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Feasibility study of flat plate heat exchanger and micro-channel heat exchanger

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Abstract

Heat transfer is key parameter in industry, different types of heat exchangers are used to maintain the working performance at extreme temperature. The radiator type of heat exchanger is used to remove the surplus heat from the engine in automobile vehicles. This heat exchangers are manufactured by using the plate fin technology. The micro-channel technology is one of the technology which can be used in household air conditioning and automotive air conditioning system. The advantage of this technology is light weight, compact and high heat transfer capacity. The micro-channel gives the extra micro effects in heat transfer application. Now a day the increasing demand in market is light weight and compact devices. Least but not last, a new design of heat exchanger is proposed based on these extra micro-effects. In this work, we try to develop the new heat exchanger by using the micro-channel technology for the purpose of engine cooling application in automobile vehicles. This work describes the CFD simulation as well as experimental testing.

Keywords:*Heat Exchanger, Micro-Channel Technology, micro-effects, CFD Analysis, Fins, light weight, compact.*

1. Introduction

Heat transfer and fluid management systems are key parameters in the aerospace and automotive industry. Maintaining the working and performance of systems dealing with extreme temperatures, heat transfer systems play a pivotal role and hence their effective functioning is a prerequisite. The heat exchanger is a system component which effectively and efficiently transfers heat from one medium to another medium. Usually, the fluids which travels through separate chambers, the walls of which act as a primary heat transfer surface. Within the flow chambers secondary heat transfer surfaces may present, usually in the form of corrugated metals also known as fins. The wide range of fluids can be used, the most popular ones being air, oil, water and coolant liquid. In all over the world, the different types of heat exchanger used for different work. For the performance point of view engine cooling is one of the important parameters in automobile vehicles. Generally, the oil cooling technology is used for the cooling of the engine [1].

Oil cooling is the use of engine oil as a coolant, typically to remove surplus heat from an internal combustion engine. The hot engine transfers heat to the oil, which then usually passes through a heat-exchanger, typically a type of radiator known as ‘oil cooler’. The cooled oil flows back into the hot object to cool it continuously.

Oil cooling is commonly used to cool high-performance motorcycle engines. Generally, the cylinder barrel remains air-cooled in the traditional vehicles, fashion, but the cylinder head benefits from additional cooling. As there is already an oil circulation system available for lubrication, this oil is also piped to the cylinder head and used as a liquid coolant. Compared to an oil system completely used for lubrication, oil cooling requires additional oil quantity, a greater flow rate through the oil pump, and an oil cooler.

Plate fin-and-tube heat exchangers are employed in a wide variety of engineering applications, for instance, in air-conditioning equipment, process gas heaters, and coolers. They are quite compact, lightweight, and characterized by a relatively low-cost fabrication. The heat exchanger consists of mechanically or hydraulically expanded plurality of equally spaced parallel tubes through which a heat transfer medium such as water, oil, or refrigerant is forced to flow while a second heat transfer medium such as air is directed across the tubes in a block of parallel fins. In such type of heat exchangers, continuous, plain or louvered fins are used on the outside of the array of the round tubes to improve the heat transfer coefficient of heat exchanger [2].

Generally, the plate fin heat exchanger is used for cooling of the oil. Plate-fin exchangers have been produced since the 1910s in the auto industry (copper fin–brass tubes), since the 1940s in the aerospace industry (using aluminum), and in gas liquefaction applications since the 1950s using aluminum because of the better mechanical characteristics of aluminum at low temperatures. They are now used widely in electric power plants (gas turbine, steam, nuclear, fuel cell, etc.), propulsive power plants (automobile, truck, airplane, etc.), systems with thermodynamic cycles (heat pump, refrigeration, etc.), and in electronic, cryogenic, gas-liquefaction, air conditioning, and waste heat recovery systems [3].

The plate fin heat exchanger consists of two types of flat plates in which one is an upper flat plate and another one is the lower flat plate, turbulence plate, and fins. The upper flat plate and lower flat plate are attached to each other. The turbulence plate is placed in between these two flat plates upper and lower. The turbulence plate is generally used to create the turbulence between the cooling medium. The brazing technology is used in manufacturing this type of plate fin heat exchanger. The aluminum material is used for manufacturing the pale fin heat exchanger. This type of plate fin heat exchanger is used in two-wheeler, three-wheeler, four-wheeler such as the car, truck, jeep, motorcycle. The main application of plate fin heat exchanger is to cool the engine with the help of engine oil. The oil is a cooling medium used in the engine as well as a heat exchanger. This type of heat exchangers is also known as “Oil Cooler.

In recent years, with increasing demand for lightweight and rising copper prices, copper substitution is also a widespread concern. Under the premise of meeting the heat exchange demand, the micro-channel heat exchanger can reduce equipment weight, improve the device compact. The manufacturing costs can be reduced and the product competitiveness can be improved by using aluminum. Micro-channel heat exchanger has been extensive researched and applied in cooling of electronic equipment. Along with the improving of process technology, micro-channel technology is gradually used in household air conditioning and automotive air conditioning systems. The hydraulic diameter of micro-channel is less than 1mm. According to applications the size and shape of micro-channel can change. Also, the width and the number of holes in micro-channel can be changed [4,5].

The survey of heat exchanger and micro-channel, the main thing is recognized that the aluminum heat exchangers have high heat transfer capacity. Also, these aluminum heat exchangers have less weight and lower costs as comparing to copper heat exchangers.

The aim of the present work is to investigate, numerically and experimentally, the performance of micro-channel heat exchanger. The experiment is conducted for heat transfer medium (oil) with different mass flow rate as well as secondary cooling medium (air) with validation in air velocity.

2. Experimental

2.1 CFD Analysis

The CFD analysis is carried out on micro-channel heat exchanger. The 3D modeling of the heat exchanger is created by using Solid Edge software. For numerical analysis Ansys 16.0 software is used. For the meshing of the heat exchanger, different methods are used for different part of the heat exchanger. Multizone method is used for the inlet and outlet pipe of heat exchanger. In this multizone method, hexa mapped meshing, pave surface mesh and Hexa-core free meshing is used. Tetrahedron patch confirming method is used for the inlet and outlet side-channel of the heat exchanger. Also, multizone method is used for the micro-channel. In this multizone method, hexa mapped meshing, uniform surface mesh and Hexa-core free meshing is used. Five layers of inflation are achieved on whole heat exchanger. By using these methods, skewness of 0.91is achieved successfully. The following fig. 1 - fig. 3 shows the meshing done on the heat exchanger.

In the heat exchanger, the oil is used as a cooling medium, which is incompressible so pressure based solver is used. The inlet temperature is 100°C for heat exchanger. The three-different mass flow rates are used for CFD analysis such as 5 lpm, 10 lpm and 12 lpm. No heat is generated within the system.

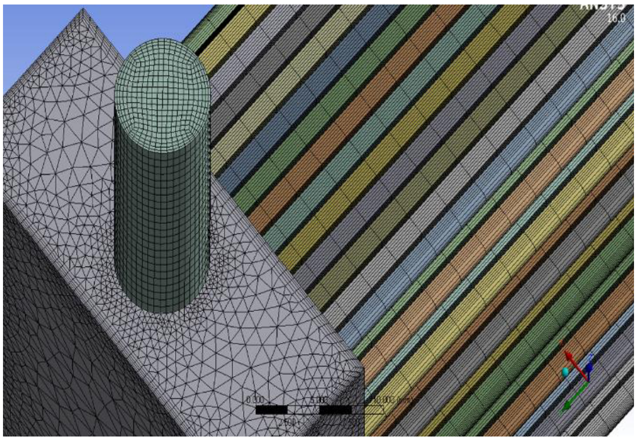

Fig.1 Mesh on inlet outlet pipe

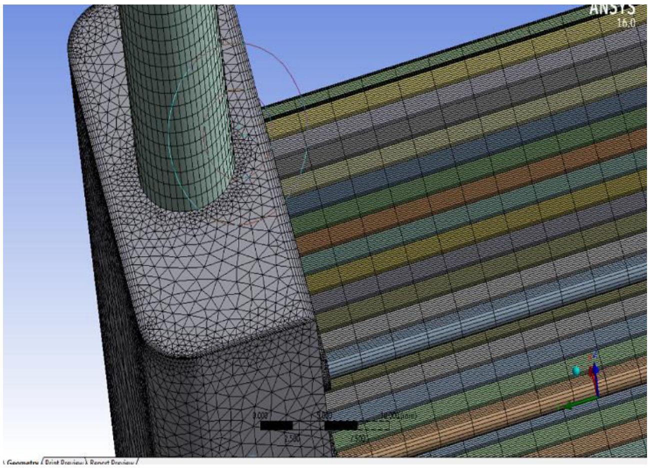

Fig.2 Mesh on inlet pipe and side-channel

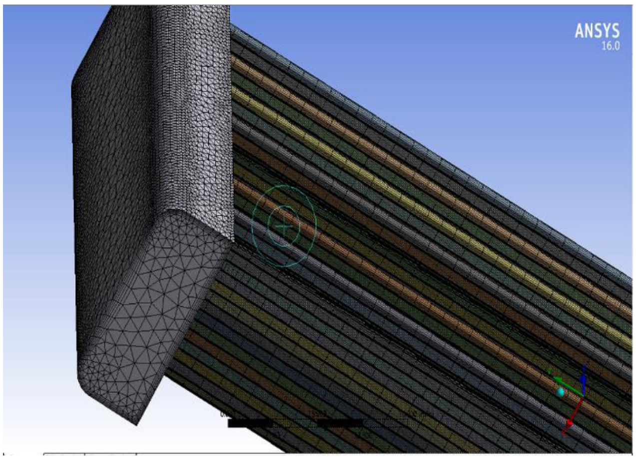

Fig.3 Mesh on bottom of side-channel

2.2Experimental Setup

Fig. 4. shows a schematic diagram of the experimental setup used in the test. The experimental setup consists of blower-duct assembly, anemometer, reservoir tank, pump, ball valve, flow meter, pressure gauge and cooling medium (oil) heater, main switch, temperature controller, temperature indicator, temperature sensor.

During the test, the SAE 20W40 engine oil used. The table I, shows physical properties of SAE 20W40 engine oil. The oil is heated with the help of a heater up to 110^{0}C. The hot oil is sucked with the help of a pump. The oil flow rate is controlled with the help of two ball valves, in which one ball valve is fitted in main line and other is in bypass line. The float type rotameter is used to measure the oil flow rate. During the test, the blower duct assembly is used to pass air over the heat exchanger. The fan type anemometer is used to measure the air velocity.

During test the heater is controlled with the help of cutoff switch and the temperature sensor (thermocouple). To measure the oil temperature at the inlet and outlet of heat exchanger j-type thermocouple is used. Also, the k-type thermocouple is used to measure the surface temperature of the heat exchanger.

During the time of test, the atmospheric temperature was 30^0 C to 38^0 C. These tests are carried out on the different mass flow rate of cooling medium which is 5 lpm, 10 lpm and 12 lpm with two different air velocities 4 m/s and 6 m/s respectively and also different temperatures range such as 40^{0}C - 100^0 C, with the step of 5^{0}C.

Table 1properties of engine oil sae 20w40

Density (ρ)		889 kg/m^3
Specific Heat (Cp)		2308 j/kg.k
Thermal Conductivity (k)		0.1347 w/m.k
Kinematic Viscosity	@40 ^{0}C	116 mm^2/s
	@100 ^{0}C	15.1 mm^2/s
Viscosity Index		135
Flash Point		236 ^{0}C

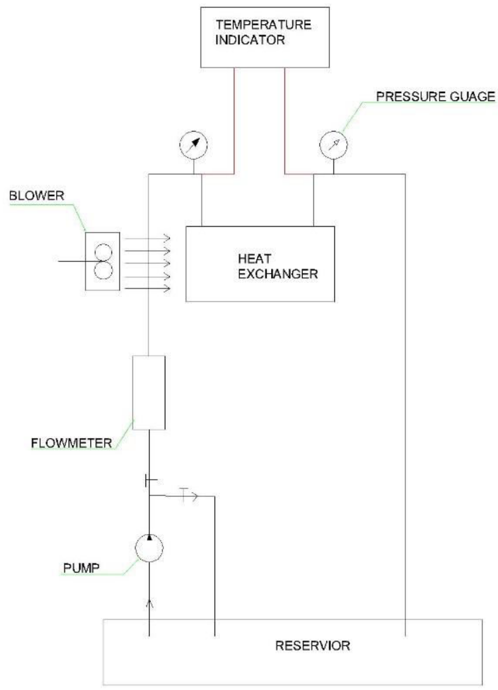

Fig.4 Schematic Diagram of Experimental Setup

These tests are performed on two different heat exchangers plate-fin heat exchanger and Micro-channel heat exchanger. During test, the temperature drop and pressure drop between inlet and outlet is measured.

3. Result and discussion

3.1Validation of CFD model

The following table II shows the validation of CFD models with some errors. Table shows the comparison result between numerical analysis and experimental analysis. From this table understand that at 5 lpm flow rate the numerical analysis gives 15 ^{O}C temperature drop and the experimental analysis gives 20 ^{O}C temperature drop, 10 lpm flow rate the numerical analysis gives 11^{O}C temperature drop and the experimental analysis gives 15^{O}C temperature drop, 12 lpm flow rate the numerical analysis gives 8 ^{O}C temperature drop and the experimental analysis gives 12^{O}C temperature drop. From these two analysis, 4 % - 7% error obtained. Fig. 10. Shows the graph of comparison between numerical and experimental analysis. Hence the CFD models are acceptable with small errors.

Table 2 Outlet temperature at 100 ^{0}c inlet temperature

	5 lpm	10 lpm	12 lpm
CFD Result (^{O}C)	85	89	92
Experimental Result (^{O}C)	80	85	88
Error (%)	6.25	4.7	4.54

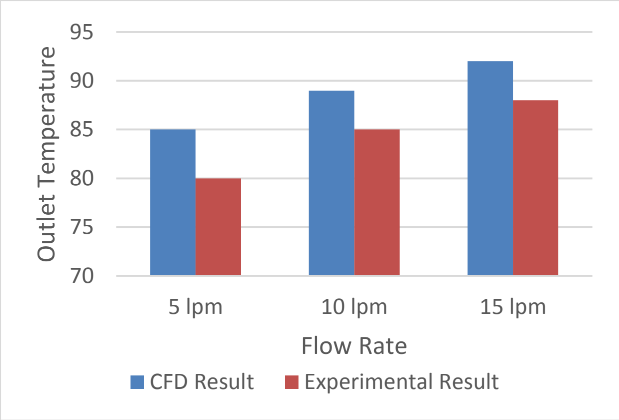

Fig.5 Outlet temperature at 100 ^{0}C inlet temperature

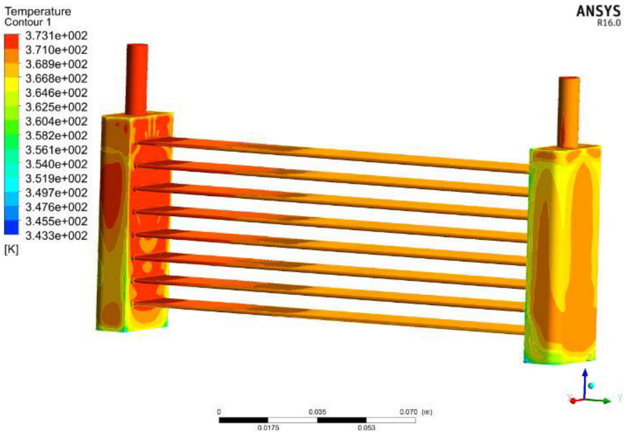

Fig.8 Temperature profile of 12 lpm flow rate

Fig. 6, 7, 8 shows that the temperature distribution profile of three different flow rates 5 lpm, 10 lpm and 15 lpm respectively. From these figures, we can understand the temperature drop in the heat exchanger. The 5 lpm flow rate gives the temperature difference of 15°C between inlet and outlet is. Similarly, the 10 lpm flow rate gives 11°C temperature difference and the 12 lpm flow rate gives 8°C temperature difference between inlet and outlet.

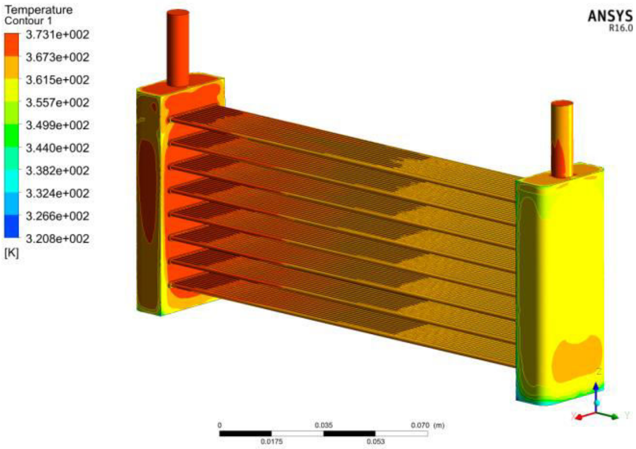

Fig.6 Temperature profile of 5 lpm flow rate

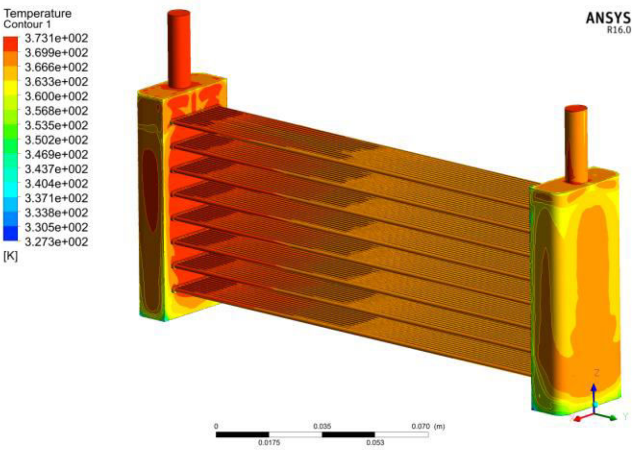

Fig.7 Temperature profile of 10 lpm flow rate

Fig. 9 shows the result of 10 lpm mass flow rate with air velocity 4 m/s. From this test graph, we can understand that the micro-channel heat exchanger has high heat transfer capacity than the plate-fin heat exchanger. The micro-channel heat exchanger gives up to 20^{0} C temperature difference as compare to plate-fin heat exchanger gives up to 15^{0} C temperature difference.

Fig. 10 shows the result of 10 lpm mass flow rate with air velocity 6 m/s. From this test graph, we can understand that the micro-channel heat exchanger has high heat transfer capacity than the plate-fin heat exchanger. The micro-channel heat exchanger gives up to 27^{0} C temperature difference as compare to plate-fin heat exchanger gives up to 18^{0} C temperature difference.

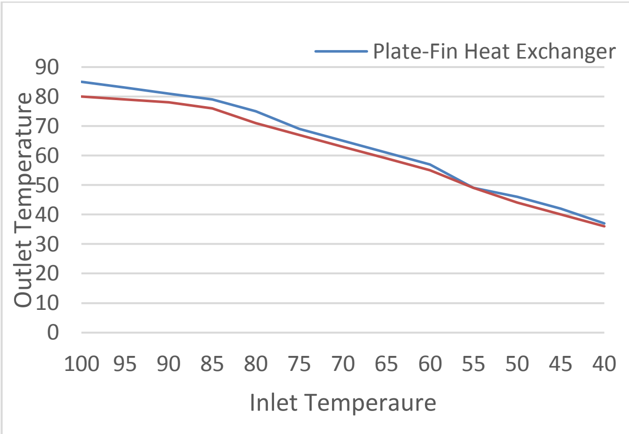

Fig.9 Reduction in temperature using two different heat exchanger at 10 lpm oil flow and 4 m/s air velocity.

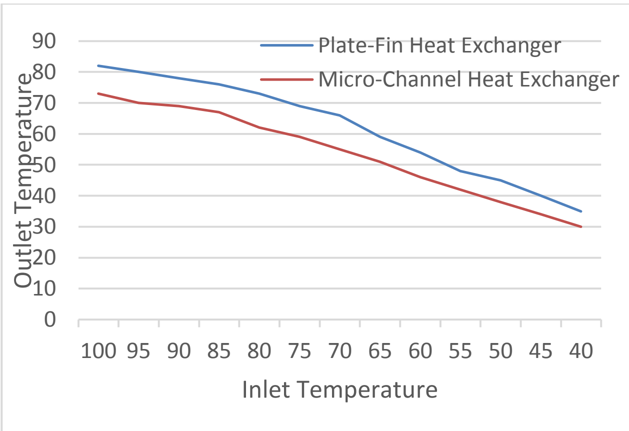

Fig.10 Reduction in temperature using two different heat exchangers at 10 lpm oil flow and 6 m/s air velocity

Fig. 11 and Fig. 12 shows the result of three different velocities. During test the one thing is recognized that as compares to high mass flow rate, the low mass flow rate of cooling medium in the heat exchanger gives better results in temperature drop. During test on micro-channel heat exchanger up to maximum 27 ^{0}C temperature drop is obtained. It is also observed that at as compared to low air velocity the high air velocity helps better heat transfer from the heat exchanger.

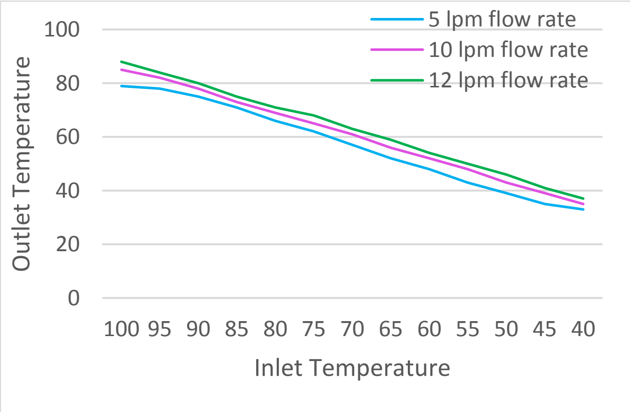

Fig.11 Reduction in temperature at 5 lpm, 10 lpm and12 lpm flow rate with air velocity 4 m/s.

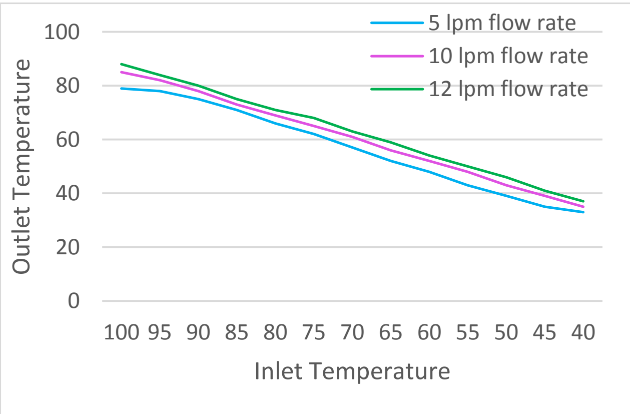

Fig.12 Reduction in temperature at 5 lpm, 10 lpm and 12 lpm flowrate with air velocity 6 m/s.

It is also observed that if the oil mass flow rate increases, then the pressure in the heat exchanger also increases. For 5 lpm mass flowrate the heat exchanger gives 0.2 bar pressure drop. Similarly, for 10 lpm and 12 lpm mass flowrate the heat exchanger gives 0.5 bar and 0.6 bar pressure drop respectively.

Conclusions

1) Micro-channels are good alternative for plate with the improvement 30% improvement in heat exchanger.
2) Micro-channel heat exchanger reduces the weight of automobile, which will lead to better fuel economy.
3) CFD tool is very effective and cost saver for design and development of heat exchanger with some % of error.
4) The size of channel is important in the design point of view of heat exchanger. It effects pressure drop of cooling medium in heat exchanger.
5) In micro-channel heat exchanger temperature drop results obtained were better than those compared to plate fin heat exchanger.
6) In the testing, the one thing is recognized that it as compared to high mass flowrate the low mass flow rate of cooling medium in the heat exchanger gives better results in temperature drop.
7) It is also observed that at as compared to low air velocity the high air velocity helps better heat transfer from the heat exchanger.
8) At the pressure point of view if the oil mass flow rate increases, then the pressure in the heat exchanger also increases. Similarly, as compared to high mass flowrate the low mass flow rate gives less pressure drop.
9) The micro-channel heat exchanger can be used in various types of heat transfer applications in industry.

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