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Enhancing the IC Engine Performance by Preheating the Inlet Air Through Recovering the Heat from Exhaust Gas

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Abstract:- The Internal Combustion Engine has been a primary power source for automobiles over the past century. Presently, high fuel costs and concerns about depletion of the available natural resources have resulted in increasingly complex engine designs to decrease fuel consumption. A concrete and serious effort has being laid down in order to find the best ways of using the deployable sources of energy in to useful work in order to reduce the rate of consumption of fossil fuel as well as pollution. The objective of this research paper is all about to develop better understanding of the performance characteristics of the engine with Inlet Air Preheater and to increase engine performance by recovering the heat from the exhaust gases in order to provide a better fuel economy. And also this preheating of the air will result in better vaporization of the fuel inside the carburetor (In case of SI engines) which results in better combustion of the fuel and thereby reduce the harmful emissions of the carbon monoxides in to the atmosphere.

I. INTRODUCTION

The extinction of the present fuel resources is nearly unavoidable due to their increasing consumption and their demand. According to the International Energy Agency (IEA), fossil fuels accounted for more than 81% of global energy production in 2019. Thus primary energy consumption in the world was from burning of fossil fuels which are non-renewable. Now a days the consumption of the fossil fuels is 1, 00,000 times faster than their natural formation. Also the combustion of the fossil fuel results in carbon monoxide and Hydrocarbons emissions due to the incomplete combustion.

Out of the total heat supplied to the engine in the form of fuel, approximately, 30 to 40% is converted into useful mechanical work. The remaining heat is expelled to the environment through exhaust gases and engine cooling systems, resulting in to entropy rise and serious environmental pollution, so it is required to utilize waste heat into useful work.

Given the importance of increasing energy conversion efficiency for reducing both the fuel consumption and emissions of engine scientists and engineers have done lots of successful research aimed to improve engine thermal efficiency including supercharge, lean mixture combustion, enhanced fuel-air mixing, turbo-charging, and variable valve timing. However, around 60-70% of the fuel energy is still lost as waste heat through the coolant or the exhaust. Hence in all the energy saving technologies studied, engine exhaust heat recovery is considered to be one of the most effective. Many researchers recognized that Waste Heat Recovery from engine exhaust has the potential to decrease fuel consumption without increasing emissions.

The recovery and utilization of waste heat not only conserves fuel, usually fossil fuel but also reduces the amount of waste heat and greenhouse gases dumped to environment. Thus it is important to conserve this energy through exhaust heat recovery techniques. Such a waste heat recovery would ultimately reduce the overall energy requirement and also reduce the impact on global warming.

This paper gives a comprehensive review of the waste heat from internal combustion engine, waste heat recovery system.

II. POSSIBILITY OF HEAT RECOVERY AND AVAILABILITY FROM I.C. ENGINE

According to the Kelvin plank statement of thermodynamics, it is impossible to construct a device that operates in cycle and produce no other effect rather than to receive the heat from a single reservoir and to convert it in to the equitable amount of work. Hence it is impossible to design a engine which converts complete heat energy in to the useful work perhaps heat which is being rejected in to the atmosphere can be recovered up to some extent. Waste heat is heat, which is generated in a process by way of fuel combustion or chemical reaction, and then “dumped” into the environment even though it could still be reused for some useful and economic purpose. The quantity of the waste heat is a function of both the temperature of the waste heat gases and mass flow rate of exhaust gas.

In internal combustion engine approximately 30 to 40% is converted into useful mechanical work. The remaining heat is expelled to the environment through exhaust gases and engine cooling systems. It means approximately 60 to 70% energy losses as a waste heat through exhaust (30% as engine cooling system and 30 to 40% as environment through exhaust gas). Exhaust gases immediately leaving the engine can have temperatures as high as about 450-600°C. Consequently, these gases have high heat content, carrying away as exhaust emission.

III. THEORETICAL ANALYSIS BY COMPARING WITH CARNOT CYCLE

The Carnot cycle is a theoretical thermodynamic cycle. It estimates the maximum possible efficiency that a heat engine can poses during the conversion process of heat into work which is working between two thermal reservoirs.

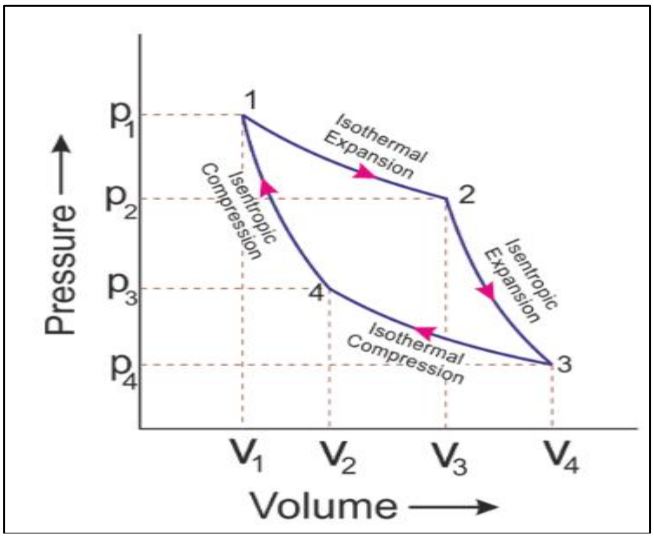


Fig 1 P-V Diagram

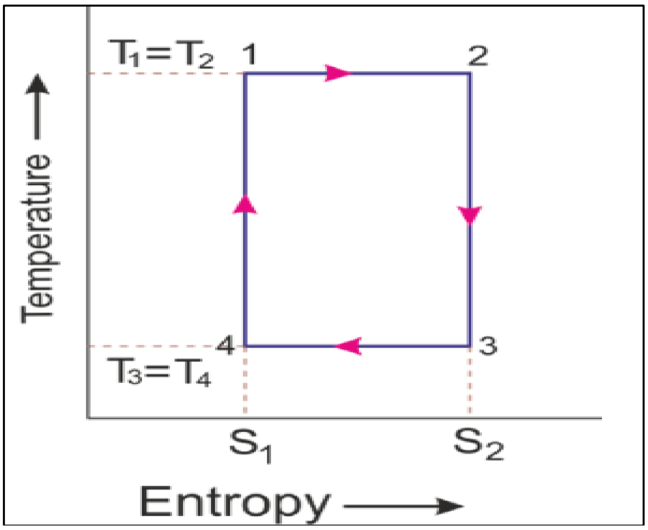


Fig 2 T-S Diagram

Four successive operations are involved: isothermal expansion, adiabatic expansion, isothermal compression, and adiabatic compression.

$$\eta = \frac{\text{Work Output}}{\text{Heat Supplied}} = \frac{Q_1 - Q_2}{Q_1} = \frac{T_1 ds - T_2 ds}{T_1 ds} = 1 - \frac{T_2}{T_1}$$

The efficiency of the Carnot cycle can be increased by either increasing the temperature (T_1) at which heat is being added or by either decreasing temperature (T_2) at which heat is being rejected.

Here by recovering the heat from the exhaust gases the mean temperature of the heat rejection will be decreased and thereby increases the the efficiency.

- *Air Preheater*

An air preheater is a device designed to heat air before another process (for example, combustion in a boiler) with the primary objective of increasing the thermal efficiency of the process. The concept of increasing the fuel efficiency of a petrol engine is to pre-heat the intake air which is flowing through the carburetor. The humidity in the atmospheric air affects the petrol vaporization in the carburetor. Therefore, by pre-heating the inlet air to the carburetor for a considerable amount, the vaporization can be ease and in turn complete combustion is achieved.

Passing the inlet air through the exhaust gases manifold will increase the temperature of the inlet air due to the heat transfer from the exhaust gases to the inlet air. The design is in such a way that the Inlet air flow is in opposite direction to that of the exhaust gases ensures a better heat transfer by counter flow. More tubes are provided in order to increase the area of heat transfer but also one of the major factors to be considered is Back pressure developing inside the engine. Hence the exhaust manifold cross sectional area is increased so that even due to the presence of the inlet air tubes there will be no obstacle for the flow of exhaust gases.

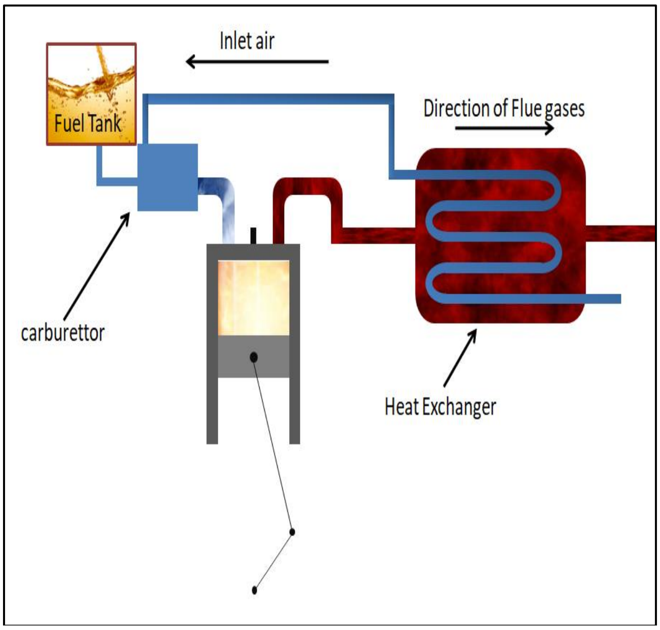


Fig 3 Air Preheater Setup in an IC Engine

The selection of material for the heat exchanger is critical and it has to serve the design purpose. It should be best studied and also cheap in cost. The tubes should have very good thermal conductivity. It should also be resistant to chemical corrosion as well as erosion. In order to fulfill the above considerations, aluminum is taken as a preheater because it's strong, and light in weight. It is readily available because it is most abundant metal on earth and it is cost-effective.

IV. PRACTICAL OBSERVATION

The software Diesel-RK is used to record the performance testing on the engine.

- *Scheme of Experimentation*

The testing of the engine is carried out at different inlet air temperatures ranging from 28-42℃ . And also at each temperature the first 3 readings are taken at constant speed and at different loads and whereas the readings from 4-6 are taken at variable speed and loading conditions on the engine.

- *Engine Testing Specifications,*

- The brake drum diameter = 30 cm
- Thickness of the belt = 19 mm.
- Calorific value of the fuel = 42,400 kJ/kg
- Specific Gravity of the fuel = 0.84
- Specific heat of air at constant pressure(C_p)= 1.005 KJ/kg-k
- Air Fuel ratio = 14.2: 1

Table 1 Observations and Calculations at Various Inlet Air Temperatures

		Observations									Calculations							
Inlet air temp		Spring load	Speed	Time for consumption of 1cc of fuel	Mass flow rate of engine cooling water	Temperature readings (℃)				Mass flow rate of fuel	B.P	F.P (From william's line)	I.P	η mech	η bth	η ith	BSFC
(℃)	S. No	(kgf)	(rpm)	(s)	(kg/hr)	cooling water inlet	cooling water outlet	inlet air temp	exhaust air temp	(kg/hr)	(kW)	(kW)	(kW)	(%)	(%)	(%)	(kg/kWh)
28	1	2	1920	10.4	420	28	30.7	28	540	0.2908	0.6289	0.7	1.3289	47.32	18.36	38.8	0.4624
	2	2.5	1920	8.6	420	28	30.8	28	580	0.3516	0.7861	0.7	1.4861	52.9	18.98	35.89	0.4473
	3	3	1920	7.2	420	28	31	28	620	0.42	0.9433	0.7	1.6433	57.4	19.07	33.22	0.4452
	4	2.5	1840	10.2	420	28	31.1	28	560	0.2965	0.7533	0.7	1.4533	51.83	21.57	41.62	0.3936
	5	3	1680	9.6	420	28	31.3	28	600	0.315	0.8254	0.7	1.5254	54.11	22.25	41.12	0.3816
	6	3.5	1560	9.1	420	28	31.5	28	640	0.3323	0.8942	0.7	1.5942	56.09	22.85	40.73	0.3716
30	1	2	1940	10.6	420	28	30.6	30	535	0.2853	0.6354	0.7	1.3354	47.58	18.91	39.74	0.449
	2	2.5	1940	8.6	420	28	30.7	30	590	0.3516	0.7943	0.7	1.4943	53.16	19.18	36.08	0.4427
	3	3	1940	7.4	420	28	31.1	30	610	0.4086	0.9531	0.7	1.6531	57.66	19.81	34.35	0.4287
	4	2.5	1840	10.4	420	28	31.2	30	540	0.2908	0.7533	0.7	1.4533	51.83	21.99	42.43	0.386
	5	3	1680	9.8	420	28	31.4	30	580	0.3086	0.8254	0.7	1.5254	54.11	22.71	41.97	0.3739
	6	3.5	1560	9.5	420	28	31.6	30	630	0.3183	0.8942	0.7	1.5942	56.09	23.85	42.52	0.356
35	1	2	1950	9.9	420	28	30.6	35	530	0.3055	0.6387	0.7	1.3387	47.71	17.75	37.21	0.4783
	2	2.5	1950	8.8	420	28	30.7	35	570	0.3436	0.7984	0.7	1.4984	53.28	19.73	37.03	0.4304
	3	3	1950	8	420	28	31	35	620	0.378	0.9581	0.7	1.6581	57.78	21.52	37.24	0.3945
	4	2.5	1840	10.6	420	28	31.2	35	530	0.2853	0.7533	0.7	1.4533	51.83	22.42	43.25	0.3787
	5	3	1680	10	420	28	31.2	35	550	0.3024	0.8254	0.7	1.5254	54.11	23.17	42.83	0.3664
	6	3.5	1560	9.6	420	28	31.7	35	620	0.315	0.8942	0.7	1.5942	56.09	24.1	42.97	0.3523
38	1	2	1975	10.8	420	28	30.5	38	520	0.28	0.6469	0.7	1.3469	48.03	19.62	40.84	0.4328
	2	2.5	1975	8.8	420	28	30.6	38	580	0.3436	0.8086	0.7	1.5086	53.6	19.98	37.28	0.4249
	3	3	1975	7.4	420	28	30.9	38	615	0.4086	0.9703	0.7	1.6703	58.09	20.16	34.71	0.4211
	4	2.5	1840	10.8	420	28	31.1	38	525	0.28	0.7533	0.7	1.4533	51.83	22.84	44.07	0.3717
	5	3	1680	10.3	420	28	31.2	38	540	0.2936	0.8254	0.7	1.5254	54.11	23.87	44.11	0.3557
	6	3.5	1560	9.8	420	28	31.6	38	610	0.3086	0.8942	0.7	1.5942	56.09	24.6	43.86	0.3451
42	1	2	1960	10.4	420	28	30.8	42	510	0.2908	0.642	0.7	1.342	47.84	18.74	39.18	0.453
	2	2.5	1960	8.4	420	28	30.9	42	560	0.36	0.8025	0.7	1.5025	53.41	18.93	35.44	0.4486
	3	3	1960	7.1	420	28	31.1	42	600	0.4259	0.963	0.7	1.663	57.91	19.2	33.15	0.4423
	4	2.5	1840	10.2	420	28	31.2	42	510	0.2965	0.7533	0.7	1.4533	51.83	21.57	41.62	0.3936
	5	3	1680	9.6	420	28	31.4	42	520	0.315	0.8254	0.7	1.5254	54.11	22.25	41.12	0.3816
	6	3.5	1560	9.1	420	28	31.8	42	590	0.3323	0.8942	0.7	1.5942	56.09	22.85	40.73	0.3716

- *Model Calculations for 1st Reading at Inlet Air Temperature 30℃.*

- *To find Brake Power,*

$$= \frac{2\pi NT}{60} = \frac{2 \times \pi \times 1940 \times (2 \times 9.81) \times (0.15 + 0.0095)}{60 \times 1000}$$

Brake power =0.6354 kW

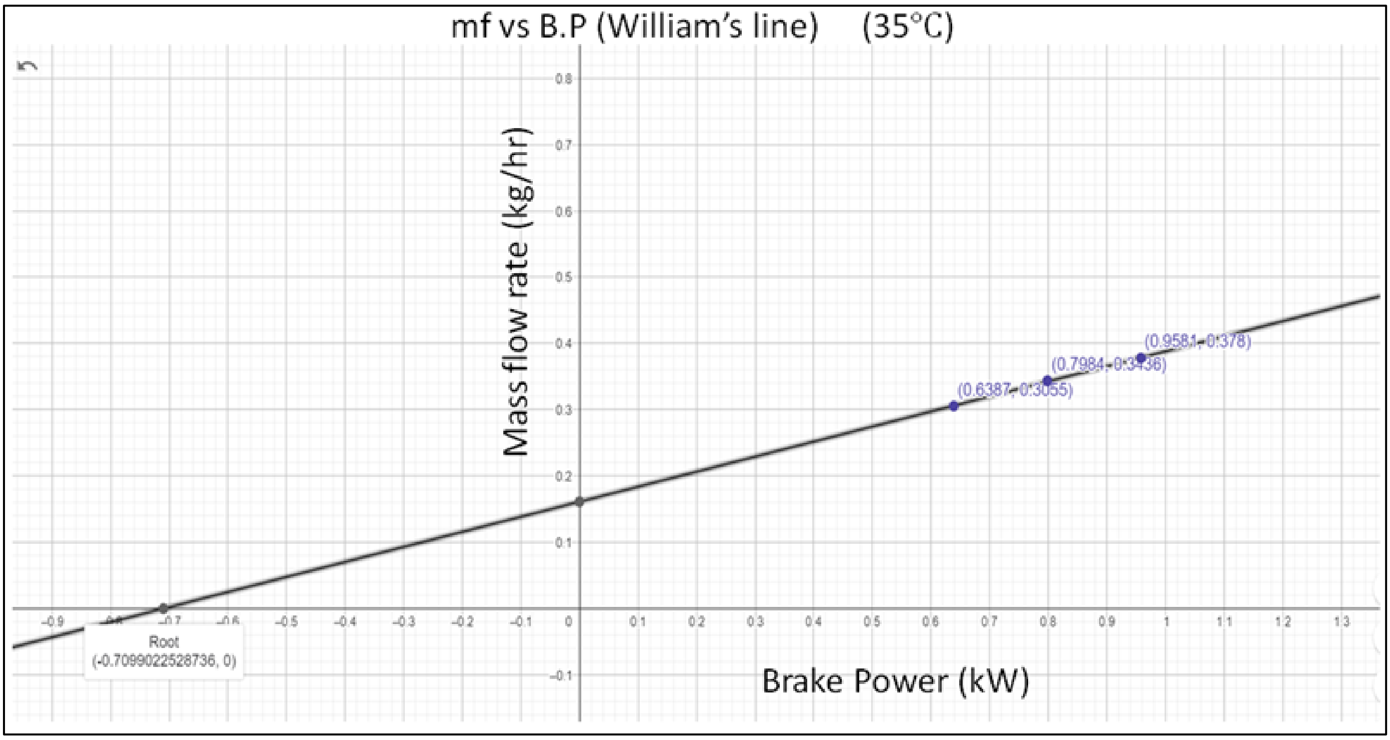
- *To Find Mass Flow rate of the Fuel,*

$$= \frac{\text{Sp. Gravity of fuel } \times 3600}{\text{Time for consumption of 1cc of fuel} \times 1000} = \frac{0.84 \times 3600}{10.6 \times 1000} = \ 0.28528\ \text{kg/hr}$$

- *To Find the Friction Power,*

The friction power is determined by plotting a graph of mass flow rate of fuel vs. Brake power (William's Line)

The first 3 readings are only considered because the engine is running at constant speed. Similarly, the graph is drawn for all the temperatures values and the approximate average value obtained is 0.7kW.



Graph 1: William's Line to Determine Friction Power

- *To Find Indicated Power,*

I.P= B.P + F.P

=0.6354+0.7 = 1.3354 kW

- *To Find Mechanical Efficiency,*

$$= \frac{B.P}{I.P} = \frac{0.6354}{1.3354} = 47.585\%$$

- *To Find Brake Thermal Efficiency,*

$$= \frac{\mathrm{B.P} \times 3600}{\mathrm{Mf\ of\ fuel}\ \times \mathrm{C.V\ of\ fuel}}$$

$$= \frac{0.6354 \times 3600}{0.2853 \times 42400} = 18.909\%$$

- *To Find Indicated Thermal Efficiency,*

$$= \frac{\mathrm{I.P} \times 3600}{\mathrm{Mf\ of\ fuel}\ \times \mathrm{C.V\ of\ fuel}}$$

$$= \frac{1.3354 \times 3600}{0.2853 \times 42400} = 39.74\%$$

- *To find BSFC,*

$$= \frac{\mathrm{Mf\ of\ fuel\ (kg/hr)}}{\mathrm{B.P}} = \frac{0.2853}{0.6354}$$

=0.449 kg/kWh

Table 2 Performance Characteristics Comparison Table

S.No	η bth (%)					η mech (%)					BSFC (kg/kWh)				
Inlet air temp	28	30	35	38	42	28	30	35	38	42	28	30	35	38	42
1	18.36	18.91	17.75	19.62	18.74	47.32	47.58	47.71	48.03	47.84	0.4624	0.449	0.4783	0.4328	0.453
2	18.98	19.18	19.73	19.98	18.93	52.9	53.16	53.28	53.6	53.41	0.4473	0.4427	0.4304	0.4249	0.4486
3	19.07	19.81	21.52	20.16	19.2	57.4	57.66	57.78	58.09	57.91	0.4452	0.4287	0.3945	0.4211	0.4423
4	21.57	21.99	22.42	22.84	21.57	51.83	51.83	51.83	51.83	51.83	0.3936	0.386	0.3787	0.3717	0.3936
5	22.25	22.71	23.17	23.87	22.25	54.11	54.11	54.11	54.11	54.11	0.3816	0.3739	0.3664	0.3557	0.3816
6	22.85	23.85	24.1	24.6	22.85	56.09	56.09	56.09	56.09	56.09	0.3716	0.356	0.3523	0.3451	0.3716

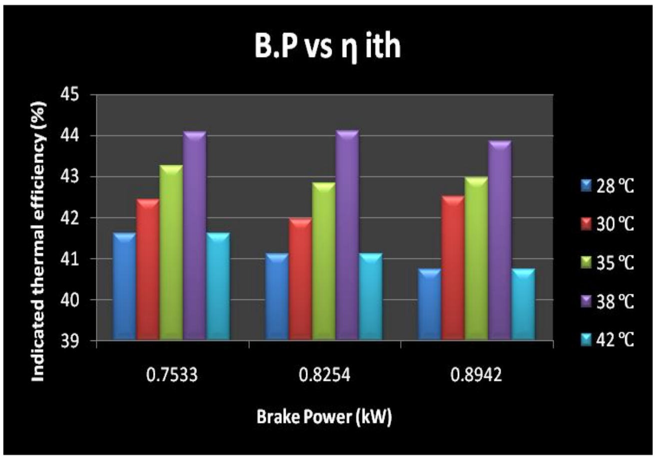


Fig 4 B.P vs. η ith

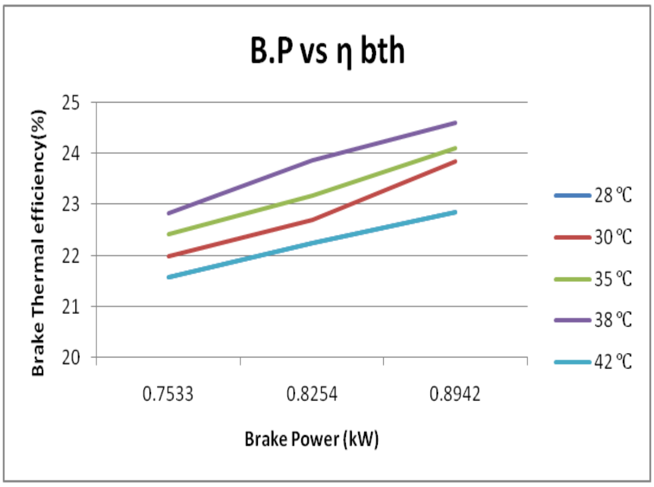


Fig 5 B.P vs. η bth

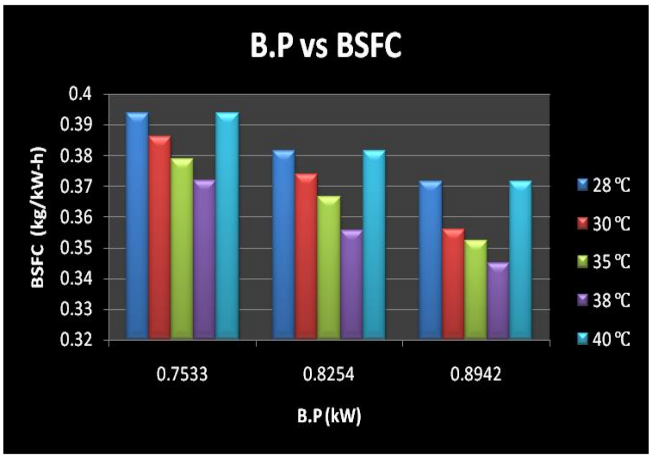


Fig 6 B.P- vs. BSFC

- *Heat Balance Sheet*

- *To Determine the Total Heat Supplied,*

$= Mf \times C.V = 0.2853 \times 42400$

$= 12096.72\ kJ/hr$

- *To determine the amount of heat carried away by engine cooling water,*

$= Mw \times Cp \times (T2 - T1)$

$= 420 \times 4.186 \times (30.6 - 28)$

$= 4571.11\ kJ/hr$

- *To determine the amount of heat carried away by the exhaust gases,*

$= Mf \times (A.F.R + 1) \times Cp \times (T2 - T1)$

$= 0.2853 \times 15.2 \times 1.005 \times (535 - 30)$

$= 2200.91\ kJ/hr$

Table 3 Heat Balance Sheet

S.No	Heat supplied					Heat converted in to useful work					Heat carried away by cooling water				
Inlet air temp (℃)	(kJ/hr)					(kJ/hr)					(kJ/hr)				
	28	30	35	38	42	28	30	35	38	42	28	30	35	38	42
1	12330	12097	12953	11872	12330	2264	2287.4	2299.3	2328.8	2311.2	4746.9	4571.1	4571.1	4395.3	4922.7
2	14908	14908	14569	14569	15264	2830	2859.5	2874.2	2911	2889	4922.7	4746.9	4746.9	4571.1	5098.5
3	17808	17325	16027	17325	18058	3395.9	3431.2	3449.2	3493.1	3466.8	5274.4	5450.2	5274.4	5098.5	5450.2
4	12572	12330	12097	11872	12572	2711.9	2711.9	2711.9	2711.9	2711.9	5450.2	5626	5626	5450.2	5626
5	13356	13085	12822	12449	13356	2971.4	2971.4	2971.4	2971.4	2971.4	5801.8	5977.6	5626	5626	5977.6
6	14090	13496	13356	13085	14090	3219.1	3219.1	3219.1	3219.1	3219.1	6153.4	6329.2	6505	6329.2	6680.9

Table 4 Heat Balance Sheet

Heat carried away by the exhaust gases					Unacounted losses					According to heat balance sheet				
(kJ/hr)					(kJ/hr)					(kJ/hr)				
28	30	35	38	42	28	30	35	38	42	28	30	35	38	42
2274.4	2200.9	2310.1	2061.6	2079	3044.5	3037.3	3772.7	3086.2	3017	12330	12097	12953	11872	12330
2964.8	3007.8	2808.1	2844.9	2848.7	4190.3	4293.7	4139.4	4241.7	4427.8	14908	14908	14569	14569	15264
3798.2	3620.2	3378	3601.5	3630.4	5339.5	4823.1	3925.7	5131.5	5510.8	17808	17325	16027	17325	18058
2409.6	2265.6	2157.3	2083	2119.7	1999.9	1726.5	1601.5	1626.9	2114	12572	12330	12097	11872	12572
2752.4	2592.8	2379	2251.5	2300.1	1830.3	1542.8	1845.3	1599.7	2106.8	13356	13085	12822	12449	13356
3106.6	2917.4	2815	2696.5	2781.8	1610.3	1030.2	816.85	839.78	1407.8	14090	13496	13356	13085	14090

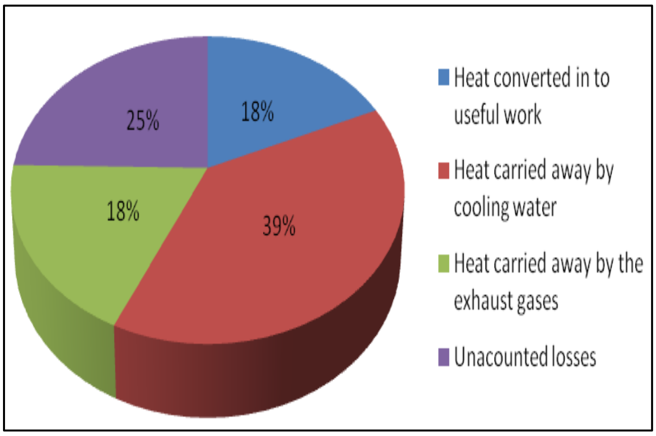


Fig 7 Pie chart showing the Energy Distribution in Heat Balance Sheet

V. CONCLUSION

The investigation is focused on the effect of preheating the inlet air and to enhance the engine performance and try to recover the waste heat from the exhaust gases.

The brake thermal efficiency has increased from 18.36 to 19.62 % when the temperature is increased from 28 to 38°C and also the Brake specific Fuel Consumption decreased from 0.4624 to 0.4328 kg/kW-h in the first reading. Hence the fuel consumption can be decreased by preheating the inlet air.

The performance characteristics are compared on the graphs and it can be observed that the efficiency is increasing as the inlet air temperature is increasing but as the temperature goes beyond 40°C, The air becomes thinner and it does not expand much so doing less work and thus, it will again reduce the engine efficiency and also the volumetric efficiency will decrease and thereby it will result in incomplete combustion due to the insufficient availability of oxygen.

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