Fig. 1.

![Fig. 1: The disintegration of fuel droplet in a generic combustion chamber [14]](image)

The droplet formed depends on factors such as surface tension and viscosity, both of which reduce with increasing temperature. Heating the fuel can reduce droplet sizes further. Smaller droplets ensure thorough mixing of air and fuel, hence ensuring improved burning. This is illustrated in Fig. 2.

![Fig. 2: Quicker disintegration of fuel by the proposed hypothesis](image)

II. SYSTEM SETUP

Since the fuel (petrol) needs preheating, small and affordable modifications to the already existing systems need to be made. This is such that today’s automobile system design undergoes no major change. A diagram describing this system design is shown as follows.

![Fig. 3: Block Diagram of system setup.](image)

As can be seen the design change is minimal. A fuel line connects the already existing fuel tank to a preheating container. The container is designed to hold a volume depending in the size of the exhaust manifold. This container is placed within the manifold such that it receives heat directly from the exhaust gases. There exists a fuel line connecting the container back to the Carburettor or Fuel Injection System.

A. Fuel Line.

The material used for the fuel line could be reinforced rubber flex pipe as it can withstand high pressures of up to 6Mpa and temperatures of around 2500°C.[1]

B. Pre-Heating Container.

The Preheating container should be made of a material that is a good heat conductor, able to withstand temperatures up to 1200°C[2] without undergoing any chemical change and any considerable change in physical properties. That is the material should have a

1. Low specific heat capacity.
2. Low Thermal expansion coefficient.
3. Inert chemical property.
4. The volume of the preheating chamber is assumed to be such that it fits snugly into the exhaust manifold.
C. Exhaust Manifold changes.

The exhaust manifold, in order to house the pre-heating container will have to undergo changes as well. The exhaust manifold is electronically operated [3] and its operation depends on the temperature in the pre-heating container.

III. SYSTEM WORKING

The process stages of the project can be divided into 4 parts, namely The Fuel Passage, Heating Mechanism and The Return Path and Fuel Injection.

In a regular carburetted engine the fuel line connects the fuel tank to the carburettor. The fuel is then mixed with the Air at the required ratio. The Air carries the fuel into the combustion chamber. In a fuel injected engine though, the fuel would be pressurised using a pump and then sent to the injector from where the required quantity of fuel would be injected into the cylinder.

The block diagram of our setup is as follows.

A. Fuel Passage Diversion

In our setup, from the fuel tank, the fuel is transported via the fuel line made of reinforced rubber flex material, the fuel line is designed to handle high pressure of the fuel coming from the primary pump in the fuel tank. The line feeds the fuel into the pre-heating container.

B. Heating Mechanism

The fuel in the pre-heating chamber is heated using the exhaust gases. The flow of these exhaust gas is controlled with the help of an electronically controlled bypass valve. When the engine starts, the valve allows exhaust gases to come in contact with the pre-heating container. Once the required temperature is acquired, the valve changes position such that the exhaust gases no longer heat the container, when the temperature drops below the necessary value, the valve changes position again to restart heating process.

C. The Return Path

The fuel once heated to the required temperature of 246°C within the exhaust, travels via a secondary fuel pipe made of the same material to the fuel injection mechanism, at this point the fuel is both pressurised and at an elevated temperature.

D. Fuel Injection

Once the fuel reaches the fuel injection system it follows the regular process. The heated fuel is injected into the engine cylinder. Due to the high temperature of the fuel near 246°C, the droplet size and viscosity of the injected fuel is drastically reduced as compared to a conventional system. This has great consequences on combustion properties as stated ahead.

E. Working characteristics

Thorough atomization depends on pressures used, the droplet size and willingness of the fuel jet to be disintegrated. Droplet size depends on surface tension and degree of fuel jet disintegration depends on viscosity. Viscosity gradually declines with increasing temperature. The following graph depicts the viscosity reduction with increasing temperature.

The Surface Tension and Viscosity share a near linear relationship \( \ln \sigma = \ln A + \frac{B}{\eta} \) (Panofsky’s equation)[15] where \( \sigma \) is the surface tension and \( \eta \) is the viscosity. A and B are constants which depend on the components of the mixture of hydrocarbons making up petrol. Working temperatures are carefully selected based on optimizing adequate lubrication for the fuel injector and sufficient droplet size for good atomization. The average compression ratio for today’s vehicles is roughly 9.5, assuming 17°C to be the starting temperature, isentropic compression results in 440°C.
Considering that heat is lost to cylinder walls, the final temperature after compression can range between 250-350°C\(^{13}\). As the air is hotter than the fuel and is of greater quantity, the resulting charge will be of the same temperature regardless of pre-heating. Therefore, the anti-knocking properties will not be affected. However, unexpected knock can be controlled through stratification or delaying fuel injection and controlling the rate of delivery as is seen in the diesel engine.

IV. IMPROVEMENTS TO BE EXPECTED

The thermal efficiency of an engine is the fraction of heat generated from burning fuel successfully turned into useful power for motion. Thermal efficiency depends on the architecture of the engine and the working fluid dynamics on how expanding gases can effectively be converted into torque to drive the crankshaft. Therefore, torque is a function of the amount of fuel burnt which depends on the engine size or Torque is ideally a uniform value. But in generic terms, although almost steady for most of the curve, there are variations in the torque at lower and higher engine speeds. At lower engine speeds, heat is absorbed by the cylinder bore which is maintained at temperatures lower than the expanding gases, at higher engine speeds, there is lesser time for successive collisions between fuel and oxygen molecules due to uneven air fuel mixture or charge. Although older carburetted engines could maintain evenness, they have the shortcoming of being unable to keep the air-fuel ratio constant, which also leads to varied torque. This is illustrated in Fig. 6.

\[\text{Power-band is the section of the graph from the point of maximum torque to the point of power drop. A generic power curve is illustrated in Fig. 7.}\]

Even mixtures improve the possibility of successive collisions between oxygen and fuel and facilitate smooth engine running with near constant torque which results in fewer vibrations and improved engine life and increased comfort for passengers as uniform acceleration eliminates jerk.

\[\text{Power is a function of the torque and engine speeds. The power drop happens when torque falls at a faster rate than engine speed rise. Therefore, if the torque were more uniform, the power-band can be widened and greater power can be achieved for the same engine speeds facilitating better acceleration. Fig. 8 illustrates the concept.}\]

Emissions of H-C or hydrocarbon depend directly on how much fuel goes unburnt due to the lack of successful collision between fuel and oxygen molecules. CO or carbon monoxide emissions are the most prominent and most dangerous among the emissions from the engine. They occur due to the lack of oxygen in the burning of the hydrocarbon. However, there is sufficient oxygen available due to stoichiometric air-fuel ratio being used. Homogeneity of the mixture should eliminate the possibility of insufficiencies and hence reduce carbon monoxide. Therefore, catalytic converters can concentrate on NOx emissions alone which will
reduce their complexity in design and manufacture, thereby reducing the costs there to counterbalance the costs incurred in the extra investments in the exhaust system design.

V. COLLATERAL DAMAGE

A. Temperature vs. Viscosity

We notice that the Viscosity of the fuel is indirectly proportional to the Temperature [4] and thus even though reducing the viscosity of the fuel improves the fuel droplet properties and provides better homogeneity in the air-fuel mixture; it affects the lubrication [9] provided for the steady operation of the fuel injector[10]. The change in viscosity is seen only to be marginal.

B. Spontaneous Combustion of Finely atomized charge

The temperature of the Fuel is higher than the normal working temperature which leads to better atomization and increased thermal efficiency, but if the mechanism is not designed properly then there is a chance that the extremely fine air-fuel charge which enters the cylinder might undergos spontaneous combustion leading to undesirable effects like knocking etc.

C. Economic considerations

Although there will be an added investment in the fabrication of a new exhaust system, it will be counterbalanced by a simpler catalytic converter. Current on road vehicles can also implement the simple change without a substantial investment.

D. Fuel injector heating

The injector, which would otherwise be cooled with the help of flowing fuel surrounding it, is now exposed to much higher temperatures.

VI. CONCLUSION

The pre-heating of charge is beneficial in many ways. It is expected to increase power output of the engine by 20-30%. Due to the extreme homogeneity of the air-fuel mixture present in the cylinder during power stroke, the combustion is near ideal and the flame travel is assumed to be steady and uniform. This leads to maximum utilization of the specific heat [11] of the fuel (GCV=48,000 kJ/kg) which results in an improved Thermal efficiency and in turn, an improved overall efficiency of the engine. The technology uses heat from the exhaust flue gases to increase the temperature of the fuel at the inlet to around 200 degree Celsius (<246 degree Celsius for petrol) which decreases the surface tension and viscosity [7] leading to better homogeneity in mixing of fuel and air and the resulting atomized mixture has many desirable properties such as increase in engine power, economy, efficiency and complete combustion which are needed for optimum performance. Without this technology, the heat from the exhaust gases will effectively be used to improve combustion.

VII. FUTURE WORKS

A. Heat recovery mechanism from the Exhaust manifold

It is possible to design effective heat transfer surfaces between the fuel pipelines and the exhaust manifold such that the temperature of the heated petrol must not exceed 246 degree Celsius (since the auto ignition temperature of petrol is 246-280 degree Celsius). Additional valve mechanism should be provided along the exhaust manifold, which switches the exhaust gas flow path from the exhaust gas-petrol heat exchange surface to the normal path when the temperature of the fuel exceeds the safe value.

B. Application of this technology to Diesel engines

Currently, we have discussed the implications of this technology to the Otto cycle 4-stroke petrol engines[12]. The same can be applied to the Diesel cycle engine, which uses compression ignition technology. A few minor modifications have to be carried out in terms of maximum temperature attainable by exhaust gas-Diesel fuel [9] heat exchanger Mechanism etc.

C. Polymer fortification technology

Research is going on about materials (Polymers) that can make extremely small droplets of fuel act like solids when subjected to enormous stress by imparting a visco-elastic[6] surface to the spherical droplets. During the power stroke it leads to individual droplets having a near-ideal combustion and flame travel along the volume, which results in maximum utilization of specific heat of the fuel and minimum wastage.

This would lead to even higher thermal/overall efficiencies and desirable Engine parameters such as more power and better mileage etc.

D. Fuel pre-heating optimization to maximize fuel injector life and engine efficiency.

By experimenting with higher working temperatures, smaller droplets can be obtained. This is at the cost of lubrication properties which can reduce fuel injector life. Therefore, tests will be carried out to reach an optimum value of temperature for all-round efficient functioning.
VIII. ACKNOWLEDGMENT

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IX. REFERENCES


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