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IMPROVEMENT OF FUEL ECONOMY OF A COMMERCIAL CNG VEHICLE BY OPTIMIZATION OF FAN DUTY CYCLE

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ABSTRACT:- In todays world where containing the use of fossil fuels is getting difficult and resources of these food for vehicles nearing to end, it is extremely important to use fuels efficiently. Even though vehicle electrification in world is building stronger base and India is no exception to this improvement however its still extremely gutsy to say business vehicles will follow comparable course of events of zap. This withdrawal of force takes cost for power accessible at haggles at last winds up in higher fuel utilization. So to diminish the heap on the motor, we decided to streamline the plan of the motor fan to further develop the efficiency of the vehicle. This should be possible by upgrading the fan commitment towards motor while vehicle running. This incorporates changes in engine design, engine calibration, engine hardware, combustion characteristics and engine exhaust after-treatment systems. Still it was decided that the newly developed BSVI vehicles should have atleast 10% better fuel efficiency with respect to its predecessor versions.

Key words – Fan Duty Cycle, Fuel Efficiency, Engine coolant temperature

I. INTRODUCTION

In todays world where containing the use of fossil fuels is getting difficult and resources of these food for vehicles nearing to end, it is extremely important to use fuels efficiently. Even though vehicle electrification in world is building stronger base and India is no exception to this development but its still very courageous to say commercial vehicles will follow similar timeline of electrification.

to extract maximum fuel efficiency from vehicles. Simple answer - Making your engine to produce more power and eat up less fuel. But it's the most ideal statement to make. Actually many ways are available in market – but those comes with certain price .i.e. at the cost of development time, material cost, development cost, implementation cost etc.

One of the straightforward region strike, is the decrease of assistant burden on vehicle/motor to expand eco-friendliness. There are numerous helper loads on the motor like force directing siphon, cooling siphon, water siphon, motor fan (mechanical), alternator and their separate pulleys etc. While running the vehicle these parts pull out extensive measure of force from motor to work.

This withdrawal of force takes cost for power accessible at haggles in the end winds up in higher fuel utilization .So to diminish the heap on the motor, we decided to enhance the plan of the motor fan to further develop the efficiency of the vehicle. This should be possible by streamlining the fan commitment towards motor while vehicle running. As Indian auto industry moved from BSIV to BSVI emission norms from 1st April 2020, manufacturers had to make many technological changes in the vehicle to comply it. This includes changes in engine design, engine calibration, engine hardware, combustion characteristics and engine exhaust after-treatment systems. Still it was decided that the newly developed BSVI vehicles should have at least 10% better fuel efficiency with respect to its predecessor versions.

Considering the enormous changes in overall engine package, it was never an easy task to face on. Change in emission transient testing cycle hit the fuel efficiency worst to bring emissions under BSVI limits. Hence optimization of engine auxiliary load was the area to focus on while keeping development time and cost in mind.

II. LITERATURE SURVEY

Energy Consumption Test and Analysis Methodology for Heavy-Duty Vehicle Engine Accessories. (SAE International Journal of EnginesVol. 11, No. 5 2018)
Fuel economy is a crucial parameter in long-haulage heavy-duty vehicles. Researchers tended to focus initially on engine combustion efficiency, while modern researchers turn their attention to the energy consumption of engine accessories in an attempt to enhance fuel economy. The accessories investigated in this study include the cooling fan, water pump, air compressor, power steering pump, air-conditioning (AC) compressor, and generator. Normally, accessory energy consumption analysis is based on rig data and simulation results. Here, we focus on the disparate test environments between the rig and vehicle to establish a novel constant power test method; the proposed method provides accurate accessory power data under different working conditions. A typical highway driving cycle is selected to collect accessory duty-cycle. The heavy-duty vehicle accessories' energy consumption distribution under highway road conditions is obtained through the repeated road tests. Accessories comprise energy consumption proportions of 4.7%-6.4% of the engine in winter and 10.3%-12.6% in summer; they show different characteristics under different temperature or road conditions. The two influence factors of accessory energy consumption, constant power and duty cycle, are analyzed to evaluate possible energy-saving

schemes. Applying the clutch or electrical accessories, especially for the cooling fan and air compressor, is recommended.

Analytical and experimental characterization of viscous fan clutch performances including thermal dynamics. (Published November 29, 2015)

This paper presents an investigation on the performance characterization of viscous fan clutch with double grooves including thermal behaviors. A detailed mathematical model of the fan clutch is established by taking into account the viscosity variation of the viscous fluid with shear radius and temperature, and an iterative algorithm is proposed to calculate the performances of the fan clutch. Laboratory experiments are then carried out on a performance measurement setup for viscous clutch, for validating the proposed mathematical model and calculation method. Based on the verified model and calculation algorithm and the experimental setup, the performances of six alternative viscous fan clutch designs are studied. The combined analytical/experimental results suggest that the clutch performances degrade with the increase of the input speed, and the proposed model and calculate method are valid and can be successfully employed to facilitate the design of new viscous fan clutches as well as control system development, for saving cost and shortening development period.

Experimental Study on Diesel engine fitted with visco fan drive. (Bulletin of the Transilvania University of Braşov • Vol. 9 (58) No. 1 - 2016)

The paper studies the performance increase of a heavy duty diesel engine when the cooling fan is driven discontinuously. A viscous fan was initially investigated on a dedicated fan bench in terms of air flow rates versus pressure loss, consumed power and efficiency. The viscous fan was tested further, being mounted on a turbocharged diesel engine with two types of coolant heat exchangers. The thermal behavior was analyzed using as indicator the engine thermal constant. The experiments confirmed the requirements for controlled drive of cooling fan in heavy duty vehicles.

Theoretical investigation of heat balance in direct injection (DI) diesel engines for neat diesel fuel and gasoline fumigation. (O. Durgun a,1, Z. Sahin b, a Karadeniz Technical University, Faculty of Engineering, Mechanical Engineering, Trabzon, Turkey)*

The main purpose of the presented study is to evaluate energy balance theoretically in direct injection (DI) diesel engines at different conditions. To analyze energy balance, a zero-dimensional multi-zone thermodynamic model has been developed and used. In this thermodynamic model, zero-dimensional intake and exhaust approximations given by Durgun, zero-dimensional compression and expansion model given by Heywood and quasi-dimensional phenomenological combustion model developed by Shahed and then improved Ottikkutti have been used and developed with new approximations and assumptions. By using the developed model, complete diesel engine cycle, engine performance parameters and exhaust emissions can be determined easily. Also, by using this model energy balance can be analyzed for neat diesel fuel and for light fuel fumigation easily. In the presented study, heat balance has been investigated theoretically for three different engines and various numerical applications have

been conducted. In the numerical applications two different turbocharged DI diesel engines and a naturally aspirated DI diesel engine have been used. From these numerical applications, it is determined that, what portion of available fuel energy is converted to useful work, what amount of fuel energy is lost by exhaust gases or lost by heat transfer. In addition, heat balance has been analyzed for gasoline fumigation and some numerical results have been given. Brake effective power and brake specific fuel consumption increase and brake effective efficiency decreases for gasoline fumigation for turbocharged diesel engines used in numerical applications.

III. PROBLEM STATEMENT

'Improvement in fuel economy by design and optimization of engine cooling fan to improve fan duty cycle thereby reducing auxiliary load on the engine.'
Considerations –

- Vehicle under trial is commercial CNG vehicle.
- Engine fan used in vehicle is viscous mechanical fan.
- Fuel Economy trial conducted will be in city route.

There is considerable reduction in fuel economy of the vehicle due to changes in engine calibration and after-treatment system of the vehicle. Hence engineers had to look for alternate options to improve the fuel efficiency.
In this research work, focus is on the reduction of engine auxiliary load and there by improving power available at vehicle. This will enable the optimized utilization of the fuel.

IV. OBJECTIVE / TARGET FOR PROJECT

The study considered here is the commercial vehicle powered by CNG fuel IC engine.

This vehicle uses mechanical viscous fan as part of the cooling arrangement in engine.

As part of the project statement, 2 targets are set –

1. Increase in overall fuel efficiency of the vehicle (~ 5-7%)
2. Reduction in fan duty cycle with optimization of fan (~ 15-20%)

In-order to meet general customer requirements and as part of benchmarking fuel economy data, the above target values were decided considering the limitation of development time, cost and resource availability. Reduction in parasitic consumption will help to improve overall efficiency and hence fuel economy of the vehicle.

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4.1 ENGINE FAN CHARACTERISTIC

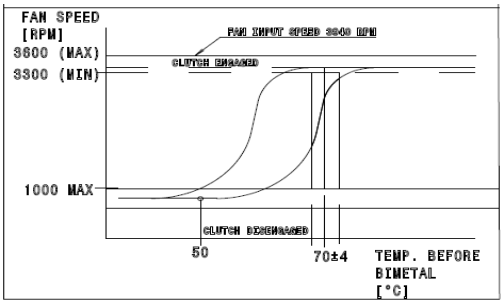


Fig 4.1 Front of fan temp measurement



Fig 4.2 Engine Fan Testing at rig

The engine fan curve is plotted by arranging fan speed against air inlet temperature at front of fan. As mentioned earlier, the temperature sensing strip (bimetal) senses the temperature of incoming air temperature and as per calibrated value the engagement of the fan starts. The engagement of the fan starts partially at certain temperature and slowly it increases as the temperature of the air increases as shown in fig.

While disengaging, the curve followed by the fan is steeper than engagement curve shown in fig. This hysteresis loss is not taken into consideration during testing. The testing on the test rig is done in controlled environment. The temperature of the incoming air is controlled and increased gradually by the

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Fig 4.3 automatic heated blower machine and the fan is coupled to a rotating shaft

4.2 ON-ROAD TESTING OF THE EXISTING MODEL



Fig 4.4 Fan Speed Measurement

To understand and obtain the existing model data, the vehicle is tested for fuel economy in city route. Various sensors were connected to measure the engine parameters data such as engine fan speed, front of fan air temperature, engine coolant temperature, engine speed, radiator in-out temperature, and vehicle distance etc. whereas engine performance data is obtained from engine ECU like accelerator pedal position, engine torque and basic engine performance parameters.

Fuel used in this trial is commercial CNG filled at MNGL gas station. The pressure at which gas is filled in all trials is maintained around 180 - 200 bar. The vehicle ran till one cylinder of the vehicle is empty and readings were recorded for calculation of fuel efficiency. Traffic variation is excluded in this trial.

4.3 TEST DATA ANALYSIS

- The collected data is plotted together against engine speed, fan speed, coolant temp and air temp at front of fan.
- Engagement of fan is decided based on the fan speed conditions.
- This gives us the duration for which engine fan was engaged.
- We calculate the fuel economy in this trial since main aim is to improve overall vehicle fuel economy.

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- And considering engineering margin for failure, new optimized engine cooling model is finalized for testing.

4.4 FAN DUTY CYCLE

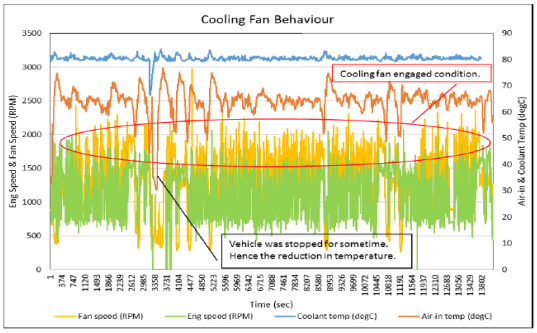


Fig 4.5 Engine Cooling Fan Behaviour

The fig 4.5 shows the overall duty cycle of the engine. It includes data from engine speed, engine coolant temperature, fan speed, temperature before fan to give us a clear picture.

These quantities are plotted against time duration for which the engine / vehicle was under test. The stabilization temperature of engine coolant is observed at 83°C whereas temperature before fan was observed between 60 – 70 °C.

As the temperature of air at fan increases, the fan started for engagement gradually. Also when temperature of air is dropped, the speed of fan is reduced which can be observed from the graph.

4.5 FAN ENGAGEMENT DETECTION

The engagement or disengagement of the fan can be determined from the speed of the fan. The input for fan speed is engine speed but the pulley on which fan is mounted is having different diameter and hence it is helpful to know the fan is functional or not.

We used following formula to develop the relation between engine speed and fan speed.

1. Fan at idle condition (No engagement)

   Fan speed < engine speed * fan pulley ratio

2. Fan at partial engagement (< 100% engagement)

   Fan speed > engine speed * fan pulley ratio

3. Fan at 100% engagement

   Fan speed = max engine speed * fan pulley ratio

4. fan pulley ratio = Fan speed / engine speed

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Parameter	Readings				
	1	2	3	Average	Ratio
Low Idle Crankshaft speed	697	693	691	693.7	1.23
Fan pulley speed	850	854	851	851.7	
	1	2	3	Average	Ratio
High idle Crankshaft speed	2500	2500	2499	2499.7	1.23
Fan pulley speed	3075	3080	3080	3078.3	

Table 4.1 Fan Pulley Ratio

4.6 TEST RESULTS –

- Fuel Economy

Test No	Test Condition	Fan Details	Total Vehicle kms	Total gas consumed kg	Fuel Economy km/kg
1	City cycle	70 ^{0}C	83.115	8.441	9.84
2	City cycle	70 ^{0}C	83.445	8.5	9.9

Table 4.2 Fuel Economy Test Results

- Fan Duty Cycle

Test No	Test Condition	Fan Details	Duty Cycle%
1	City cycle	70 ^{0}C	75
2	City cycle	70 ^{0}C	73

Table 4.3 Fan Duty Cycle Test Results

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From the test results it can be seen that the fan duty cycle of the vehicle is higher as compared to the normal duty cycles. And considering the engine coolant temperature stabilizing around 85°C, there is scope of improvement for fan duty cycle and subsequently overall fuel economy of the vehicle.

4.7 FAN BEHAVIOUR ANALYSIS

This part of analysis involves study of fan behaviour with respect to air in temperature.

Hysteresis characteristics, exact engagement temperature, duration of engagement, time required for engagement and disengagement is analysed here. Fig shows the multiple occasions where fan is getting engaged at temperatures around 50°C which is quite low compared to ambient and engine bay area temperature and hence it is the reason behind higher fan duty cycle of the fan. This can be improved by changing the engagement temperature of the fan. Delaying the engagement of fan will result in reduction in fan duty cycle.

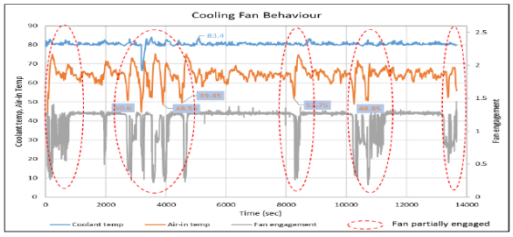


Fig 4.5 Engine Cooling Fan Analysis

4.8 FAN DUTY CYCLE SUMMARY

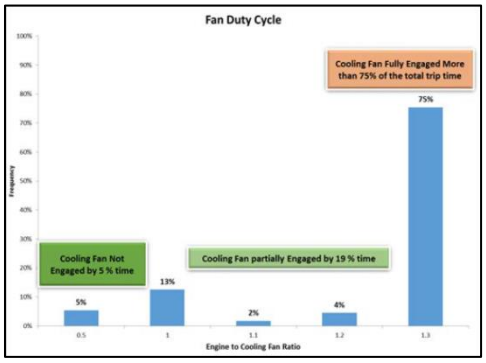


Fig 4.6 Fan Duty Cycle Summary

From the above graph, engagement of fan can be observed. It shows the percentage of the fan engagement time with respect to fan pulley ratio. From this we can say that 75% of the time fan was engaged continuously and was drawing power from engine and only 5% of the time fan was rotating in no load state.

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These numbers of full engagement and no load condition can be improved to lower the fan duty cycle of the particular vehicle depending upon the margin of safety we have as per engine operating conditions.

4.9 ENGINE COOLANT TEMPERATURE

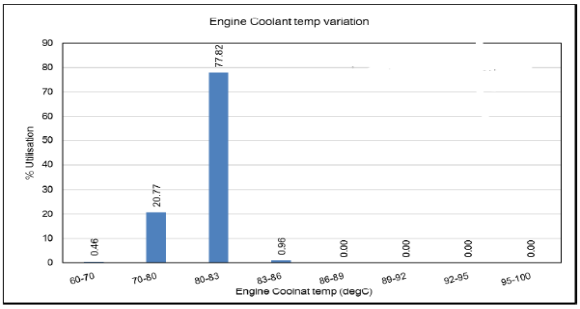


Fig 4.7Engine Coolant Temperature Summary

The normal engine coolant operating temperature for engine during this trial stabilizes around 80 – 83°C. This range contributes around 77% of the total time duration of the entire vehicle running duration. The safe operating zone for engine coolant – ethylene glycol 50% & water 50% - is around 100 – 110°C for particular engine. Hence from engineering point of view, the engine coolant temperature can still be elevated by 8 – 10°C to utilize the margin and thereby reduce the engine warm up time and fan engagement to draw the air on radiator for taking out the excess heat from coolant.

4.10 ENGINE TORQUE DEMAND

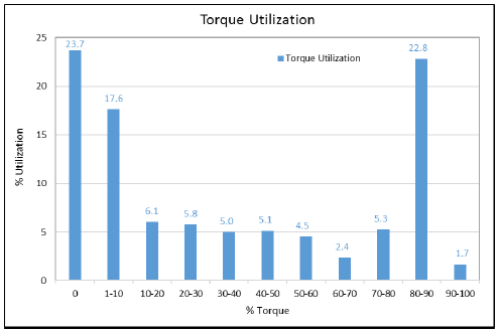


Fig 4.8 Engine Torque Utilization

Vehicle is operating with maximum available torque zone which in turn is beneficial towards fuel consumption perspective. Since lower engine rpm consume less fuel and can deliver required amount torque to propel the vehicle. From this analysis we don't see much scope to improve for torque utilization during the city run of the vehicle.

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4.11 EFFECT OF CHANGE OF COOLING SYSTEM ON HEAT LOAD ON ENGINE

It is evident that the change of engine cooling components will change the heat load on engine during its operating duration. The contribution of coolant temperature change towards heat rejected by coolant can be calculated. This is due to change in behaviour of engine cooling fan which we delayed to engage during the vehicle is running.

Following are the formulae for calculation of heat load on the engine –

- Qtotal = mf * Ne * Qf
- Wm = Ne
- Qw = mw* Cpw * (Tin - Tout)
- Qexh = (Ne * mf + ma) *Cpexh * (Texh – T0)
- Qu = Qtotal – (Wm+ Qw+ Qexh)

Heat Balance Calculations					
Parameters	Unit	Qty			
Inputs		Existing		Proposed Estimated Design	
Power	kW	62		62	
SFC	g/kWhr	228		215	
Air Flow Rate	kg/hr	210		210	
Coolant Flow Rate	lpm	150		150	
Temp Coolant In	◦ C	**83**		**92**	
Temp Coolant Out	◦ C	**80**		**90**	
Temp Exhaust Outlet	◦ C	620		600	
Output			%		%
	kW	141.4	100	133.3	100
Heat for mechanical power	kW	62.0	44	62.0	43
Heat to radiator	kW	31.6	22	21.1	25
Heat through exhaust	kW	39.4	28	38	28
Heat radiated	kW	6	4.2	9	2.8

Table 4.4Heat Load Calculations

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Above heat load calculations from existing engine cooling shows the 22% of heat is rejected towards radiator from overall duty cycle of the vehicle. Considering a regular practice, a radiator is designed to take 30 – 33 % of warmth load through the coolant and subsequently we have around 8 – 10% of edge to expand the warmth load on radiator by expanding the motor coolant temperature. Incaseof plan we proposed, where the motor cooling fan will be locked in 8^0C later than the current commitment temperature, it is normal that the motor coolant temperature will be raised by equivalent measure of temperature. With that contemplations, we have assessed the motor warmth load on radiator and it will be expanded by 3 - 4% according to above estimations. This will fall inside the safe working zone of the radiator as well as engine coolant.

Hence in phase II of this project, we will change the design of the fan which will make engagement delayed by 8ºC to reduce the overall engagement duration in vehicle duty cycle and we expect the same improvement in fuel economy of the vehicle.

4.12 SIMULATION TESTING -

To understand the effect of theoretical calculations and proposed design based on thermal load, simulation testing is the ideal way to get more realistic test results.Our aim was to calculate the fuel economy of the vehicle with reduced auxiliary load on the engine and hence specific Siemens Green software was used to run the test.

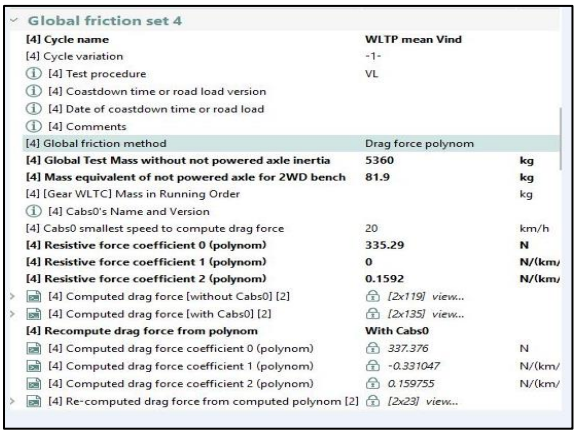
All required input parameters were given related to engine and vehicle including fuelling, electrical load and driveline components. Based on these parameters, by running WLTC cycle, fuel economy was calculated.

We ran two iterations

i) with existing fan setup
ii) with updated fan setup

for base testing we had previously tested data from reference engine testing and for iteration 2 we modified the engine and fuelling map as per reduction in power consumption by the fan.

Input data -



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Iteration 1 –With existing fan setup

Run criteria

Title	Value	Unit
Raw fuel consumption (with print interval)	9.86562	L/100km
Raw CO2 emission from global factor (with print interval)	223.456	g/km
Phase1Low fuel consumption(with print interval)	10.4784	L/100km
Phase2Mid fuel consumption(with print interval)	9.36301	L/100km
Phase3High fuel consumption(with print interval)	0	L/100km
Phase4ExtraHigh fuel consumption(with print interval)	0	L/100km
Undefined	0	L/100km
Undefined	0	L/100km
Undefined	0	L/100km
Undefined	0	L/100km
Undefined	0	L/100km
Undefined	0	L/100km
Weighted fuel consumption (with print interval)	4.96035	L/100km
Weighted CO2 emission from global factor (with print interval)	112.352	g/km
Raw fuel efficiency (with print interval)	10.1362	km/L
Phase1Low fuel efficiency (with print interval)	9.54344	km/L
Phase2Mid fuel efficiency (with print interval)	10.6803	km/L

Table 4.5-Iteration 1 Simulation Result

Fuel Economy Result – **10.13 km/kg**

1) Iteration 2 – with updated fan

Run criteria

Title	Value	Unit
Raw fuel consumption (with print interval)	8.88115	L/100kn
Raw CO2 emission from global factor (with print interval)	201.158	g/km
Phase1Low fuel consumption(with print interval)	9.4342	L/100kn
Phase2Mid fuel consumption(with print interval)	8.42724	L/100kn
Phase3High fuel consumption(with print interval)	0	L/100kn
Phase4ExtraHigh fuel consumption(with print interval)	0	L/100kn
Undefined	0	L/100kn
Undefined	0	L/100kn
Undefined	0	L/100kn
Undefined	0	L/100kn
Undefined	0	L/100kn
Undefined	0	L/100kn
Weighted fuel consumption (with print interval)	4.46536	L/100kn
Weighted CO2 emission from global factor (with print interval)	101.14	g/km
Raw fuel efficiency (with print interval)	11.2598	km/L
Phase1Low fuel efficiency (with print interval)	10.5997	km/L
Phase2Mid fuel efficiency (with print interval)	11.8663	km/L
Phase3High fuel efficiency (with print interval)	0	km/L
Phase4ExtraHigh fuel efficiency (with print interval)	0	km/L

Table 4.6 -Iteration 2 Simulation Result

Fuel Economy – **11.8 km/kg**

With simulation testing, we observed improvement of 16% fuel economy with updated component.

V. CONCLUSION

- Fan duty cycle obtained from the test data is higher (> 70%) when tested in real world driving condition.
- There is considerable scope of improvement considering various factors like fan temp, Engine Coolant Temp , radiator in – out temp etc.
- With reduction in fan duty cycle, fuel economy of the vehicle can be improved.
- Reduction in fan duty cycle implies to lesser auxiliary on engine and hence higher torque will be available for user.
- Keeping engine cooling system parameters within acceptable limits, this development meets all vehicle requirements.
- The simulation results clearly shows improvement of fuel economy by 16% with proposed fan.
- This will help in achieving higher margins in engine emission since less fuel is consumed to attain same torque.
- Lowered fan duty cycle will be helpful in improving the life of the components.

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