Thermal Management

in Automotives

With advances in automobiles -- particularly in the electronics fostering more functionality -- the heat dissipation is increasing at a rapid rate and hence thermal management is becoming more of a driving force than ever.

Thermal management issues for trucks are even more daunting than for cars. While automobiles tend to be largely mass-produced, large trucks are typically custom-designed. In fact, successive trucks leaving an assembly line typically will have different engines and different cooling system requirements, making design and optimization of truck thermal management systems even more difficult. Engine manufacturers, truck manufacturers and equipment suppliers each have a role to play [1].

Given that there are so many components in a car or truck today, an increasing number of studies are underway to boost their performance. Such activities involve fan systems, particularly in heavy trucks. Fan power requirements in large trucks can be 35 to 50 kW. This high energy consumption can have a dramatic effect on fuel consumption. In these circumstances, axial fans are directly driven by the engine and an optimized fan shroud is used with a viscous clutch and a thermostat to control the fan [1].

The under hood air flow management is of utmost importance, because all the heat generated in the automobile components has to be removed by the motion of air in the compartment. The design of more aerodynamic body shapes results in less available grilled area and under hood space. This lack of space for airflow requires that the fan system create more pressure and that the overall system include more efficient heat exchangers.

With a reduction of external aerodynamic drag, the contribution of under hood air flow has been shown to be significant [2]. The automotive engine control module (ECM) is one component in the car that is exposed to extreme temperatures around 105 ^{o}C to 125 ^{o}C. The power dissipation of these modules is typically around 10-30 watts. The components on the ECM are generally designed to withstand 105 ^{o}C. The case to ambient thermal resistance of some of these components is approximately 1-3 ^{o}C/W [3].

Figure 1 shows a ceramic-based ECM where low temperature co-fired ceramic (LTCC) and the thick film alumina power substrate are bonded directly to the case with thermal adhesive tape. Since alumina has significantly better thermal conductivity than LTCC, it is used for the power substrate [3]

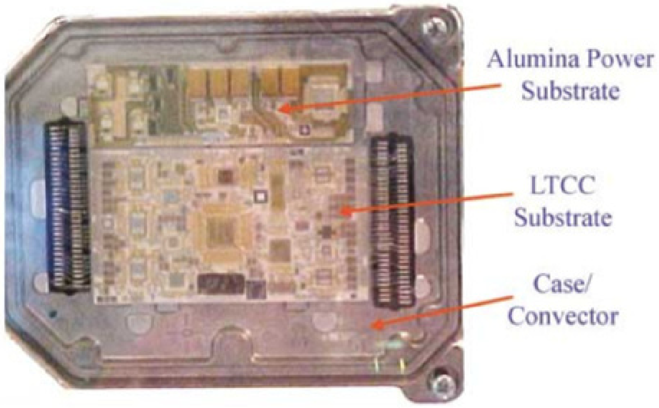

Figure 1-Ceramic-Based ECM [3]

In very high power applications, such as power steering controllers, where the case to ambient thermal resistances should be less than 1 °C/W, immersion cooling has been used. Figure 2 shows a controller for an electro-hydraulic steering motor.

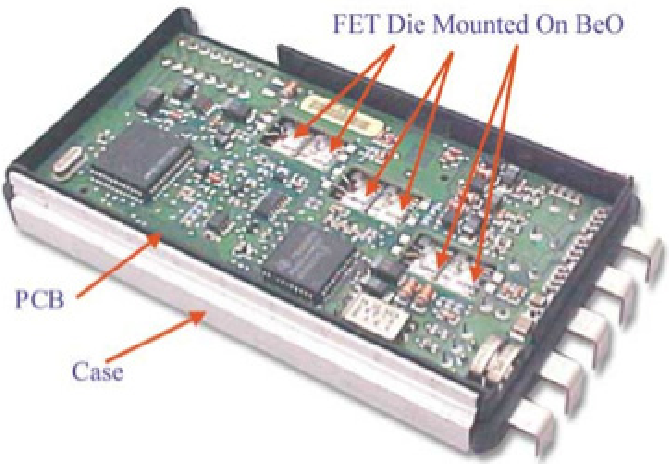

Figure 2- Immersion Cooling of A Controller for An Electro-Hydraulic Steering Motor [3]

Figure 3 shows the anticipated power dissipation for automotive electronic systems. It is seen that the starter-generator control and hybrid/EV motor control dissipate 10 to 50 times more heat than other electronic systems. These devices need special thermal management techniques to dissipate such high heat fluxes.

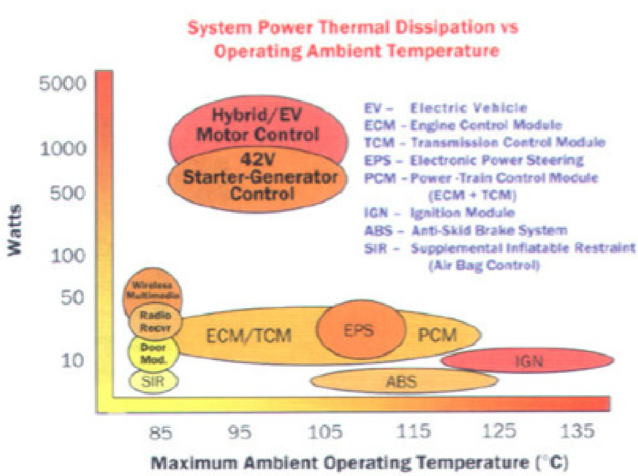

Figure 3- Power Dissipation of Different Electronic Systems in An Automobile [3]

Ales et al. [4] used the Lattice-Boltzamann Method (LBM) to simulate the flow aerodynamics and flow distribution in the underhood of a car. The LBM method is an alternative solver to Navier-Stokes solvers. They do not need any special iterative procedure and fulfill mass, momentum and energy conservation by design. As a result, LBM methods are very efficient.

They [4] applied the LBM method to a Ford Mondeo geometry as shown in figure 4. The computational domain included the exterior body, under the car and under hood.

Figure 4- Ford Model Mondeo Used in The LBM Simulation [4]

The lattice size was around 18 million voxels (elements) and contained the same number of surfels (surface elements). The heat transfer between the airflow and coolant in the heat exchanger was modeled with the 1D- tool.The 1D-tool does not model all the details of the heat exchanger. The heat transfer coefficient, which is a function of both air flow rate and coolant mass flow rate, was interpolated using a sandwich formula as shown in figure 5.

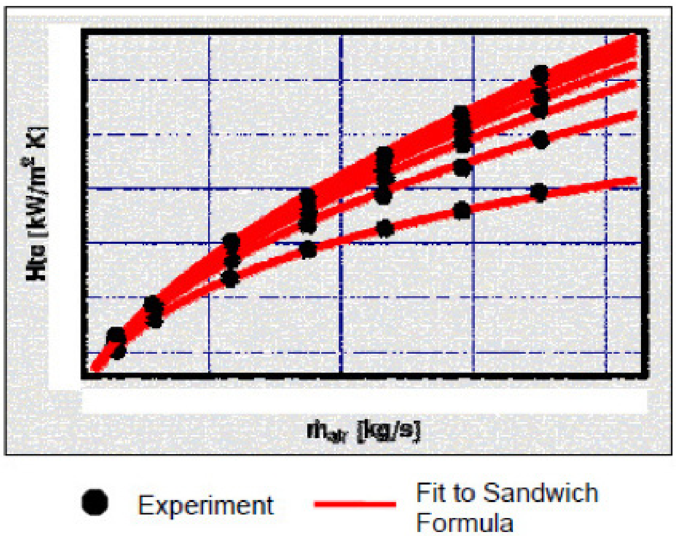

Figure 5- Heat Transfer Coefficients For The Radiator Fit To Experimental Data [4]

The actual data was not shown by the authors because of confidentiality issues. The above heat transfer coefficients were then used in their modeling.

The thermal management of vehicles is a complex subject consisting of interactions between aerodynamics of flow at the exterior of the car and under hood flow distribution and thermal coupling between different components in the engine compartment. Some major governmental agencies, such as the Argon National Laboratory and Oakridge National Laboratory have been working and doing research on various parts of the automobile. They have been working with companies such as Adapco and USCAR to develop computational techniques for modeling and analysis.

CFD packages can be used to model the flow around and under the hood of the automotive. Sound engineering judgment is required to model only components of major influence and reduce the complexity of CFD analysis.

References

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