



Evaluation of Charge Air Cooler to Enhance Performance for Passenger Car

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ABSTRACT

Charge air cooler is extensively used in diesel engine mostly for marine applications. The main purpose of a charge air cooler is to cool the engine air, ensuring efficient performance. The main objective of the charge air cooler is to reduce the pressure drop and the outlet temperature. In this paper, the charge air cooler was designed, simulated and developed in MAHLE Behr India Private Limited, Pune. Based on the simulation and experimental results it is observed that pressure drop and outlet temperature are in good agreement as per the requirement.

Keywords— Charge air cooler (CAC), pressure drop, outlet temperature, starccm simulation.

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INTRODUCTION

Charge air cooler is an air-to-air or air-to-liquid heat exchange device used on turbocharged and supercharged (forced induction) internal combustion engines to increase their volumetric efficiency by increasing

intake air-charge density through isochoric cooling. A decrease in air intake temperature provides a denser intake charge to the engine and permits more air and fuel to be combusted per engine cycle, increasing the output of the engine.

Limited amount research work has been carried out by many researchers working in the area of the charge air cooler. Their work has been reported by performing in-depth literature review through earlier published research work, journal papers and technical reports. This section focuses on the work done by many researchers working in the region of the charge air cooler. Kolb et al. [1] describes a new long life, heavy duty, air-to-air charge air cooler (CAC) which has specific application in heavy duty trucks, buses, off-highway vehicles and construction equipment, in which through structural modeling and fatigue analysis is carried to come across minimum reliability requirements. Mannoni et al. [2] performed experimental study on an all-nylon charge air cooler development for automotive application. The results obtained during the project deployment in terms of performance comparison between metal and nylon Charge air Coolers are described. Knaus et al. [3] has given a brief overview of the Behr reliability management system, including, as an integral element and the validation process. It defines the application of test methods as well as simulation tools and related coupling strategies which are used to validate charge air coolers. Simulation of the main validation tests for charge air coolers is executed. For this study a CFD simulation is carried out to predict surface temperature distribution. The results are evaluated and compared with temperature measurements. Stephenson et al. [4] has optimized problem with four conflicting objectives: to reduce the pressure loss in the system, to increase the uniformity of flow in the tubes, to minimize the tank material and to conform to the package volume. In this work, CATIA v5 was used to define the package volume to which the optimized CAC must conform, and a commercial CFD tool was used to create the geometry and mesh, and to run the analysis. Xiao et al. [5] has carried out the matching design of hot side and cold side flow channels in CACs. Based on numerical simulation results, the fluid flow and heat transfer performances of 9 matched CACs were comprehensively evaluated and the optimal structure was obtained. Mohd et al. [6] have observed that the commercially available automotive intercooler used to cool down the compressed hot air from turbo compressor fails when the summers are very hot and the speed of the vehicle is lowered. As a result of this, the density of air and consequently the mass flow rate delivered by the turbo compressor and entering into the engine get reduced. W. Yaici et al. [7] have presented the results of computational fluid dynamics simulation with an aim to examine the effect of inlet air flow maldistribution on the thermo-hydraulic performance of the heat exchangers. J. Yang et al. [8] have projected an optimization design method based on constructal theory for heat exchanger design in which a simplified version of design method is recommended and the optimization problem formulations are given. Xiang et al. [9] has observed the development of heat exchangers from two streams and single operating condition to multi-stream and multiple operating conditions, passage arrangement becomes a key problem for heat exchanger design. In this paper, a new passage arrangement design method for multiple operating conditions is developed for multi-stream plate-fin heat exchangers. B. Ameel et al. [10] have observed that the heat exchangers for air conditioning applications are often fin and tube type, in which they observed that selecting special fin geometries, the thermal performance of the heat exchanger can be improved. P.

Pongsoi et al. [11] has made an effort to summarize and analyze the results of an analysis of the air-side performance of spiral (or helical) fin-and-tube heat exchangers. Moreover, the air-side performance correlations of spiral fin and circular fin-and-tube heat exchangers are compiled into this work for practical industrial applications.

From literature review it is seen that a lot of work is performed on a charge air cooler but very less amount of research work is reported for different tank material of a charge air cooler and its performance. Hence, from this case and as discussion with expert at Behr India Pvt. Ltd, an idea came in our mind to design a charge air cooler tank for the given materials with objective to reduce pressure drop and the outlet temperature to enhance performance. This paper is organized as follows: Sections 1 focus on literature review and recent development in the subject, problem formulation and objective of work is stated in Section 2, working and modeling of charge air cooler is explained in Section 3; Section 4 and Section 5 focus on computational fluid dynamics, the results and discussion is explained in section 6, concluding remark is given in Section 7.

I. PROBLEM STATEMENT AND OBJECTIVE

As per the industrial and literature survey, it is observed that a lot of work is carried out on a charge air cooler but very minute amount of research work is reported for different tank material of a charge air cooler. Hence, idea came in our mind to design a charge air cooler tank for given material.

Finally, the scope of this paper is to evaluate the pressure drop across the charge air cooler and outlet temperature to enhance performance.

II. WORKING PRINCIPLE

In diesel engine, charge air cooler is located in the middle of the turbocharger and the engine. Turbocharger is a device which offers a greater supply of combustion air by compression. The hot air coming out of the engine is passed through the turbocharger for compression. Increasing the density of the combustion air will increase combustion efficiency. Thus, the compressed air is passed through the charge air cooler to increase density of the air which ultimately lowers the temperature of the air. This cooled air, then further supplied to engine. Also, increase in density of the cooling air will lead to an increase in weight of the charge air of the system, which in turn leads to an increase in engine efficiency. The schematic layout of test set-up for measurement of outlet temperature of charge air cooler was as shown in Fig.1. The experimental setup consists of temperature sensors (TS) to sense the temperature and pass signal further for processing and also inlet and outlet temperature indicator for the display of the inlet and outlet temperature of the charge air. The experimental work was carried out to measure the outlet temperature with the help of the temperature sensors (TS).

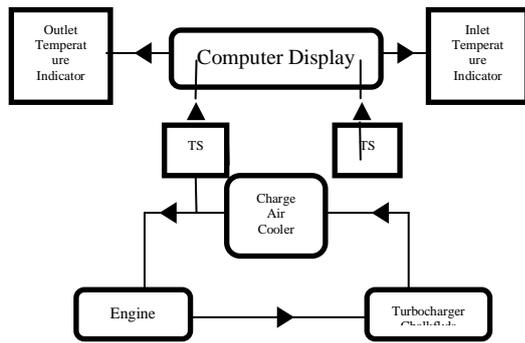


Fig. 1 Schematic layout of test set-up for measurement of outlet temperature

III. MODELLING AND DESIGN PARAMETERS

In this section complete design of charge air cooler and solid modeling achieved by using CATIA V5 software is presented. The charge air cooler consists of parts like Header, Inlet Tank, Outlet Tank, Side Plate, Tube and Fin. Charge air cooler was designed by considering some factors like cost, weight and the performance as shown in Fig.2. In design more importance has given to the simplicity, rigidity and the outer appearance. Table 1 shows major dimensional parameters of designed charge air cooler.

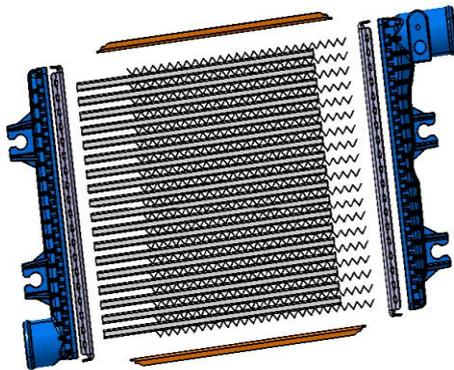


Fig 2 Charge Air Cooler

Table 1 Design Parameters

Parameters	Constraint
Engine	2.2 lit. 4 cylinder 120 HP
Block Dimension	277 X 259 X 40 mm
Frontal Area	0.07174 m ²
Fin Density(external)	65 fin/dm
Fin Density(internal)	65 fin/dm
Number of tubes	18
Number of fins	19
Tube pitch	15mm

Now a day Computational Fluid Dynamics (CFD) has become one of the key tools for engineering researchers. Present system is simulated using commercial CFD software (STAR-CCM).

IV. COMPUTATIONAL FLUID DYNAMICS

Computational Fluid Dynamics (CFD) has been gradually used for a wide variety of engineering applications. It permits us to perform simulations of complex problems, examine the effect of different design parameters, obtain detailed distributions of all relevant variables, and gain insight into the fundamental physical processes. By a proper use of modeling, one can cut down on time consuming and costly experiments and field measurements, avoid design by trial and error, obtain speedy results, and design better products and processes. Boundary conditions applied in CFD simulation are tabulated in Table 2.

Table 2 Boundary Conditions

Parameters	Constraint
Charge air flow rate	509 kg/hr
Ambient temperature	25°C
Charge air temperature before entering CAC	150°C
Cooling air speed	6m/s
Pressure at inlet	1bar

V. RESULTS AND DISCUSSIONS

CFD simulation by using StarCCM software was carried out for determination of the results for pressure drop and outlet temperature of charge air cooler. As per the requirement of the customer the results of pressure drop and outlet temperature obtained by CFD simulation are compared with the requirement. Results of pressure drop obtained by two approaches are given in Table 3 which is in good agreement as compared with the requirement. Fig. 3 shows pressure contour plot which shows absolute pressure drop along inlet tank, core and outlet tank.

Table 3 Comparison for pressure drop of CAC

Inlet Parameters		Outlet Parameters		
Internal Pressure (kPa)	External Pressure (kPa)	Required Pressure Drop (kPa)	BISS Simulation Pressure Drop (kPa)	CFD Pressure Drop (kPa)
2.20	1	7.7	7.64	7.6

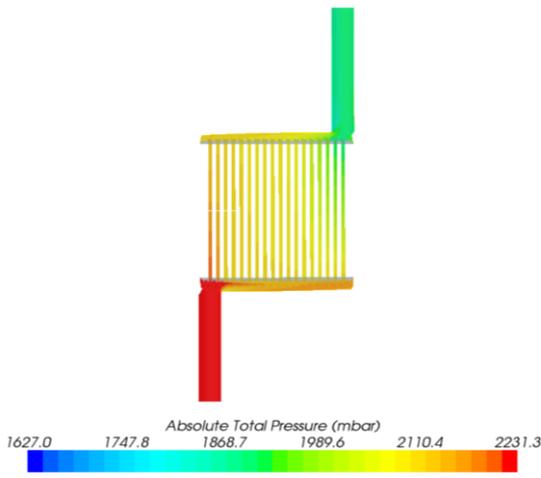


Figure 3 Pressure contour plot

Results of outlet temperature obtained by two approaches are given in Table 4 which is in good agreement as compared with the requirement. Fig. 4 shows temperature contour plot in which it is observed that temperature at outlet tank is less than the inlet tank.

Table 4 Comparison for outlet temperature of CAC

Inlet Parameters		Outlet Parameters		
Ambient Temp (°C)	Charge Air Inlet Temp (°C)	Required Outlet Temp (°C)	CFD Outlet Temp (°C)	Tested Outlet Temp (°C)
25	150	55	51.4	53

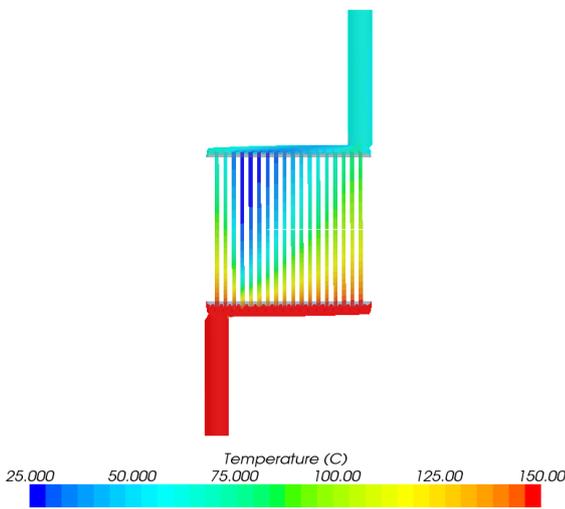


Figure 4 Temperature contour plot

VI. CONCLUSION

The primary objective is to estimate the pressure drop and outlet temperature with objective to maintain pressure drop across the charge air cooler and to reduce the outlet temperature. This objective was achieved with the help of computer aided simulation tools, commercially available software's, and experimental investigations. The design of the charge air cooler was carried out as per company standards both manually and by using software.

The outlet temperature of hot & cold air has been found to be close to the experimental values. The simulated results predict the temperature distribution reasonably at different locations of heat exchanger. After analysis of charge air cooler the temperature ranges between the acceptable limits. It means the analysis is quite realistic and gives result in acceptable range.

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