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Study and Comparison of charge air cooling techniques & their effects on Efficiency of automobile engine

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Abstract

The objective of a turbocharger is to improve an engine's volumetric efficiency by increasing the density of the intake gas (usually air, entering the intake manifold of the engine). When the pressure of the engine's intake air is increased, its temperature will also increase. Turbocharger units make use of an intercooler to cool down the inlet air. In the existing direct charge air coolers the atmospheric air is used to cooldown the charge air.It means the charge air is fed to the direct charge air cooler located at vehicle front, and then it flows to the engine through the long routing.Here, our purpose is to bring the temperature of intake air nearer to the ambient temperature & reduction of the pressure drop. The intercooling of intake air is greatly increased by installing a specially designed intercooler i.e. Indirect charge air cooler in which air will run as hot fluid and coolant (glycol + water) will run as cold fluid. The intake air will be cooled down by the air flowing through the fins of the intercooler and the coolant coming from the Low temperature radiator which is mounted in front of High temperature Radiator at the vehicle front. And hence the density of air is increased by increasing the temperature drop across the intercooler.

Keywords: *Intake manifold, direct charge air cooler, Turbocharger, Indirect charge air cooler.*

1. Introduction

The Charge air cooling requirements are increasing to meet the upcoming stringent emission targets like BSVI in India, Charge air cooling requirements are increasing due to higher turbocharger outlet temperature and pressure, higher EGR rates in modern boosted engine.

The engine manufacturers are always in search of methods to increase the power output at the same volume displacement. By applying the thermodynamic laws, the quantity of air - fuel mixture inserted in combustion chamber can be raised primarily by turbo charging, which leads to the increase of air pressure and temperature in the combustion chamber meaning that engine operates at a higher thermal load. Secondly, the charge air can be cooled allowing higher mass of air to be introduced in the combustion chamber, every cycle, thus leading to higher power output and lower fuel consumption. Also, the charge air cooling reduces the temperature in cylinders and exhaust system, improving engine durability. On emissions, inter cooling produces lower smoke (particulate) emissions as effect of higher density and air-fuel ratio, as well as lower NOx emissions.

With the introduction of BSVI emission norms in 2022, the OEMs will have to avoid harmful emissions in any conceivable real life situation. The stringent emission targets up to 88% reduction in NOx and 82% reduction in PM requires effective charge air cooling.

Intercoolers have been increasingly used in internal combustion engines with supercharging since 1990s because of their positive effect on engine power and fuel consumption. To cool a fluid, including liquids or gases, between stages of a multi-stage heating process the Charge air cooler is used, typically a heat exchanger that removes waste heat in a gas compressor. The Charge air cooler is placed somewhere in the path of air that flows from the turbo/supercharger to the motor. The Charge air cooler is needed in Air intake system because of the physics of air described in the Ideal Gas Law, that is PV= nRT. Describing the ideal gas law as basic because pressure and temperature are directly proportional, as it create more pressure with turbo or supercharger, which produce more heat as well. The high temperature air is less dense and therefore contains less molecules of oxygen per unit volume. This means less air for the engine in a given stroke and therefore less power produced. High temperature air also causes a higher cylinder temperature and therefore can aid in pre-detonation of the combustion cycle causing detonation. Intercoolers increase the efficiency of the air intake system by reducing charge air heat created by the turbocharger and promoting more thorough combustion. This removes the heat of compression (i.e., the temperature rise) that occurs in any gas when its pressure is raised or its unit mass per unit volume (density) is increased. The purpose of this project is to enhance the charge air cooling technique by using the indirect charge air cooling technique, where the charge air cooling done by using the additional coolant circuit. By decreasing the charge air cooler temperature, hot air flow passes through charge air cooler will be more cooled before its enter intake engine. The performance of engine increases When air is cold because it has more oxygen, good density and volume.

1.1 Types of Intercooler

Number of ways to improve the possibility of the runway the engine, one of which is by way of mounting the turbo intercooler. Turbo charge air cooler function is as a reduction in engine temperature is very high after being taken from the relief valve. There are a number of benefits perceived by its users. First, the refuse in air temperature causes the air molecules become more dense. The more thick air molecules inside the inlet, the greater the power produced by the machine. In addition, lower temperatures also decrease the symptoms of tickling (knocking). According to the requirement and development. Intercooler designed a variety of forms. More design considerations in priority to optimize the cooling air without much reducing the pressure turbo (Turbo Pressure).

In general, the intercooler can be divided into 3 types.

a. Air to air

Air to air intercooler is a type of the most widely used in cars today. Of particular interest in this type of indentation intercooler and changes in size should be as little as possible. In addition, the connections and rubber hoses should be of good quality to be able to withstand the pressure Turbo. The erection Turbo also need to be considered, must be placed in a place that as many as possible get a breath of fresh air when the car moves.

b. Air to water

The water pump is the most important component in this type of charge air cooler. For that is usually connected with a water pump mounted 12-volt batteries series or parallel. In this type of Charge air cooler the water is circulated to cool the charge air, basically works the same principle as the radiator water.

c. One-shot intercooler

This type Charge air cooler is not suitable for everyday vehicles, but for vehicles Drag Race. Usually the medium used for this type of charge air cooler is N_2. This type of Charge air cooler has the ability of air cooling is very high .

2. Literature Survey

This section includes the literature survey of earlier research work made by various researchers on Charge air cooling techniques. Various researchers presented the different techniques in the development of charge air coolers and performance improvement. This section presents the summary of this research work.

- **Veneţia SANDU [1]**Studies the performance of a heavy duty turbocharged diesel engine when the inlet air is cooled in an air-to-air heat exchanger, being turned into a turbocharged and charge air cool engine. There were presented the tests performed on dynamometer, being analyzed engine performance parameters such as torque, ratedpower, hourly and specific consumptions and smoke level on the speed characteristic at total load. A stress is disabled on the influence of air charge thermodynamic parameters on cooler efficiency and pressure loss.
- **J.N. Devi Sankar, P.S.Kishore [2]** have done thermal analysis of indirect charge air cooler, The analytical calculations done to obtain the performance factors like Colburn-j factor, Fanning friction factor, heat transfer coefficient, overall heat transfer coefficient and effectiveness of heat exchanger. From the obtained results, graphs are drawn to assess the performance of the water charge air cooler.
- **MohdMuqeem , Dr. Manoj Kumar [3]** have designed the charge air cooler of a turbocharger unit to enhance the volumetric efficiency of diesel engine by making the charge air cooler unit refrigerated to some extend by passing the conditioned air into it as the cold fluid, coming from cooling coil of the additive air conditioning system. By this method, the compressed hot air will be cooled by the mixture of two, the cooled air from air conditioning system and the climatic air coming from the front side of the vehicle.
- **Eric Brouillard , Brian Burns , Naeem Khan , John Zalaket [4]** have studied to search a visible solution to decreasing the air temperature of the inlet in a turbocharged system for an internal combustion engine while making any major modifications to the existing system. The proposed idea was to create an additional system integrated on the charge air cooler using the existing air conditioning system. The principle of copper tubing in front of the existing intercooler, while properly combined into the air conditioning system, is to add additional cooling to the inlet air to increase performance of the engine. During this experiment, a illustration of the proposed system was created using real world conditions to get data for validating the probability of the proposed system. Through a number of various tests and conditions, it was concluded that the concept is a viable solution to reducing the heat of the intake air in a turbocharged system.
- **Dr. sc. Naser B. Lajqi, Dr. sc. Bashkim I. Baxhaku Mr. sc. Shpetim B. Lajqi [5]** have arranged an own worked out programmed code in MATLAB, were presented effect of charge air cooler (as a heat swapping device air-to-liquid with three various size and over – all heat transfer coefficient and one base) at e multi-cylinder engine performance for operation at a constant speed of 1600 RPM. They shows the simulation predictions of temperature and pressure in cylinder for three tip of intercooler. Also presented the temperature and pressure in inlet, exhaust manifold and other performance.
- **M.Y.A. Mifdal1, M.H.Nuraida, O. Norzalina, A.H. Shamil [6]** have designed the new method of cooling the air when heat of charge air cooler at certain time will increase highly due to hot air entered, weather condition. Turbo charge air cooler Cooling System are design operated automatically to detect the heat

increase at intercooler. When temperatures are increased, motor will trigger and sprayer will spray water through charge air cooler. The system generally combined in front of charge air cooler and generated by a control panel which are require 12 v power supply can directly attach from battery and tap on the circuit on which it convert to 5v by the circuit before connect to the controller. The system is provoked by the Arduino Uno as the main controller on which being program to control automatically. The control panel also can work in physically which a manual switch are connected to give choices to the user whether to choose auto or manual operating mode.

2.1 Existing System

In the normal turbocharger system, the main problem is that in the countries where summers are at very high temprature, the capability of charge air cooler goes on reducing as the ambient temperature increases because the charge air cooler cools the hot air when relatively cold air transfer through its fins. But in summers, the air temperature, which transfers through the fins of the intercooler to take the heat of the hot air, is already high, so the efficiency of the intercooler gets decreased. Second deficiency of this charge air cooler is that it works correctly when the vehicle is running at high speed so that air passes through the fins of the charge air cooler at suitable speed which is fitted at the front of the vehicle otherwise the intercooler will not be able to reject the heat taken from the hot air. It means charge air cooler of normal turbo unit is more effective at high speeds and its efficiency goes on reducing as the speed of vehicle decreases. When an charge air cooler is working efficiently, the inlet air arrives hot and leaves a lot colder. Therefore, there's a temperature drop across the core. A perfectly efficient charge air cooler would drag the temperature of the decreased air down to ambient. But no charge air cooler is perfectly efficient, so the temperature drop across the core is always much less than this.

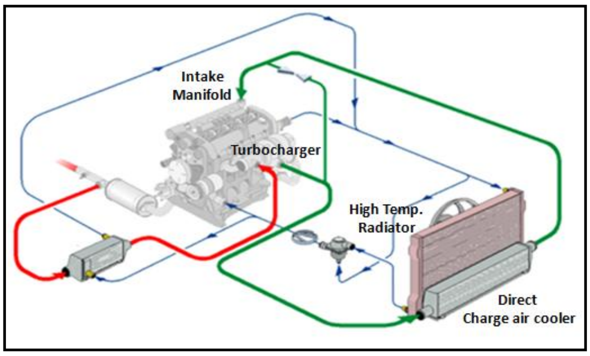

Fig.1 Direct/Air to air charge air cooler system

In above figure shows direct Air to air charge air cooler. Using this cooling system, the charge air is getting cooled directly with the external i.e. ambient air. It means the charge air is fed to the direct charge air cooler located at vehicle front, and then it flows returned to the engine through the long routing.

3. Proposed Work

Indirect or water charge air cooling (WCAC) technology offers firstly the possibility of charge air thermal management by regulating the coolant flow and secondly the possibility to reduce the air volume between compressor of the turbocharger and the intake ports of the engine. This technology provides a solution between the conflicting targets of compact packaging, the achievement of the charge air cooler thermal performance target and the reduction of gas side pressure drop and in that way contributes to improved transient engine behaviour.

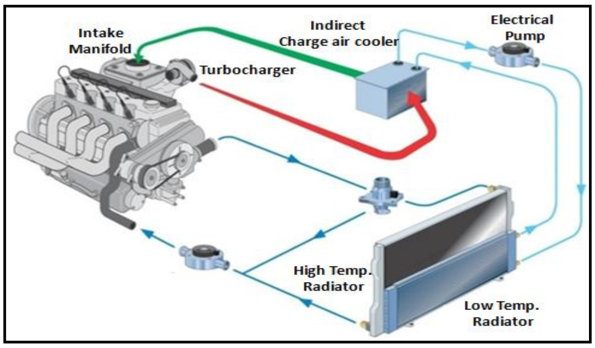

Fig.2 Indirect / Water cooled charge air cooler system

Fig.2 shows the circuit of water cooled charge air cooler (WCAC). Here the coolant is water. The water is circulated through a circuit. This circuit consists of a radiator and a pump. The water after passing through radiator passes to water charge air cooler thereby removing heat from air. The present work is mainly focused on WCAC with same fin configurations, core size of the exchanger as charge air cooler (CAC). WCAC will have some advantages over charge air cooler (CAC).

3.1. Objective

- To overview various techniques for charge air cooling.
- To calculate the performance of direct & indirect charge air cooler using simulation methods.
- To measure the performance of charge air cooler on test rig at test centre of Mahle Behr.
- Analysis and correlation study between results of simulation and measured performance results.
- Comparative analysis of performance results obtained for direct & indirect charge air cooler.

4.Performance Analysis of Direct & Indirect Charge Air Cooler

Sr.No.	Specification	Parameters / Values
1	Engine Volume	2.2 L
2	Maximum Power	140 bhp @ 3750 rpm
3	Maximum Torque	330 Nm @ 2000 rpm
4	No. of Cylinders	4
5	Valves per Cylinder	4

6	Valve System	DOHC
7	Fuel Type	Diesel
8	Fuel System	Common Rail Direct Injection (CRDi)
9	Drive System	2 Wheel Drive(Front)
10	Maximum Speed	220 km/h

Table1. Specifications of the engine for which the design of intercooler is being proposed.

4.1 Analysis of Direct charge air cooler

4.1.1 Simulative approach by using Behr Integrated simulative software tool

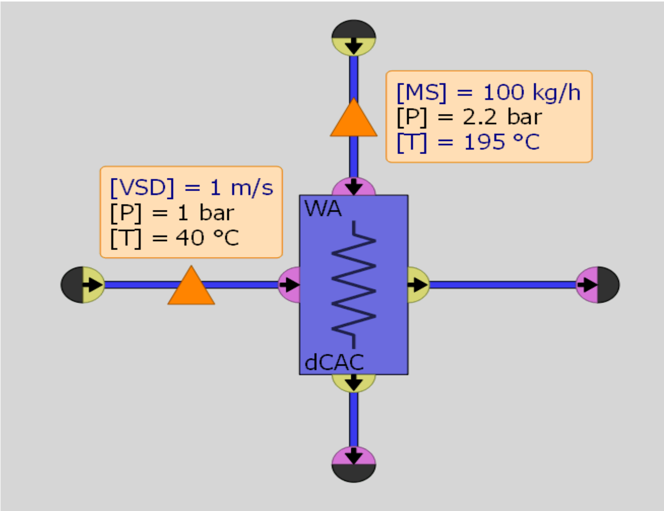

Fig.3 Simulative approachfordirect charge air cooler

Sr.No.	Specification	Parameters / Values
1	Charge air inlet Pressure	2.2 Bar (abs)
2	Charge air inlet Temperature	195 ◦C
3	Atmospheric Temperature	40 ◦C
4	Atmospheric pressure	1.013 Bar
5	Charge air flow rate	100 , 266 , 400 , 500 , 600 Kg/hr
6	Atmospheric air flow rate	1,2.5,4,5 m/s

Table2. Input conditions for Direct Charge air

By using the above input conditions in Behr integrated simulation software, the final core size of direct charge cooler received:
Core Size: 127.2 W * 600 H * 50 T mm^3
No of Tubes:8 Nos
Tube Pitch:15 mm
Amb.air side Fin Pitch: 4mm
Charge air side fin Pitch:5.12mm

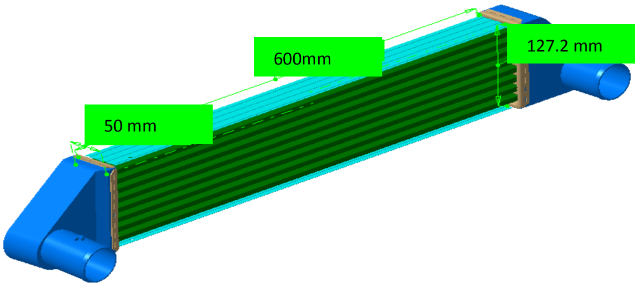

Fig.4 Direct/Air to air charge air cooler

4.1.2 CFD analysis to find the Heat rejection &pressure drop for the max Torque condition - (Charge air flow rate:266 Kg/hr , Amb air vel: 2.5m/s)

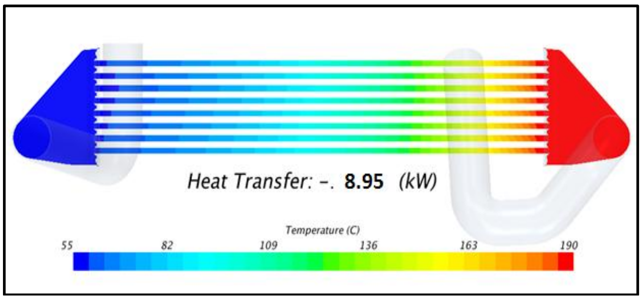

Fig.5CFD analysis for heat rejection calculation

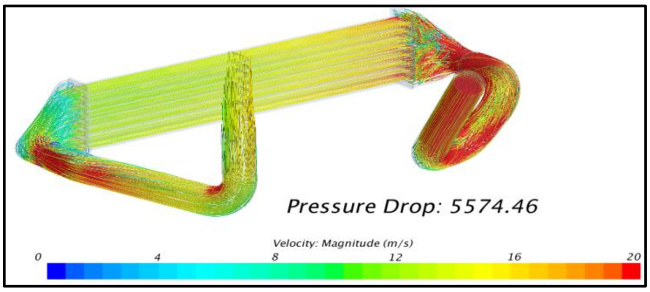

Fig.6CFD analysis for Pressure Drop calculation

4.1.3 Practical approach (System level) Test results

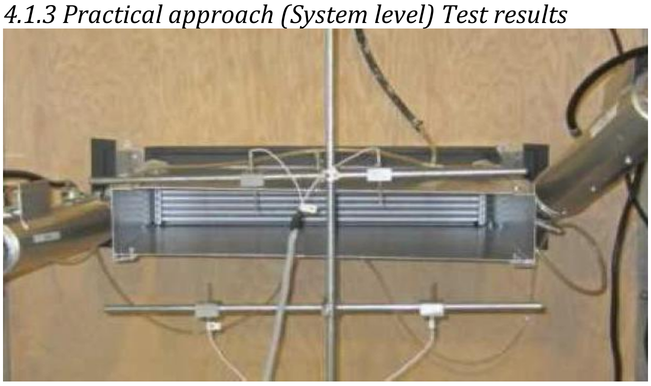

Fig 7. Test Bench set up for dCAC

4.2 Analysis of Indirect charge air cooler

4.2.1 Simulative approachby using Behr Integrated simulative software tool

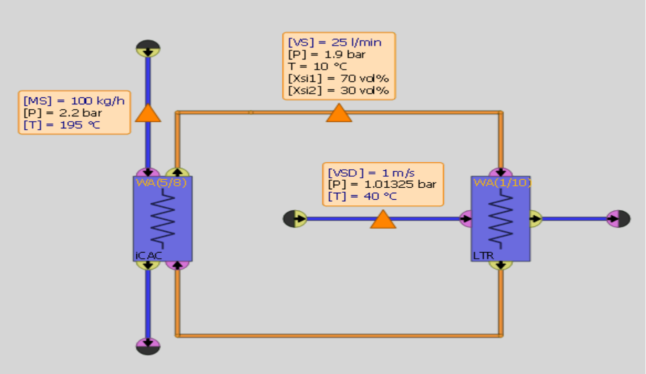

Fig 8. Simulative approach for Indirect charge air cooler

Sr.No.	Specification	Values
1	Charge air inlet Pressure	2.2 Bar (abs)
2	Charge air inlet Temperature	195 ◦C
3	Atmospheric Temperature	40 ◦C
4	Atmospheric pressure	1.013 Bar
5	Coolent inlet pressure	1.9 Bar (abs)
6	Coolant flow rate	25 lpm
7	Charge air flow rate	100 , 266 , 400 , 500 , 600 Kg/hr
8	Atmospheric air flow rate	1,2.5,4,5 m/s

Table3. Input conditions for Indirect Charge air

By using these input conditions in Behr integrated simulation software, the final core size of direct charge cooler received:

iCAC Core Details:
Core Size: 133.8 * 171 * 64.0 mm^3
No of Tubes: 13 Nos
Tube Pitch:10.5 mm
Charge air side Fin Pitch: 1.81mm
Coolant side fin Pitch:6.06mm

LTR core Details:
Core Size: 254.5 * 550 * 26 mm^3
No of Tubes: 31 Nos
Tube Pitch:8 mm
Air side Fin Density: 2.35mm

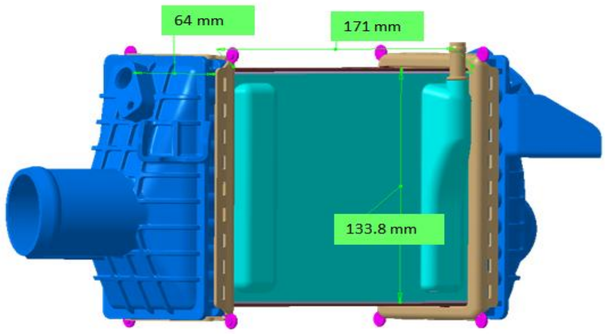

Fig.9. Indirect charge air cooler

4.2.2 CFD analysis to find the Heat rejection &pressure drop for the max Torque condition - (Charge air flow rate:266 Kg/hr , Amb air vel: 2.5m/s)

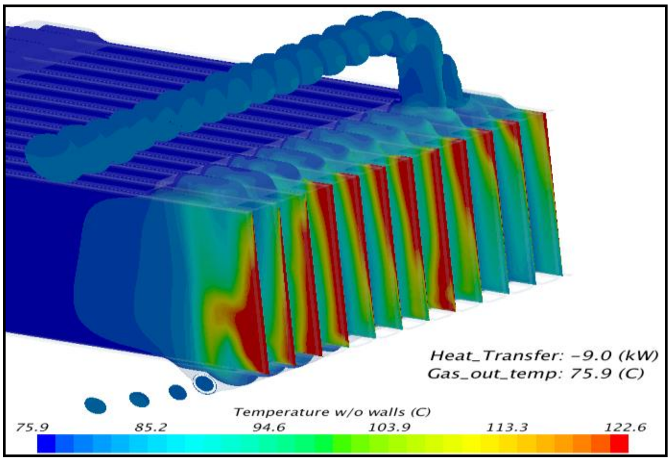

Fig 10. CFD analysis for Heat Rejection

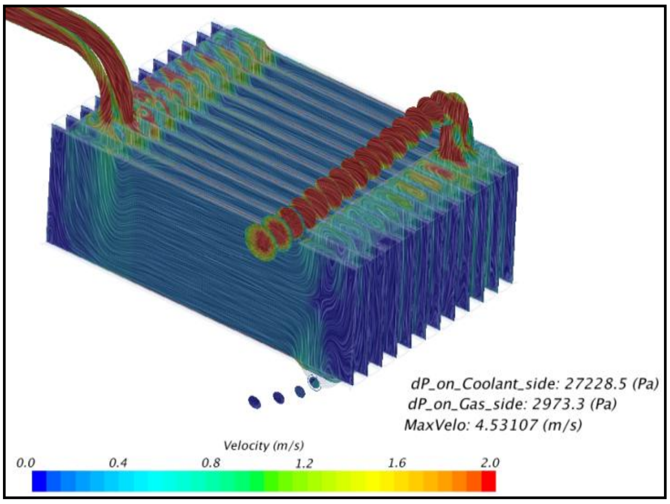

Fig 11. CFD analysis for pressure Drop

4.2.3 Practical approach (system level) Test result

Fig 12. Test Bench set up for iCAC

5. Results & Discussion

5.1dCAC vs iCAC Outlet temperature Comparison result at max Torque Condition (Amb. Air flow:2.5m/s)

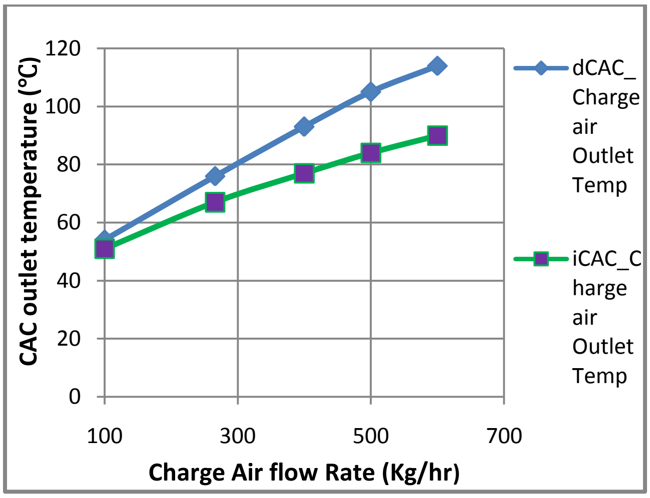

Fig 13. Performance comparison curve (Outlet temp Vs Charge air flow)

5.2dCAC vs iCACCharge air side pressure drop Comparison result

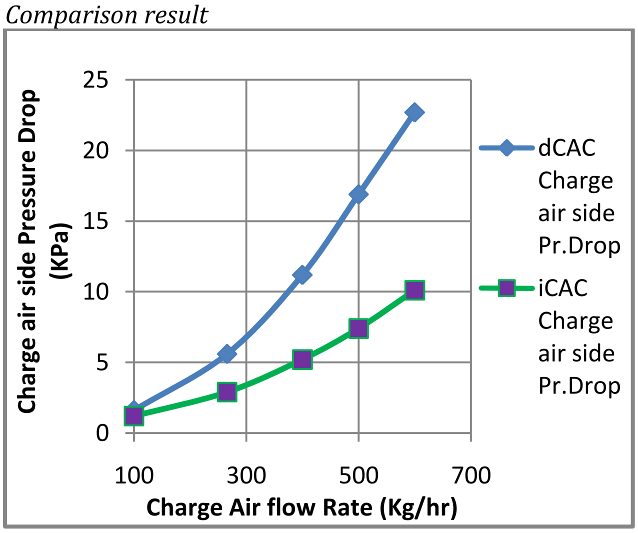

Fig 14. Performance comparison curve (Charge air Pressure Drop Vs Charge air flow)

6. Conclusion

1. From the above collected data , Calculations & graphs, it is being concluded that the heat rejection capacity of direct charge air cooler is less than the Indirect (water) charge air cooler , even the envelope size significantly higher than indirect charge air cooler.

2. The bigger size & packaging concept (mounting at vehicle front) of direct charge air cooler leads to the higher pressure drop of charge air which affects the Vehicle performance like fuel economy.

3. The indirect (water) charge air cooler is compact & having higher heat rejection capacity, less pressure drop will positively help to meet the upcoming stringent emission norms in India.

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