SIX STROKE ENGINE USING GASOLINE AND R-123

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Abstract

In any Internal Combustion Engine, only 35% of the available energy is converted into the crankshaft energy. The remaining portion of the energy is either expelled into the atmosphere or it increases the temperature of the engine block. This is desirable as the conversion of heat energy into mechanical energy is more efficient at higher temperatures. However, beyond a certain limit it sets up thermal stresses and in extreme cases it causes engine seizing. Thus a cooling system is employed to remove this heat and transfer it into the atmosphere with the help of a radiator or a heat exchanger. In a six stroke engine, this heat transferred by the coolant is reduced. As there have been several advancements in the recovery of energy from exhaust gases such as turbochargers, Thermoelectric Generators and other such techniques, energy recovery by adding two strokes with a working fluid as a refrigerant is unique. The study shows that around 30% of the heat is carried away by the coolant and hence this is amount of energy that can theoretically be harvested. Since this offers a superior cooling system, the chances of detonation is also considerably lowered. By reducing the amount of heat expelled into the atmosphere, the overall efficiency is improved. In today's age of rapidly depleting natural resources (fossil fuels), it is of utmost importance to converse these non-renewable sources of energy. Since the IC Engine has reached a state of saturation, waste heat recovery is the best way to improve the efficiency and hence reduce the fuel consumption.

Keywords: *Six Stroke Engine, Waste heat Recovery, Cooling System, and Efficiency*

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1. INTRODUCTION

In today's world, IC Engines are a major source of power is almost all automobiles and in a few energy production sources. Since they run on fossil fuels which are non-renewable source of energy, it is utmost importance to converse it to the extent possible. As the emissions of the IC Engines include CO_2, CO, NO_x and other harmful gases, by improving the efficiency of the IC Engine, the emissions are also reduced thus reducing its impact on the atmosphere. This is of great relevance today since many problems plaguing the earth's atmosphere such as ozone layer depletion, heat retention by greenhouse gases are caused by the combustion of fossil fuels. In any IC Engine around 35% of the heat produced by combustion is converted into useful crankshaft power. While friction accounts for around 5% of the power, exhaust gases and cooling systems account for 30% of the energy each. In today's world, IC Engines have reached a state of saturation i.e. further improvement can only be marginal. In order to obtain significant improvement, regeneration [1] is the only viable option. There are several avenues to harvest the energy from the exhaust gases such as turbochargers [2], thermoelectric generators [3], Piezoelectric Generators [4]; recovering energy from the cooling system is an esoteric one. Such an energy recovery system would not only improve the efficiency of an IC Engine but also reduce the amount of fuel consumed. This paper gives a thorough insight into the harvesting waste heat from the cooling system of an IC Engine. The figure below shows the distribution of energy of a typical IC Engine.

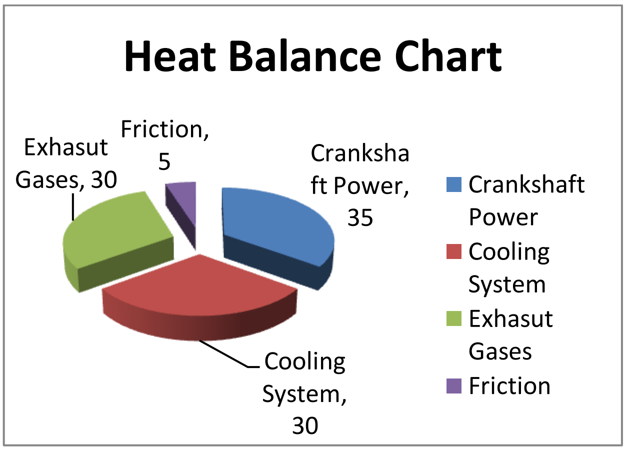

Fig 1- Pie Chart depicting distribution of energy in an IC Engine

2. SIX STROKE ENGINE

In a conventional Gasoline powered IC Engine, there are four strokes which are suction, compression, power and exhaust. During suction, fresh air fuel mixture (called charge) is sucked into the combustion chamber through the inlet valve by the downward movement of the piston. The exhaust valve is shut during this stroke. This charge is then compressed by the upward motion of the piston in the second stroke. The spark plug ignited this compressed charge thus initiating the combustion of the fuel. Since both the valves remain closed, it pushes the piston downwards during the power stroke. During the exhaust stroke, the upward movement of the piston coupled with the open exhaust valve pushes the exhaust gases out of the cylinder. The opening and closing of the valves is decided by cams. In a six stroke engine [5], after the four strokes, a secondary working fluid (not the fuel) is injected into the cylinder block through the inlet valve and both the valves are shut. Since the secondary working fluid is at lower temperature, on contact with the hot cylinder block, it expands thus pushing the piston downwards. The upward movement of the piston pushes the secondary working fluid out of the cylinder into a storage tank generally or if the secondary working fluid is air, it is expelled into the atmosphere through the exhaust valve. This produces power and reduces the load on the cooling system.

3. SECONDARY WORKING FLUID

There have been several six stroke engines which use water or air as the secondary working fluid. The secondary working fluid is injected into the cylinder through the intake manifold at the end of the fourth stroke. The fluid absorbs the heat in the cylinder block thus expanding and pushing the piston downwards. This produces work and also absorbs the heat from the cylinder thus reducing the load on the coolant.

3.1 Water as the Secondary Working Fluid

Theoretically, water is injected into the cylinder at the end of the fourth stroke [6]. Due to the temperature of the cylinder block, it is converted into steam thus pushing the piston downwards. Water was considered as a suitable choice since it is abundantly available, easy to store and cost effective.

One of the major problems encountered was that there were instances where the water injected was not entirely converted into steam. This resulted in traces of water left behind in the cylinder. Since water inhibits combustion, it affected the characteristics of the flame front in the succeeding cycle. Also, cylinder showed signs of corrosion due to the injection of water to the metal at high temperature.

3.2 Air as the Secondary Working Fluid

Quite recently, air was considered as an alternative to water. Air from the atmosphere is injected into the cylinder block after the fourth stroke. Due to the thermal expansion, air expands thus producing crankshaft work [7]. One significant advantage was that the air could be expelled into the atmosphere. The lack of a heat exchanger made the entire set up lighter and more compact. Although this eliminated most of the drawbacks, since there was no change of phase, the expansion was lower. This resulted in a lower power output from the additional two strokes.

3.3 R-123 as the Secondary Working Fluid

To overcome this, a suitable secondary fluid is to be employed. By using R-123 as the secondary working fluid, most of these problems can be overcome. R-123 is subjected to Gas refrigeration cycle also known as Reverse Rankine Cycle. Ideally, it consists of two isentropic and two isobaric processes. The table below shows the various properties of R-123

Table 1- Properties of R-123

Sl. No	Parameter	Value
1	Chemical Formula	$CHCl_2CF_3$
2	Molecular weight	152.93
3	Boiling Point (1 atm)	27.85°C
4	Critical Temperature	183.68°C
5	Critical Pressure	36680 kPa
6	Critical Density	550 kgm^{-3}
7	Critical Volume	0.00182 m^3kg^{-1}

Consider the Figure below. It is a Gas Refrigeration Cycle or also known as a Reverse Rankine Cycle [8]. The R-123 from the engine is passed through a compressor during process 1-2. The high-pressure, high-temperature gas at state 2 is cooled by rejecting heat to the surroundings. This is followed by an expansion process (2-3) in the turbine which is ideally isentropic in nature. Finally, the fluid at state 3 is injected into the engine after the fourth stroke.

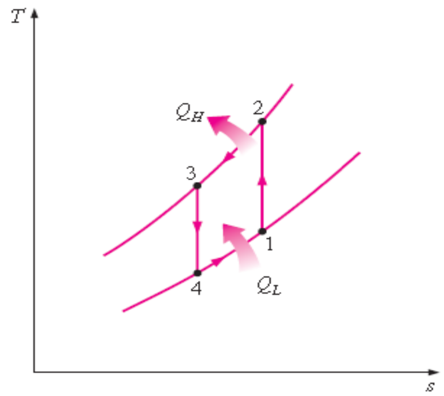

Fig 2- The T-s graph of an ideal Reverse Rankine Cycle

4. MODIFICATIONS TO REVERSE RANKINE CYCLE

In reality, there is always a pressure loss during heat rejection and there are isentropic processes. Therefore to ensure maximum turbine output, the fluid is passed through the turbine after exiting the engine. This ensures that fluid is not in liquid state at the turbine blades. To further aid cooling of the fluid, the fluid is passed thorough a nozzle and then expanded into a low pressure chamber. This utilizes Joule-Thompson Effect which states that “when a gas is expanded through well insulated device, at a temperature below the maximum inversion temperature, the enthalpy of the gas reduces”.

The heat exchanger is used to reduce the load on the compressor. Since a part of the heat is already transferred into the atmosphere, the enthalpy of the gas reduces. The figure below shows the layout of the modified Reverse Rankine Cycle. In the figure given below, the heat exchanger 1 is the process of heat transfer from the engine to R-123 and heat exchanger 2 is the process of heat transfer from R-123 to the atmosphere

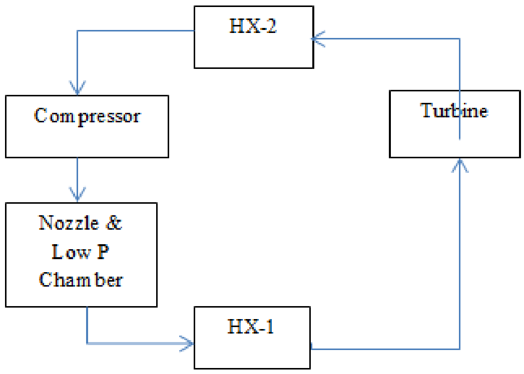

Fig 3- The layout of the Modified Reverse Rankine Cycle

5. THERMAL ANALYSIS

The above concept was mathematically modelled and solved. Below are the vital stages during the calculation of the heat transferred.

Bernoulli's Equation

$$\frac{P}{\rho g} + \frac{V}{2g} + z = Constant$$

R-123 is stored as saturated liquid in a storage tank at 2 bar and 50°C. During the flow from the tank to the cylinder, the friction between the fluid and the piping system is neglected. Assuming the cylinder block is a standard temperature and pressure, the potential head is negligible,

$$\frac{200 * 10^3}{13 * 9.8} = \frac{1 * 10^3}{9.62 * 9.8} + \frac{V^2}{2g}$$

$V=174.81ms^{-1}$

To find out the nature of the fluid at a time infinitesimally after entering the cylinder,

$$Re= \frac{\rho vD}{\mu}$$

$$Re= \frac{9.62*174.81*.0774}{.4*10^{-3}}$$

$$Re= 3.11*10^5$$

Hence the flow is turbulent in nature.

For a turbulent flow,

$$Nu= .036*(Re^{0.8})*(Pr^{0.33})*(D/L)^{.055}$$

$$Pr^{0.033}= (\frac{C*\mu}{k})^{0.33}$$

$$Pr^{0.033}= (\frac{1022*.4*10^{-3}}{.075862})^{0.33}$$

$$Pr^{0.033}= 1.752$$

$$(D/L)^{0.055}= (0.074/0.077)^{0.055}$$

$$(D/L)^{0.055}= 0.098$$

$$Nu= 1.619*10^3$$

$$Nu= \frac{h*D}{k}$$

$$1.619*10^3= \frac{h*0.074}{0.07856}$$

$$h= 1718W/m^2K$$

$$Q= h*A*(T_{surface} - T_{\infty})$$

$$A= 2*\pi*0.077*0.074$$

$$A= 3.5*10^{-2}$$

$$Q= 1718*3.5*10^{-2}* (200-150)$$

$$Q= 9.22*10^3 J$$

Therefore, the fluid absorbs 9.22kJ of heat every cycle. Since R-123 is chemically stable up to 250°C, it is safe to assume a factor of safety of 2 and hence the maximum temperature attained by the fluid restricted to 125°C

$$Q= m*C_p* (T_2 - T_1)$$

$$Q= m*1022*(125 - 50)$$

$m=.12kgrev^{-1}$
Work done per cycle= $P*(V_2 - V_1)$
$W_c = 200*10^3*(0.0767*.12 - 0.00025)$
$W_c = 1.79kJ/rev$

This is the work extra work obtained by the expansion of the secondary working fluid. Assuming a mean engine speed of 1500 rpm,

No. of revolutions= 1500/60= 25 rev/s

$$W=1.79*25= 44.75kW$$

To compress R-123 from standard temperature and pressure, a compressor of

$$W_{compT} = \frac{\gamma}{\gamma-1}*m*R*(T_{out} - T_{in})$$

$$W_{compT}= 3.5*0.12*55.4*(125-50)$$

$$W_{compT}= 17.45kW$$

Assuming an efficiency of 80%,

$$W_{compA}=W_{compT}/Efficiency$$

$$W_{compA}= 21.82kW$$

$$W_{net} = W - W_{compA}$$

$$W_{net=} 44.75-21.82$$

$$W_{net=} 23kW$$

6. CONCLUSION

Since IC Engines today have reached a state of saturation in terms of efficiency, regeneration is the only viable option. There is large potential for energy recovery through regeneration in an IC Engine. Although there have been several advances in the recovery of heat from exhaust gases, regeneration through cooling system is in its nascent systems. Six stroke engines have been conceptualized for decades now. The amount of money to be spent to regenerate a unit of power from cooling systems is a lot higher than designing a larger engine. Hence, automobile companies go for a larger engine. However, with today's energy crisis, it is of utmost importance to save every drop of fossil fuel. Therefore, automobile companies should invest in regenerative systems. Six stroke engines is a wonderful concept that integrates concepts of Rankine Cycle and Vapor Compression Cycle with Diesel Cycle to improve efficiency.

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LIST OF SYMBOLS USED

- P- Pressure
- P_1- Pressure in storage Tank
- P_2- Pressure in Cylinder
- ρ- Density
- g- Acceleration due to gravity
- v_2- Velocity in the cylinder
- Re- Reynold's Number
- μ- Viscosity
- D- Diameter of Cylinder (Bore)
- L- Stroke of Cylinder
- Pr- Prandtl Number
- C- Specific heat of R-123
- k- Conductivity of R-123
- h- convective heat transfer coefficient
- A- Area of interaction b/w R-123 and cylinder
- $T_{surface}$- Temperature of Cylinder
- T_∞- Temperature of R-123 at entry of cylinder
- Q- Heat transferred from the cylinder
- m- Mass flow rate of R-123
- W_c- Work done per cycle
- W_{compT-} Theoretical Work by the compressor
- W_{compA}- Actual Work by the compressor
- W_{net}- Net work done

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