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A comparative study on intercooler for turbocharged unit using mathematical modelling

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ABSTRACT

In today's era pollution is a major problem in the environment. But vehicles are the major cause of environmental pollution to over from this effect in BS3 engines intercooler is used to cool down the compressed air temperature from the turbocharged unit. The purpose of the research paper is to take mathematical modelling of an intercooler and reduce the outlet temperature by cooling it down with some modification.

Keywords— *Intercooler, Turbocharger, Mathematical modelling*

1. INTRODUCTION

Turbocharger used in BS2 for increasing the air flow rate and output power of the engine. The advantages of increasing pressure increase the inlet air density and temperature during the pressure raising process. Once the temperature increases, air density decreases, so the power of the engine increases and the emission rate also increases.

After that in BS3 intercooler was used to cool down the compressed air temperature from the turbocharger. After cooling the density will increase under the condition of the same air-fuel ratio. Moreover, diesel engine efficiency also increases with the temperature of turbocharged air. Meanwhile, the application of intercooler can reduce the emission of pollutant and improve engine performance. The purpose of the research paper is to take an intercooler and reduce the outlet temperature by cooling it down with some modification in the design of an intercooler and the automobile radiator system. For the conceptual design, the plan is to eliminate the fins of the intercooler and add rectangular cuboid for water circulation inside the rectangular cuboid over the flat tube surface. To cool down the temperature of air instead of using air to air cooling process and also add an additional system to the radiator.

The inlet and outlet temperature were measured to record the temperature changes across the system by Computational Fluid dynamics (CFD) fluent16.0 analysis technology software.

2. LITERATURE REVIEW

Various authors have carried out their work on intercooler in automotive commercial vehicles.

Mohd Muqeem et.al designed of an intercooler for turbocharger unit to cool down the compressed hot air. His aim was to enhance the volumetric efficiency of the diesel engine. It observed that the mass flow rate of atmospheric air gets reduced due to the increase in temperature of the atmosphere in hot summer days.

Mr Huajie Wu, Xiaofeng Dai, Yi Zhang, et al. (2015) analyzed the heat transfer in the flat tube of an intercooler to reduce the temperature of compressed air. They used computational fluid dynamics software –fluent to analyze the structural characteristics of the intercooler fins and established finite element model then the unstructured grid was used to mesh. Further study of flow modelling of intercooler was carried out **Mr.Toporcer Emil, Ing** and analyzed the effect of airflow during work of an intercooler using CATIA and CAD software. The result shows there is a low temperature of charged air obtain to utilize more effective energy to decrease the environmental load. Richard L. Roberts made concluded that the concept is a viable solution to reducing the temperature of the intake air in a turbocharged system. Through these experiments, the data showed a 6% decrease in temperature when compared to the normal operating condition.

2.1 Literature review gaps

After literature review the following gaps have been identified given below:

The currently used intercooler are air to air type cooling system due to this the air is not cool down as compare to water to air type cooling system. The pressure drop across the intercooler and through the piping which results in some loss of air density. Many researchers found that intercooler requires more space in the engine compartment.

2.2 Objectives

Based on identified literature review gaps following objectives has been set which is given below:

- To find a way out for reducing the air temperature of the intake in a turbocharger system for an internal combustion engine.
- To increase the oxygen rate and density of compressed air for better combustion.
- To increase the power and efficiency of the engine.
- To reduce the emission of pollutant.

3. DATA COLLECTION

3.1 Data Collection using Mathematical Modelling

Some important parameter used in mathematical calculations.

3.1.1 K-Thermal Conductivity (wt/m-k): The amount of energy conducted through a body of unit area, and unit thickness in unit time when the difference in temperature between the faces causing heat flow is unit temperature difference.

3.1.2 Viscosity: Viscosity is an important fluid property when analyzing liquid behaviour and fluid motion near solid boundaries. The viscosity of a fluid is a measure of its resistance to gradual deformation by shear stress or tensile stress. The shear resistance in a fluid is caused by inter-molecular friction exerted in a layer of a fluid attempt to the side by one another.

There are two measures of viscosity.

μ-dynamic viscosity (kg/m-s)

Ʋ-Kinematic viscosity (m^2/s)

The relation between those two viscosities is given below:

$$\upsilon = \frac{\mu}{\rho}$$

3.1.3 ρ-Density (kg/m^3): Density of material is the ratio of mass to the volume occupy of that particular material.

h-convectional heat transfer coefficient

3.1.4 Re-Reynolds Number: Reynolds number is the ratio of viscous force to the inertia force. Reynolds number is used to determine the types of flow. When Reynolds number is >2000, consider the flow is turbulent and it's <2000, consider the flow is laminar.

3.1.5 Nu- Nusselt Number: Nusselt no is the dimensionless parameter used in calculations of heat transfer between a moving fluid and a solid body. In heat transfer at a boundary within a fluid, the Nusselt number is the ratio of convective to conductive heat transfer across the boundary.

3.1.6 Pr-Prandtl Number: Prandtl number is also one dimensionless number which is used in the calculation of heat transfer between a moving fluid and a solid body. It is defined as the ratio of momentum diffusivity to thermal diffusivity.

4. PROCEDURE FOR CALCULATES THE OUTLET TEMPERATURE OF INTERCOOLER

Firstly find out the surface area of one tube in the intercooler, by using the following formula:

$$A_{s1} = 2 \times (l + b) \times L$$

But here no of tubes are 8 so total surface area is,

$$A_s = 8 \times A_{s1}$$

By using following formula find out characteristics length,

$$L_c = \frac{2lb}{l+b}$$

Reynolds number,

$$R_e = \frac{LcV\rho}{\mu}$$

Prandtl number,

$$P_r = \frac{\mu Cp}{K}$$

The formula of Nusselt number is used for find out the conventional heat transfer coefficient h,

$$N_u = \frac{hLc}{K} = 0.023 \times (R_e)^{0.8} \times (P_r)^{0.33}$$

By using the following relations and find out the temperature of the outlet,

$$h \times As \times [\frac{T_i + T_o}{2} - T_w] = \dot{m} \times C_p \times (T_i - T_o)$$

4.1 Calculate the Density of Outlet Air of an Intercooler

By considering continuity equations:

$$\rho_2 A_1 V_1 = \rho_2 A_2 V_2$$

Area of inlet and outlet are the same (A_1=A_2)

So consider the following equations for calculating the outlet air density:

$$\rho_1 V_1 = \rho_2 V_2$$

$$\rho_2 = \rho_1 \frac{V_1}{V_2}$$

4.2 Sample Calculations to Calculate Outlet Temperature

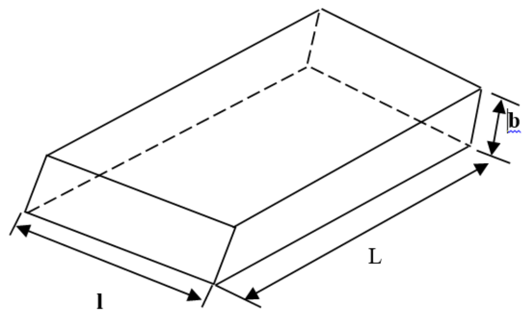

Fig. 1: Dimensions of Tube

Take,

b=0.017225m, l=0.06m, L=0.452m, V=11.17m/s,

$\dot{m}$=0.04618Kg/s, T_i=400K

T_w = 300K, ρ=0.83Kg/m^3

μ=2.290e-5Kg/m-s, K=0.0331Wt/m-K, C_p=1013J/Kg

$$A_{s1} = 2 \times (l + b) \times L = 0.0698$$

Used 8 tubes so total surface area is

$$A_s = 8 \times A_{s1} = 0.5584m2$$

$$L_c = \frac{2lb}{l+b} = 0.0267m$$

$$R_e = \frac{LcV\rho}{\mu} = 10809.67$$

$$P_r = \mu\frac{Cp}{K} = 0.7008$$

$$N_u = \frac{\text{hLc}}{\text{K}} = 0.023 \times (R_e)^{0.8} \times (P_r)^{0.33}$$

$h=42.77 Wt/m^2\text{-}K$

$$\text{h} \times \text{As} \times [\frac{T_i + T_o}{2} - T_w] = \dot{\text{m}} \times C_p \times (T_i - T_o)$$

$T_0=359.32K$

4.3 Sample calculations for calculate the density of outlet air of an intercooler

The value of ρ_1, $V_1$and V_2 at different temperature are given below,

At a temperature of 400.25°K the above values are:

$\rho_1=0.83 Kg/m^3$

$V_1=11.17m/s$

$V_2=9.38m/s$

$$\rho 2 = \rho 1 \frac{V1}{V2}$$

$\rho_2=0.9883 Kg/m^3$

4.4 Comparative analysis of normal and modified intercooler

For comparative study Technical Specifications of the Engine of Maruti Suzuki Swift, VDi has taken the detail technical specification is shown in table 1.

Table 1: Technical Specifications of the Engine of Maruti Suzuki Swift VDi

Engine RPM	Mass flow rate	Inlet temperature and density		Existing intercooler			Modified intercooler using mathematical modelling		
RPM	ṁ (Kg/s)	T_i	ρ_i	T_o	Ti-T_o	ρ_o	T_o	T_i-T_o	ρ_o
1333	0.00958	365.44	0.9718	343.28	22.16	1.0291	331.84	33.60	1.179
1913	0.0140	368.32	0.9586	345.28	23.04	1.0231	335.34	32.98	1.145
2397	0.0177	371.34	0.9458	346.12	25.22	1.0198	338.16	33.18	1.076
2706	0.0234	377.42	0.9332	348.71	28.71	1.0123	342.61	34.80	1.008
3503	0.0461	400.25	0.83	370.87	29.38	0.9518	359.00	41.25	0.943

5. RESULT AND DISCUSSION

From the above comparison, various results got to achieve the objectives of the project and due to this the various graph and table are shows for discussing the result.

Shown in the following figure 1 mass flow rate of compressed air is increased to increase the temperature of inlet air.

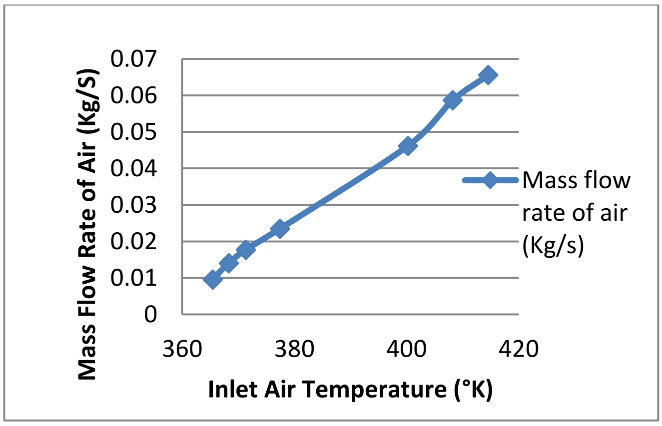

Fig. 1: Mass flow rate of compressed air at different temperature

From figure 1 the mass flow rate of air increase due to an increase in velocity of the turbine. The centrifugal fan rotates very fast by an increase in velocity and pressure of air also increases.

But according to universal gas constant,

$$PV = m \times R \times T$$

Then,

$$P \;\alpha\; T$$

(Therefore, the pressure is directly proportional to temperature)
So, from this when pressure increases the temperature of air also increases and due to this the mass flow rate of air increases.

5.1 Results by Mathematical Modeling

Under this, the various parameter which was taken from data collection is to be considered for mathematical modelling. Various heat transfer equations are used to calculate the outlet temperature of an intercooler and their results are shown in figure 2.

In figure 2,3,4 results shows that in mathematical modelling mass flow rate of air change then due to this inlet temperature of air also varies which help to calculate the outlet temperature of air by using some heat transfer equation. After receiving outlet temperature from the calculation then use the continuity equation to determine the density of air. The result shows that the density of air increases due to decrease in temperature.

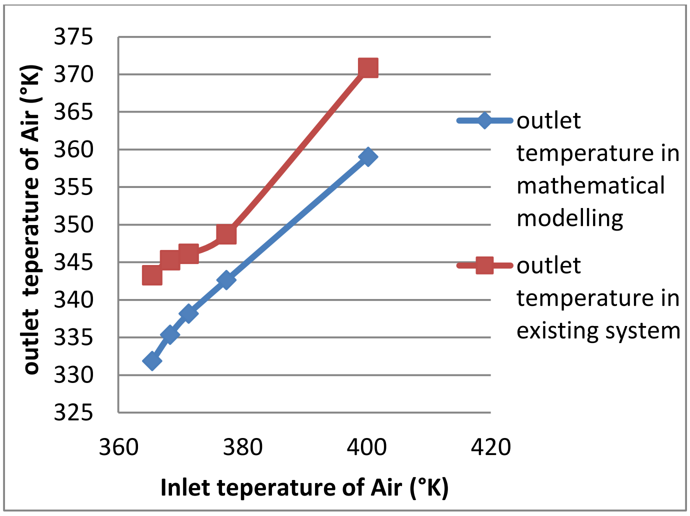

Fig. 2: Inlet and outlet temperature of compressed air by mathematical modeling

Figure 3 the temperature of inlet air increases due to this the density of inlet air is decreased. But after the modified intercooler, such type of problem is avoiding because a high amount of heat is rejected from modified intercooler are shown in the next graph of density.

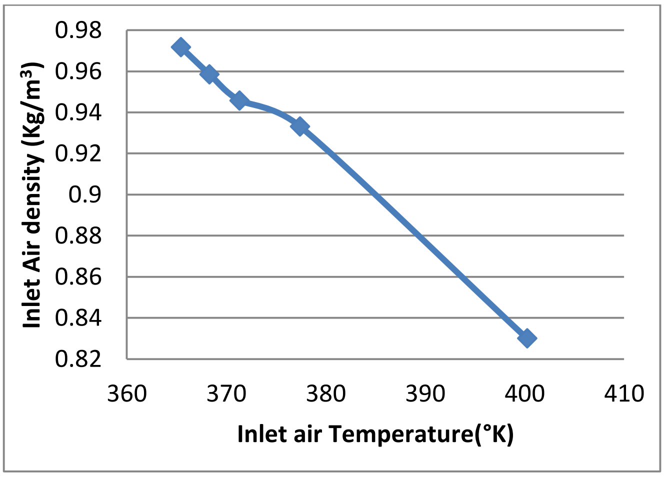

Fig. 3: Inlet air density vs. inlet air temperature

Figure 4 shows the outlet air temperature is increased and reduces the density of outlet air. But the rate of increase in outlet temperature is minimum in compare of existing intercooler system so density reduction is also minimum. It is beneficial for combustions in an internal combustion engine.

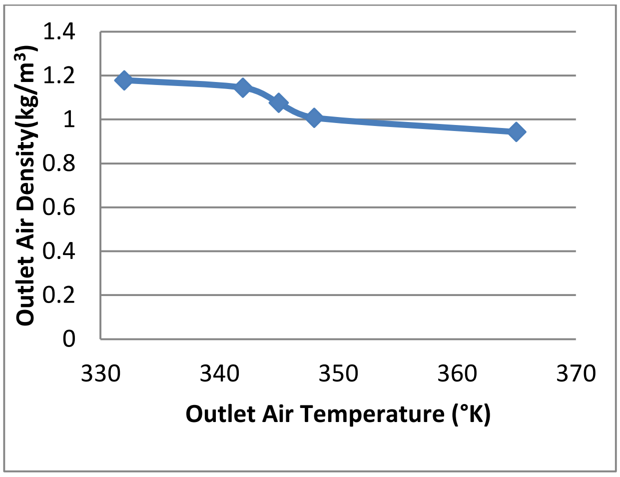

Fig. 4: Outlet density of air vs. outlet temperature of compressed air

6. CONCLUSION

In this work, analysis of modified intercooler is done using mathematical modelling. The main goal of work was to reduce the outlet temperature of the intercooler. It has been observed that for same air-fuel ratio density of compressed air is increased. Hence, the oxygen rate is increased for better combustion. Besides compressed air temperature was reduced up to 40°C. However, normal commercial intercooler temperature of compressed air reduced up to 20^0C. Therefore modified intercooler for present work is found to be successful.

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