Investigation of Radiators Size, Orientation of Sub Cooled Section and Fan Position on Twin Fan Cooling Packby 1D Simulation

Neelakandan K¹, Goutham Sagar M², Ajay Virmalwar³

Abstract: A study plan to investigate the effect of the radiator size, orientation of sub cooled section and fan position on Twin fan cooling pack system and to optimize the cooling pack performance for various markets in steady state and transient conditions for offroad vehicle. 1D modeling methodology considered with different sub-systems such as coolant, transmission, Engine oil circuit, intercooler, cabin heater/fuel burn heater and condenser, and other components such as thermostats, radiators, fans and pumps etc. GT-SUITE one-dimensional fluid dynamics, used to predict flow behavior and heat transfer characteristics in entire piping network and in other heat exchanging components of a cooling system. A preprocessing tool called COOL3D which is a inbuilt package of GT-SUITE used to build the 3D underhood thermal management models of vehicles, constructing it component by component and therefore allowing including much more details than a usual 1D simulation model. Cooling system performance is predicted in terms of SAT-Safe Ambient Temperature on radiator top hose, Engine Oil EOC Inlet (Sump) and Transmission Oil TOC Inlet which is used to compare different configurations of cooling pack. GT-SUITE object-based code helps us to build reliable cooling system and optimize the cooling pack performance for various market conditions such as Hot, Cold and Standard market and reduces our effort on real time testing.

Keywords: Underhood flow analysis, Twin fan, Cooling system, 1D CFD simulation.

1. Introduction

GT-SUITE is a fully transient commercial simulation software with multi domain applications including flow, thermal, mechanical, electrical, magnetic, and controls provides flexibility to model system level circuit and component level (technical) modeling. 1-D codes, including, GT-SUITE solves the fundamental governing equations of fluid dynamics; the conservation of mass, momentum (Navier- Stokes), and energy. The increased accuracy of fluid modeling as well as the energy/thermal management.

An engine provides mechanical energy from an air/fuel mixture with efficiency between 20 and 45%. The rest flows in kinetic and heat energy in exhaust gases and in heat energy through metallic bodies due to the frictions^[3]. In this context, the cooling system must allow the engine to give its best performance, ensure the durability of this performance and ensure engine reliability by guaranteeing an acceptable level of thermo-mechanical stresses in any point of the engine. Average heat balance of a diesel engine can reach up to 40% efficiency and direct injection gasoline engine can now reach 30% efficiency with heat losses between 18% and 20%^[4].

The liquid cooling system is also used to ensure passengers car heating, to regulate engine oil temperature, to regulate automatic transmission oil temperature and to cool EGR. In some particular cases, it can also be used to limit alternator temperature, to heat up the throttle body; to cool down power assisted steering, to extract energy from exhaust system, to cool down turbo bearing, Consequently, the number of critical situations increase, as well as control and monitoring difficulties or interferences between different requirements.

Considering the above criteria, it is necessary to select an optimum cooling pack to ensure better performance of the vehicle. In this current study we carried out a set of steady state and transient simulations to select an optimum cooling pack for our vehicle especially for off-road driving conditions. In order to provide maximum air flow in the cooling pack and considering Radiator aspect ratio we have considered a twin fan for our cooling system.

In order to improve air flow characteristics in Main & Sub Cooled sections of Radiator, we have considered four different configurations of twin fan cooling pack. The schematic of which is shown below:



Figure1: Twin Fan Pattern

2. Modeling Methodologies

The flow model involves the solution of the Navier-Stokes equations ^[5], namely the conservation of continuity, momentum and energy equations. These equations are solved in one dimension, which means that all quantities are averages across the flow direction. We used implicit time integration methods to solve the primary variables such as mass flow, pressure and total enthalpy

The conservation equations solved by GT-SUITE are shown below. The left hand side represents the derivatives of the primary variables. The methods to calculate the secondary variables, such as pressure and temperature, are discussed below in the discussion of the explicit and implicit solvers.



GEM3D is a tool that is used to build 3D model of entire cooling system which includes coolant hoses such as Radiator Top & Bottom Hoses and Heater Hoses, Bypass with Thermostat etc. total geometry is imported in GEM3D in STL format and discretized to transform the 3D model into a model file that is compatible with the GT-SUITE software. Given a wide range of component libraries that are available in this tool ensured us modeling total cooling system accurately and reducing time taken to build up the entire model manually.



Figure 2: Gem3D Model

Twin fan cooling pack underhood modeling is done by using **COOL3D**. It provides the ability to build the model in a 3D environment so that the full details of underhood air flow with the consideration of all blockages, heat exchangers and fans etc. the dimension of which are measured in Digibuck. We have included the performance characteristic curves for all Heat Exchangers such as Radiator, condenser and Low Temperature Radiators and fans. Leakages in underhood air flow, pressure drop across the components and air pre heating effects have also been considered in the model the schematic of which is shown below:



Figure 3: Underhood Model



Figure 4: Underhood Model

3. Steady State Operating Points

We have generated a set of steady state operating points by considering vehicle, engine, transmission and various market conditions which include different Vehicle Speed, different road inclinations, addition of trailer weights and idle cases etc.We carried out Steady State performance simulations for the above mentioned operating points. Form previous test correlations we added up-heat temperature limits

4. Steady State Simulation & Result discussion

Among four different configurations, the cooling Pack1 and Pack3 have shown a better air flow rates and improved SAT (Safe Ambient Temperature) values in the High Speed and Trailer towing cases respectively. We have observed only minor changes in these two packages. It is very difficult to conclude which is optimum pack between these two as packaging and vehicle application also play a major role. Taking into the consideration of off-road driving conditions, the sub cooled section of radiator should have higher air flow rates for a better Heat rejection. Below graphs Figure 4 and 5 indicates that variation of heat flux for high speed and low speed gradient steady state cases. It's clearly visible that sub cooled section of Pack1 has higher heat rejection than pack3 because of improved cooling airflow rate. And also we observed that the coolant outlet temperature of Sub Radiator for Pack1 is having better cooling when compared to Pack3. So we have selected Pack1 to study radiator size effects, in our vehicle cooling pack 18 to 20% radiator section (Sub-section) is going to use transmission cooler. It will be plate type oil to coolant heat exchanger. It will help to maintain the transmission limit temperature below the prescribed limit. Since this study

carried out for off-road vehicle we need to put extra care for transmission. Reducing and increasing radiator dimension has direct impact on cooling system performance, Based different steady state operating points we conclude optimum radiator size requirement for better cooling performance but we need to make sure it satisfying during vehicle transient running conditions.



Figure 4: External Heat Flux (Pack1-High Speed)



Figure 5: External Heat Flux (Pack1- Low Speed Gradient)



Figure 6: External Heat Flux (Pack3-High Speed)



Figure 7: External Heat Flux (Pack3- Low Speed Gradient)



Figure 8: Outlet temp of Sub cooled radiator



Figure 9: Outlet temp of Main radiator

Volume 3 Issue 10, October 2014 <u>www.ijsr.net</u> Licensed Under Creative Commons Attribution CC BY

5. Effect of Radiator size on SAT

Due to packaging constraints, we haven't changed the original dimensions of radiator. Instead we added an outboard Auxiliary radiator to take care of additional heat load in vehicle running conditions.

Addition of an auxiliary radiator has shown a significant improvement in SAT values for all steady state operating points, Figure 10, 11 and 12 shows the performance for Euro, standard and hot market respectively.



Figure11: SAT variation on Standard Market



Figure12: SAT variation on Hot Market

It can be concluded from the above predictions that cooling pack consists of 2 auxiliary radiators is showing better performance in all vehicle operating conditions. However, considering other parameters like additional weight and packaging constraints we chose an optimized cooling pack which consists of 1 outboard auxiliary radiator.

We carried out transient simulations for Nurburgring, High dune, Sand Bowl and High Speed gradient cycles for this optimized cooling pack to ensure its cooling system performance.

The Temperature variation of Coolant Top Hose, Engine Oil inlet, Transmission Oil inlet for the respective cycles is shown below:



Figure 13: Temperature variation on Nurburgring cycle



Figure 14: Temperature variation on High dune cycle



Figure 15: Temperature variation on Sand Bowl cycle

International Journal of Science and Research (IJSR) ISSN (Online): 2319-7064 Impact Factor (2012): 3.358



Figure16: Temperature variation on HS Transient Gradient cycle

The average of	merating	conditions	and its re	snective	SAT	values are	shown	helow.
The average (sperating	contantions	and its it	specifie	SAI	values are	SHOWH	DCIOW.

Transient	Speed	Gear	Engine Speed	Gross Engine Torque	SAT	Coolant Top Hose	Engine Oil EOC Inlet	Transmis sion Oil TOC Inlet
	Ave	Ave	Ave	Ave		Max	Max	Мах
	kph		rpm	Nm	deg C	deg C	deg C	deg C
Nurburgring (5 laps)	129	5	5040	212	44	97	136	110
High dune	36	3	3479	270	41	119	138	123
Sand Bowl (3 mins)	38	3	2902	263	47	113	134	119
Sand Bowl (10 mins)	39	3	2910	273	39	119	151	120
High Speed Gradient	91	4	4899	187	53	104	137	110

Figure17: Avg. SAT variation on Transient Cycles

The average SAT values are satisfying cooling system requirements.Pack1 is providing better cooling performance on Engine and transmission during high speed and off-road transient cycles.

6. Conclusions

Investigation of radiator size and twin fan cooling pack is carried out. Based on the underhood air flow and Heat Exchanger performance, we selected one cooling pack among all cooling packs considered.

Addition of an auxiliary radiator has shown improved SAT values.

Due to packaging and design constraints, we have selected an optimized cooling pack with 1Aux GT Suite has been successfully used with coupling of GEM3D and underhood module (Cool 3D)

7. Scope for Future Work

Due to software limitations it is very difficult to capture the exact air flow, up-heat air temperature and heat transfer characteristics due to shifting in fan positions and single zone condenser heat addition. So a detailed 3D CFD simulation study is required further improvements.

8. Acknowledgements

The authors would like to thank Mr. Simon Lury, Cooling System Technical Specialist, **Jaguar landrover Ltd UK**. For his valuable support and contributions during this project. We also would like to thank Mr. Diwakar Sharma, CFD Specialist, **Jaguar Land rover Ltd**, **UK** for encouraging us to publish this paper.

9. Nomenclatures

- \dot{m} boundary mass flux into volume, $\dot{m} = \rho A u$
- m mass of the volume
- V volume p pressure
- p pressur ρ density
- ρ density
 A flow area (cross-sectional)
- A_{5} heat transfer surface area
- e total internal energy (internal energy plus kinetic energy) per unit mass
- *H* total enthalpy, $H = e + \frac{p}{2}$
- 11 total enularpy, 11 = e + b
- h heat transfer coefficient
- T_{fluid} fluid temperature
- Twall wall temperature
- u velocity at the boundary Ce skin friction coefficient
- C_f skin friction coefficient C_n pressure loss coefficient
- C_p
 pressure loss coeffici

 D
 equivalent diameter
- dx length of mass element in the flow direction (discretization length)
- dp pressure differential acting across dx

References

[1] T. Hallqvist, "The Cooling Airflow of Heavy Trucks - a Parametric Study". SAE International, 2008-01-1171.

Volume 3 Issue 10, October 2014

www.ijsr.net Licensed Under Creative Commons Attribution CC BY

International Journal of Science and Research (IJSR) ISSN (Online): 2319-7064 Impact Factor (2012): 3.358

- [2] Kumar Srinivasan, Z.J. Wang, Wei Yuan, Richard Sun, "Vehicle Thermal Management Simulation".
- [3] http://www.car-engineer.com/introduction-to-coolingcircuits/
- [4] http://en.wikipedia.org/wiki/Diesel_engine
- [5] GT-Suite user 1D CFD Flow modeling Theory.

Author Profile



Neelakandan K is working as Technical specialist in TATA Technologies Ltd, INDIA, and His Research interest include: Engine, Vehicle thermal management Underhood optimization, Heat transfer and CFD.



Goutham Sagar M is working as Team Leader in TATA Technologies Ltd, INDIA, and His Research interest include: Combustion, Vehicle thermal management, Underhood optimization, Heat transfer and CFD.



Ajay Virmalwar is working as CoC Head-Durability in TATA Technologies Ltd, INDIA, and His Research interest include: Durability and CAE process Optimizations