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Modelling and Performance Analysis of Heat Exchangers for Heavy Vehicles

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Abstract

Cross flow heat exchangers made in aluminum are common as radiators in vehicles. However, due to the increasing power requirement and the limited available space in the vehicles, it is extremely difficult to increase the size of the heat exchangers (HEXs) placed in the front of the vehicles. Placing the heat exchanger at the roof or the underbody of the vehicles might increase the possibility to increase the size of the heat exchangers. A new material, graphite foam having high thermal conductivity (1700 W/ (m·K)) and low density (0.2 to 0.6 g/cm^3), is introduced as a potential material for heat exchangers in vehicles. In order to find out the proper configuration of fins with high thermal performance for a countercurrent flow heat exchanger different software's are used. Both materials are used (Aluminum, Graphite). The comparison between the corrugated wavy corrugated, pin finned, and baffle graphite foam fins are also carried out by the Analysis.

Key Words- heat exchanger, vehicle, countercurrent flow, graphite foam, thermal performance, pressure loss, fin, modeling.

Nomenclature:

Ac	minimum free-flow area [m2]
cp	specific heat [J·kg-1·K-1]
f	friction factor [-]
h	heat transfer coefficient [W·m-2·K-1]
k	turbulent kinetic energy [m2·s-2]
m	mass [kg]
Nu	Nusselt number [-]
P	power [W]
Pr	Prandtl number [-]
P	pressure [Pa]
Q	total amount of heat dissipated to air W]
Re	Reynolds number [-]
St	Stanton number [-]
T	temperature

Greek symbols

A	permeability [m^2]
ε	rate of energy dissipation
λ	thermal conductivity [W·m^{-1}·K^{-1}]
μ	dynamic viscosity of fluid [Pa·s]
ν	kinematic viscosity of fluid [m^2·s^{-1}]
ρ	density [kg·m^{-3}]

Subscripts

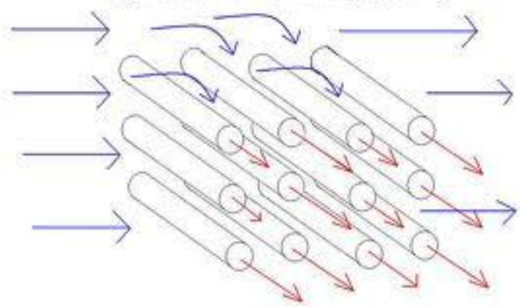
Air	air
Eff	effective
F	fluid
HEX	heat exchanger
In	inlet
Max	maximum
out	outlet
s	solid
t	turbulence

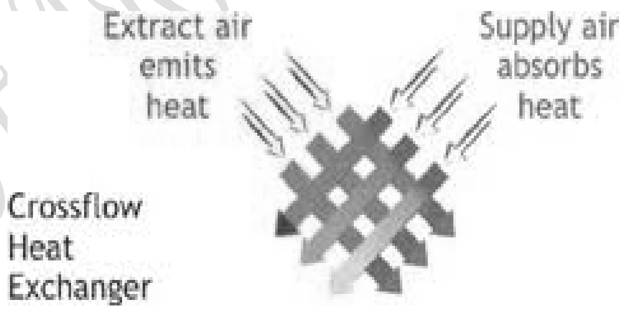
Introduction

A **heat exchanger** is a piece of equipment built for efficient heat transfer from one medium to another. The media may be separated by a solid wall to prevent mixing or they may be in direct contact. They are widely used in space heating, refrigeration, air conditioning, power plants, chemical plants, petrochemical plants, petroleum refineries, natural gas processing, and sewage treatment. The classic example of a heat exchanger is found in an internal combustion engine in which a circulating fluid known as engine coolant flows through radiator coils and air flows past the coils, which cools the coolant and heats the incoming air.

In cross flow heat exchangers, the two fluids (hot and cold) cross one another in space usually at right angles. The temperatures of this fluid will be uniform across any section in automobile radiator and the temperature of fluid is not uniform in refrigeration system.

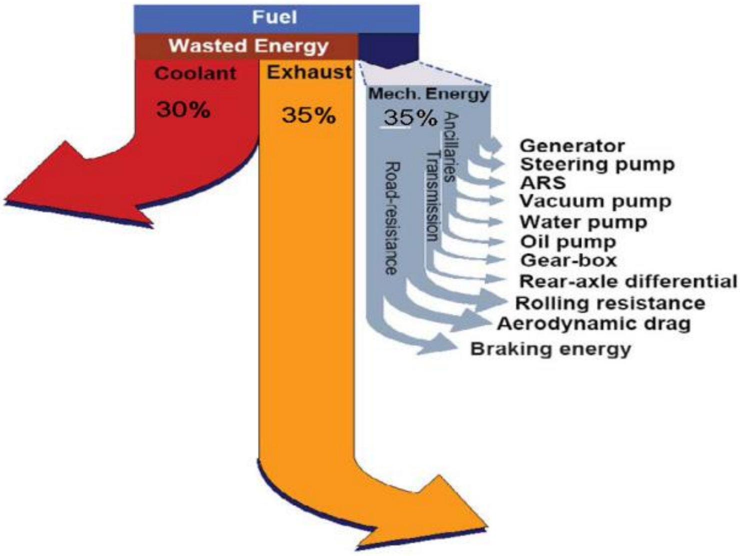
Figure 5: Cross-Flow Heat Exchanger (free flow)





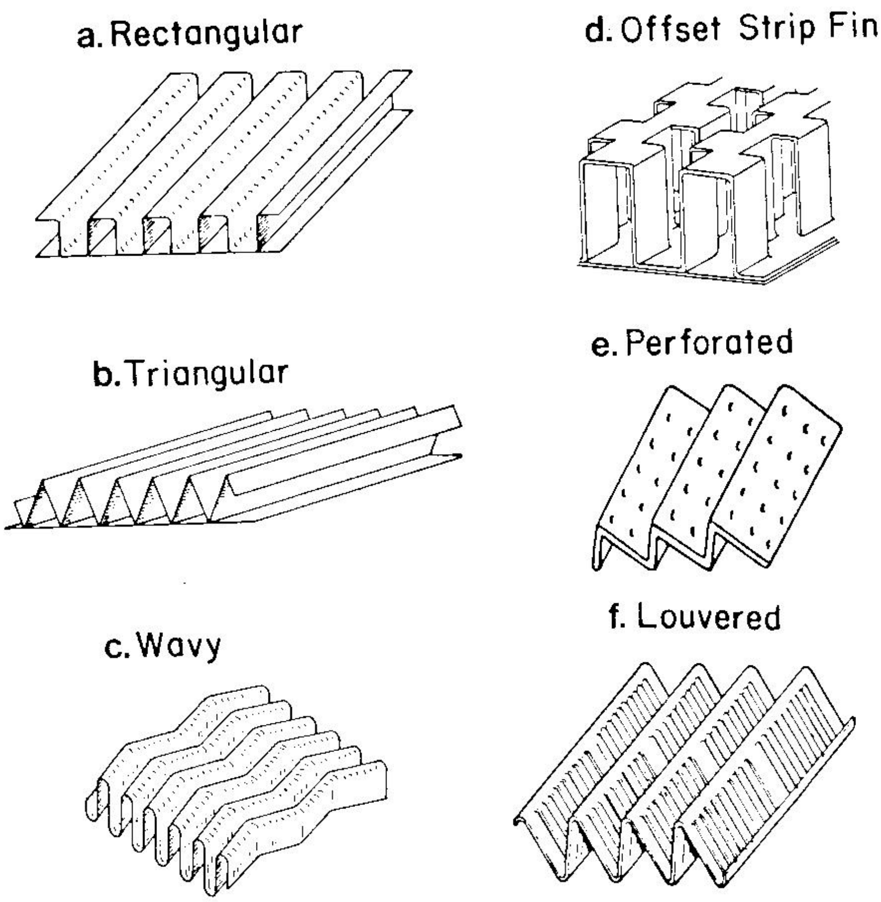
Description of System and Methodology:

Many technical developments have been introduced to meet the requirements on low fuel consumption and CO_2 emission in vehicles. Only around 35 % of the total fuel energy finally becomes mechanical work which is used for driving the vehicle. However, 30 % of the total energy input is brought away by the coolant of the engine cooling system, and another 35 % of the energy is lost to the exhaust gases.



Energy distribution in a vehicle

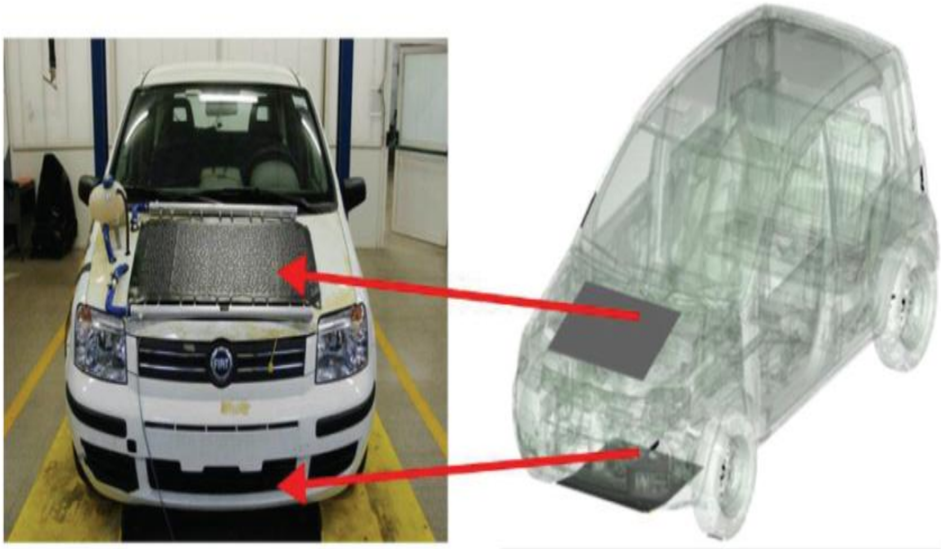
Different types of fins are compared by changing the materials (Aluminium, Graphite foam).



Based on the review work, the study will focus on the design of a countercurrent flow HEX made in aluminum or graphite foam. The thermal performance and the pressure loss are the two important factors in the heat exchanger design. In order to develop a high performance countercurrent flow HEXs, the thermal performance and pressure loss will be analyzed for different configurations of fins.

Rearrangement of HEXs Position-

In modern heavy vehicles, the amount of energy removed from the engine compartment is so large that conventional radiators and oil coolers cannot handle it. Moreover, there is space limitation in the vehicle. It is extremely difficult to increase the size of the radiator to dissipate the huge heat from the engine compartment. The position of HEXs in vehicles has to be rearranged to get a chance to dissipate the huge cooling power.



Results and Discussion:

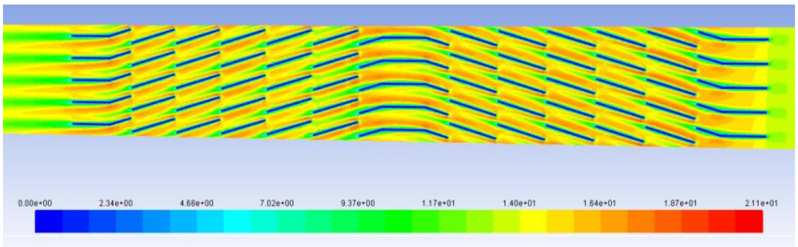
In addition, an overall performance comparison is carried out between the countercurrent flow (made in graphite foam or aluminum) and the cross flow aluminum HEXs, in terms of coefficient of performance (COP), compactness factor (CF) and power density (PD).

A block graphite foam with the size of 6 mm (width) x 50 mm (height) x 50 mm (length) is simulated. The coolant through the graphite foam block is however water instead of air (in the air zone), and a constant temperature is specified at the base of the graphite foam block. The pressure drop and Nu number were compared with the experiment and the experimental result is less than 7.1 %, and the lowest deviation is around 1.9 %. The deviation of the pressure drops between the simulation and the experimental data is less than 3 %.

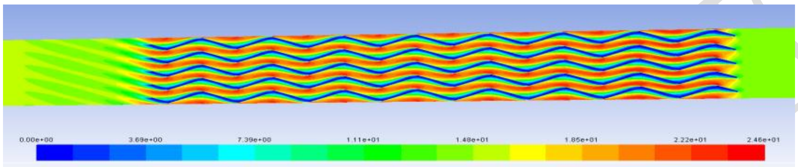
Performance Comparison among Al Fin and Graphite Foam Fin:

Pressure Loss: The pressure drops increase with increasing air velocity.

Thermal Performance:



Louver Fin

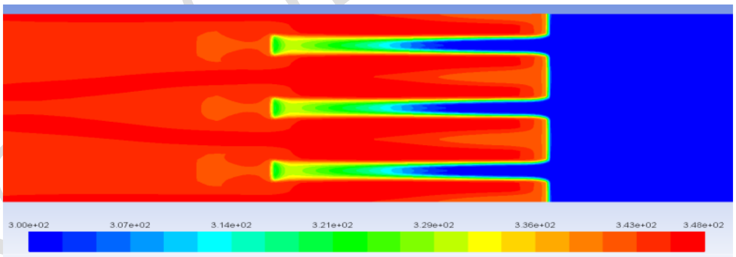


Wavy Fin

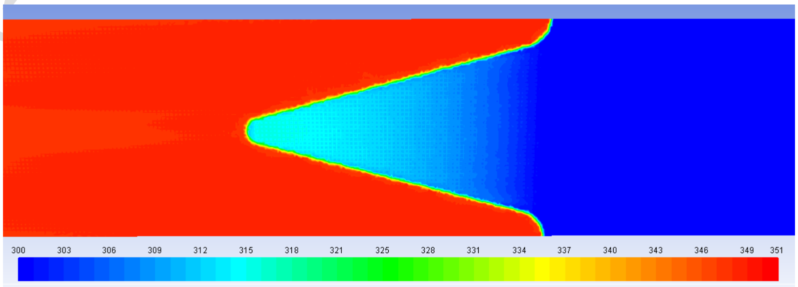
For Graphite Foam:

Pressure Loss- The pressure drop through the graphite foam is increased with increasing frontal velocity.

Thermal Performance:



Louver Fin



Wavy Fin

Conclusions - A performance comparison between the countercurrent flow HEX (made in aluminum and graphite foam) and the cross flow HEX (made in aluminum) is carried out. The major results are as follows-

-The louver fin is found to be suitable for the countercurrent flow aluminum HEX, due to better thermal performance and lower pressure drop compared to the wavy fin and the pin fin

- The power density (PD) and the compactness factor (CF) are much higher for the countercurrent flow HEX than the cross flow aluminum HEX.

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