International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 05, May-2019

An Investigation on Novel Cooling System in Place of Thermo Siphon Cooling on Horizontal Diesel Engine

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***Abstract*:- Typically, the horizontal diesel engine used for power tiller application has a thermo-siphon type cooling system. Thermo-siphon is a physical effect which refers to a method of passive heat exchange based on natural convection caused by variation in density of the fluid, which circulates a fluid without the necessity of a mechanical pump. Generally, water is used as a coolant. For a thermo-syphon cooling system, in order to achieve efficient circulation, the radiator top tank must be well above the engine, thus needing a high bonnet line. Cooled water enters the engine at the bottom of the cylinder, where the engine normally runs fairly cool and it heats up to maximum as it reaches the top of the cylinders. Therefore, it has a reduced cooling effect on the hottest part of the engine. It is difficult to fit an interior heater successfully without a water pump. Under conditions of very heavy load or in hot climates the water may not circulate as quickly as required. This paper presents for a novel cooling system for an engine, by improving the cooling performance by virtue of better coolant flow distribution in head and cylinder block of the diesel engine, with the incorporation of a water pump, ensuring positive water circulation and removal of all the disadvantages of the thermo-siphon cooling process.**

INTRODUCTION:

Power tillers or rotary tillers are self-propelled machines of 5-18 bhp and are usually powered by single cylinder horizontal diesel engines and finds application in many agriculture operations like wet land puddling, dry land puddling, ploughing, inter-cultivation, transporting, land levelling, ridging, winnowing etc. It is the most suitable power source for wet land cultivation.

Horizontal diesel engine used for power tiller application has a thermo-siphon type cooling system. Thermo-siphon is a physical effect which refers to a method of passive heat exchange based on natural convection caused by variation in density of the fluid, which circulates a fluid without the necessity of a mechanical pump. Generally, water is used as a coolant. The heated water expands, due to which the density decreases. When it cools down, its volume decreases and hence density increases. These variations in density set up convection currents so that circulation of water takes place. All components of water-cooling systems except the circulating pump are used in this case.

For a thermo-syphon cooling system, in order to achieve efficient circulation, the radiator top tank must be well above the engine, thus needing a high bonnet line. Cooled water enters the engine at the bottom of the cylinder, where the engine normally runs fairly cool and it heats up to maximum as it reaches the top of the cylinders. Therefore, it has a reduced cooling effect on the hottest part of the engine. It is difficult to fit an interior heater successfully without a water pump. Under conditions of very heavy load or in hot climates the water may not circulate as quickly as required. Some of the disadvantages of the thermo-syphon cooling system have been mentioned herein above.

To overcome the abovementioned problems, and for efficient usage of power tiller, there lies a need for a novel cooling system for an engine, by improving the cooling performance by virtue of better coolant flow distribution in head and cylinder block of the diesel engine, with the incorporation of a water pump, ensuring positive water circulation and removal of all the disadvantages of the thermo-siphon cooling process.

DESCRIPTION OF NOVEL ENGINE COOLING SYSTEM

Aspects of the present disclosure are to address at least the above-mentioned problems and/or disadvantages and to provide at least the advantages described below. Accordingly, an aspect of the present disclosure is to provide a cooling system and method for controlling the temperature of a single cylinder four stroke horizontal direct injection diesel engine implementing both the thermos siphon and forced cooling method by pumping of water. The system comprises a gear driven water pump which on rotation, pumps coolant by displacement method due to the void created, and circulates water to the cylinder, cylinder head and finally through the hose pipe to the radiator. The fan assembly mounted on the radiator driven by belt from pulley cools the engine coolant by induction.

Forced cooling system uses a pump, along with a provision for thermo-siphon cooling for single cylinder horizontal engine meant for Power tiller applications.

It is ensured coolant flow through the engines coolant jacket.
Pump casing is an integral in the crankcase itself.
The radiator being mounted at the top of the crankcase.
The fan assembly connected to the radiator driven by a belt.

International Journal of Engineering Research & Technology (IJERT)
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From the coolant sump, coolant is sucked, on rotation of the gears in the gear driven pump.

Yet another object of the present invention is to provide better cooling efficiency implies improved engine performance.

The coolant pump discharge flow varies between 40-42 L/min.

There is a weep hole for early indication of any water pump seal leak and avoidance of water mixing with engine oil in the event of a failure.

This cooling system for controlling the temperature of a single cylinder horizontal engine for power tiller is disclosed. The cooling system comprising a radiator mounted atop the engine crankcase by a plurality of bolts; a coolant sump; a coolant sump plate operatively engaged atop the engine crankcase; a gear driven pump adapted to circulate coolant from the coolant sump through the engine cylinder head and the radiator, wherein a coolant hose operatively connects the cylinder head to the radiator; a fan assembly mounted on the radiator, thereby cooling the coolant before entering the sump; and a thermosiphon cooling system operatively engaged to the engine crankcase.

DETAILS OF ILLUSTRATIONS AND DESCRIPTION

In one implementation, one such engine cooling system and method for cooling a single cylinder horizontal direct injection diesel engine has been provided for. The engine cooling system controls the temperature of the engine both by thermosiphon and forced cooling method, where the water is pumped by the gear driven water pump. The cooling system comprises of a gear driven water pump; radiator; fan assembly, said fan assembly driven by belt and a coolant sump.

Figure 1 illustrates the perspective view of cooling system arrangement of the engine with the integral volute and the water pump installation. As seen in the figure, the engine-cooling system assembly comprises of a crankcase (1), a gear driven water pump (2), a cylinder head (4), coolant hose (5), a box type radiator (7) and a fan assembly (8).

The gear driven water pump (2), as illustrated in figure 2, comprises of an impeller (10) which is firmly fixed over the integrated shaft (11) supported by bearings. The water pump (2) delivers coolant to the coolant jacket. Helical gear (12) is fixed on the impeller shaft (11) which gets the drive from the crankshaft. Pump casing (9) is an integrated unique feature made in the crankcase (1) itself. The volute casing profile is designed and machined on the engine crankcase to deliver the required flow of coolant which ensure Engine cooling system. Coolant sump (13) is an integrated unique feature on crankcase (1), which acts as sump and a coolant sump plate (3) operatively engaged on top of the engine crankcase (1) is for stagnation of coolant.

The gear driven water pump (2) uses the meshing of gears to pump fluid by displacement. On rotation, the gears get separated on the intake side of the pump, thereby creating a void and suction which is filled by the fluid (here water). The water is carried by the gears to the discharge side of the pump, where the meshing of the gears displaces the fluid.

Coolant hose pipe (5) connects the cylinder head (4) to the radiator (7). It is made of synthetic materials, including but not limited to rubber.

Radiator (7) is mounted over the crankcase (1) through bolts. Radiator is designed to have fins to provide sufficient surface area for heat transfer. Fins of the radiator are made of metal, including but not limiting to copper and tubes are made of Brass (solder coated). Radiator (7) is provided with a cap having an opening pressure of 0.9 Kg/sq.cm.

Coolant from sump (13) is sucked and forced into the annular gap between liner and crankcase (1). This coolant flows to the cylinder head (4) after cooling the liner. After cooling the valves, coolant flows to the radiator (7) through coolant hose (5) and reaches the sump (13). Heat carried by the coolant is cooled by the fan assembly (8) which is mounted on the radiator (7). The flow of the coolant is shown by the arrow, as illustrated in figure 1.

The fan assembly (8) mounted on radiator (7) driven by a belt from pulley connected to the engine's crankshaft.

Significantly, the cooling system arrangement of the engine of a power tiller can be used in both Thermosiphon cooling and forced cooling with no additional machining. However, the primary mode of cooling is accomplished by the forced cooling configuration. Only when the forced cooling configuration is out of order, the Thermosiphon cooling configuration operates to cool the engine. The Thermosiphon cooling configuration remains inactive or non-operational during forced cooling configuration.

A weep hole provision is provided for early indication of any water pump seal leak and avoidance of water mixing with engine oil in the event of a failure.

CALCULATIONS & ANALYSIS

Certain values of certain parameters have been used to get results as shown in tabular format here below.

For calculation of cooling area, given a certain mass flow rate, the number of tubes required in the radiator (7) can be estimated using the following relationship:

$$m = A_t v\rho = \left[\left(\frac{\pi d^2}{4}\right)n\right]v\rho$$

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Considering the minimum area available for flow to estimate the maximum pressure drop on the water side:

Cylinder head 4 water outlet area (20mm hose)	$A=\pi/4 \times d^2$	0.000254469	m^2
Velocity	v=m/ P x A	1.068715953	m/s
Pressure Drop (Cylinder head 7)	$(\rho \times V^2)/2$	6.033998466	mbar

Estimating the Pressure drop across the radiator:

Radiator 7 Dimensions			
L	11.8	mm	
B	2.4	mm	
Area per tube	0.00002832	m^2	
No of Tubes	117		
Total Radiator flow area	0.00331344		
Velocity	v=m/ P x A	0.082076357	m/s
Pressure Drop (Radiator)	$(\rho \times V^2)/2$	0.03558908	mbar

The Water pump (2) selected for the engine:

Parameter	Value	Unit
Pump speed	3500	Rpm
Back pressure (Max)	100	Mbar
Discharge	25	litre/min

The main aspect of the invention is to provide an efficient and optimum cooling system for an engine, detailed analysis of which is carried out using commercially available Computational Fluid Dynamics (CFD) code. The detailed CFD analysis for estimating the flow velocities at different critical locations to predict any stagnation causing boiling and necessary changes in the design are documented below along with the corresponding CFD diagrams being illustrated in the drawing section as seen in figures 5(a)-(h). Based on the CFD results, it is observed that the velocity distribution and heat transfer coefficients around the critical regions of the cooling jacket [Block (1) and Cylinder head (4)] are within acceptable limits and validated during engine testing and validation trials.

CFD analysis has been carried out with the actual parameters of the base engine for steady state incompressible coolant jacket analysis and the parameters used for different iterations has been given below in tabular format.

The following tables showing CFD analysis for baseline vs iteration 1 and iteration 2: boundary condition and domain (water jacket region under consideration). The reference gasket holes 1,2 and 3 are illustrated in figure 4.

Sr. No.	Gasket Hole Number	Baseline		1st iteration		Area mm^2
		Mass flow rate Kg/s	% of total mass flow rate Kg/s	Mass flow rate Kg/s	% of total mass flow rate Kg/s	
1	Hole 1	0.129	30.71	0.228	33.73	113.04
2	Hole 2	0.128	30.47	0.211	31.21	113.04
3	Hole 3	0.163	38.80	0.237	35.06	143.1

Sr. No.	Gasket Hole Number	Iteration 1		Iteration 2		Area mm^2
		Mass flow rate Kg/s	% of total mass flow rate Kg/s	Mass flow rate Kg/s	% of total mass flow rate Kg/s	
1	Hole 1	0.228	33.73	0.215	31.85	113.04
2	Hole 2	0.211	31.21	0.205	30.37	113.04
3	Hole 3	0.237	35.06	0.255	37.77	143.1

The pressure drop across the system is 0.149 bar at 40 litres per minute.

Sr. No	Location	Coolant Velocity (m/s)		
		Target velocity range	Baseline	1st Iteration
1	Liner Top	1.5 - 2.5	0.0 - 1.29	0.0 – 2.25
2	Around Valves	1.5 - 2.5	0.0 - 1.0	0.0 - 1.71
3	Near valve bridge	2.0 - 3.0	0.0 – 0.1	0.0 – 0.2
4	Through Gasket Hole	1.5 - 2.5	1.5 - 2.1	1.5 - 3

The pressure drop across the system is 0.138 bar at 40 litres per minute.

Sr. No	Location	Coolant Velocity (m/s)		
		Target velocity range	Iteration 1	Iteration 2
1	Liner Top	1.5 - 2.5	0.0 – 2.25	0.0 - 1.97
2	Around Valves	1.5 - 2.5	0.0 - 1.71	0.0 – 1.68
3	Near valve bridge	2.0 - 3.0	0.0 – 0.2	0.0 – 0.30
4	Through Gasket Hole	1.5 - 2.5	1.5 - 3	1.5 – 3.0

Figures 5(a) and (b) illustrate the CFD analysis of the overall assembly for all the iterations, wherein the heat transfer coefficient is within the permissible limits. In the figures the colours are value indexed at the bottom.

Similarly, figures 5 (c) and (d) illustrate the CFD analysis of the block for all the iterations, wherein the heat transfer coefficient is within the permissible limits. In the figures the colours are value indexed at the bottom.

Similarly, figures 5(e) and (f) illustrate the CFD analysis of the head for all the iterations, wherein the heat transfer coefficient is within the permissible limits. In the figures the colours are value indexed at the bottom.

Figures 5(g) and (h) illustrate the velocity of the streamline flow of the coolant through the assembly for all the iterations.

ILLUSTRATIONS

FIG 1

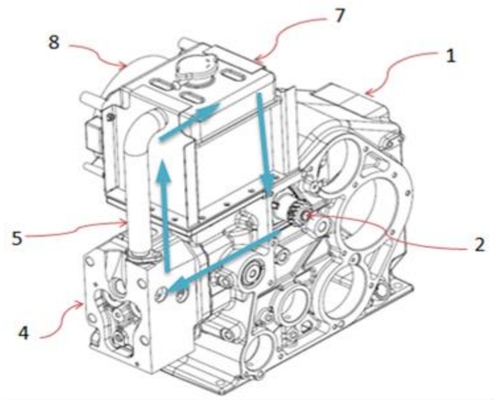

Figure 1

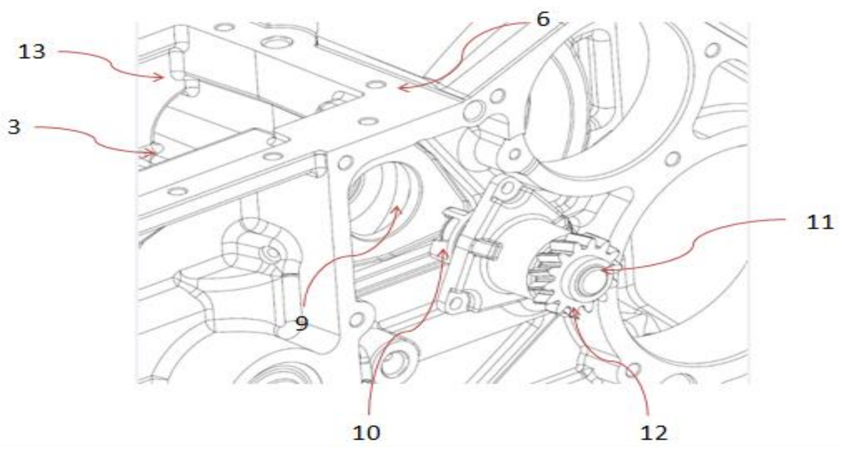

Figure 2

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ISSN: 2278-0181
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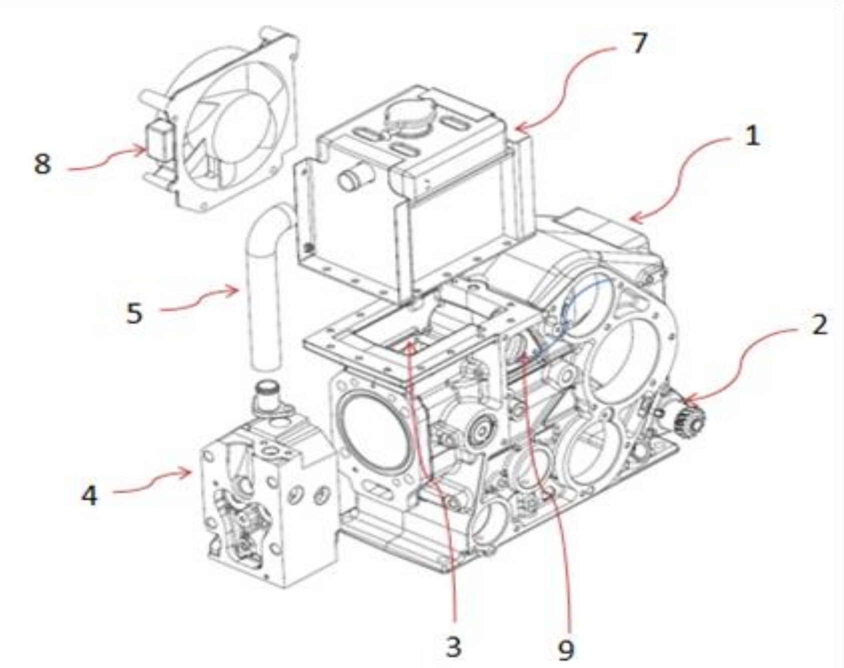


Figure 3

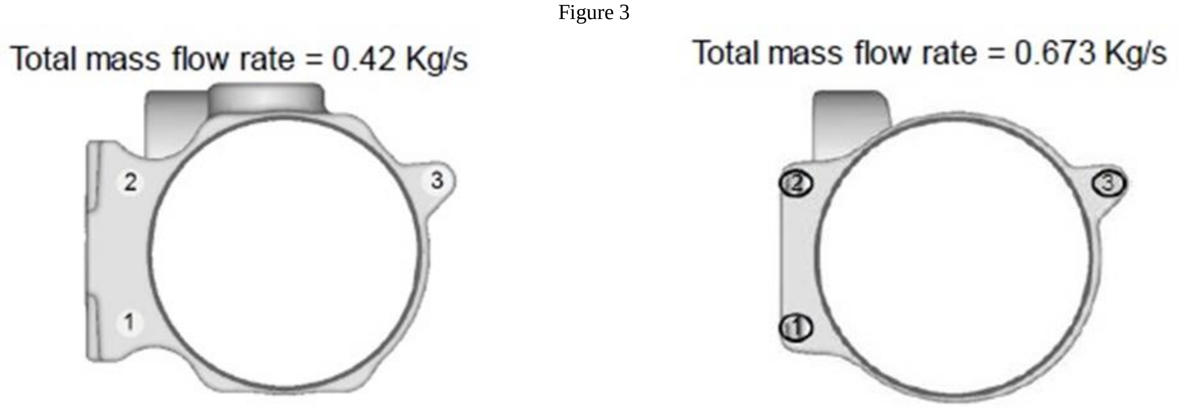
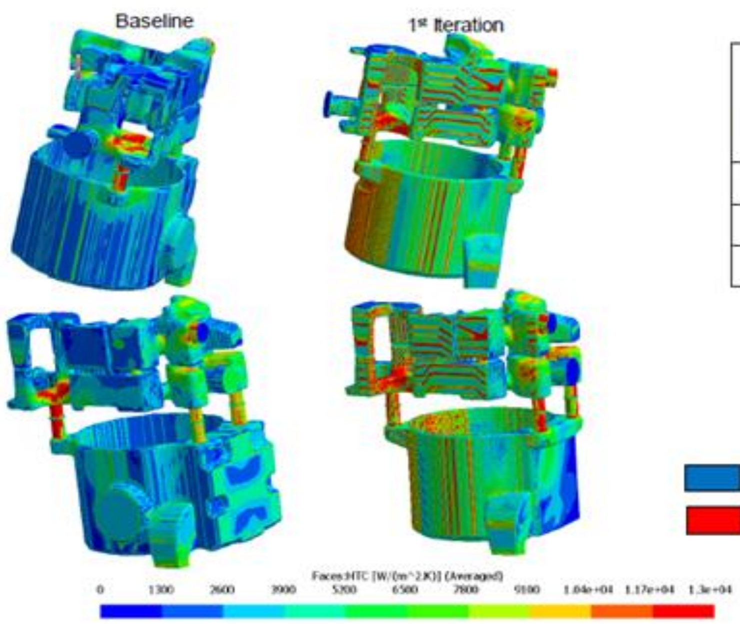


Figure 4



Sr. No.	Part	Surface Averaged HTC (W/m2.K)	
		Baseline	1st iteration
1	Block	3231.54	9904
2	Gasket	4197.26	10715
3	Head	3640	8488

		HTC (W/m²K)	
		Baseline	1st iteration
Min	Min	0	0
Max	Max	2,11,725	2,25,186

Figure 5(a)

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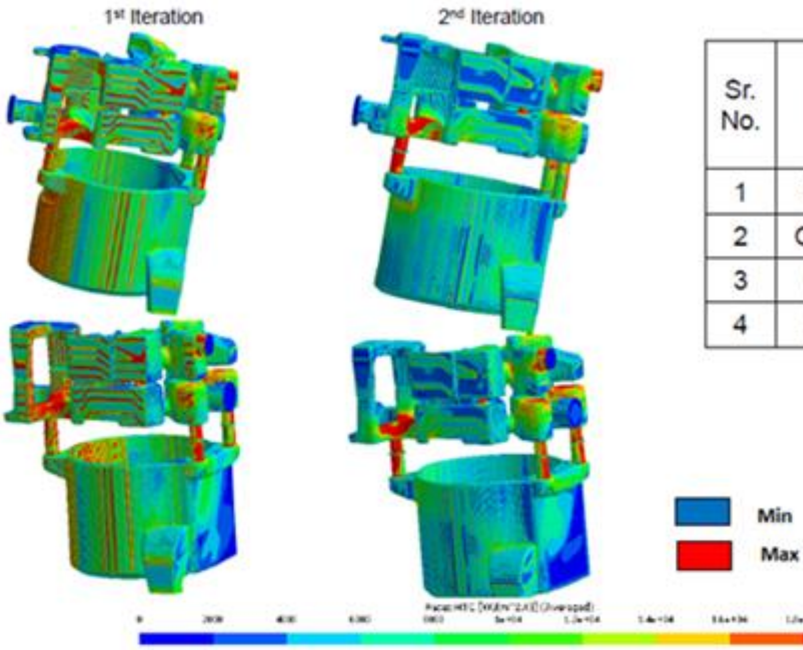
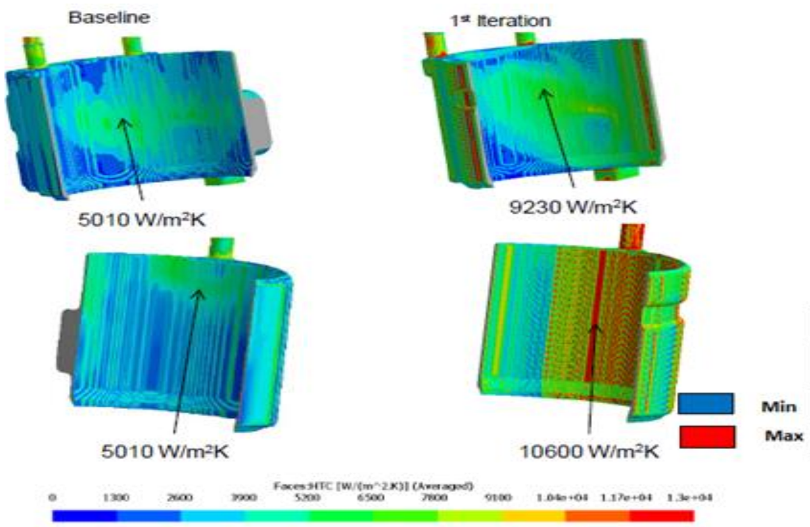


Sr. No.	Part	Surface Averaged HTC (W/m2.K)	
		Iteration 1	Iteration 2
1	Block	9904	6213
2	Gasket	10715	6289
3	Head	8488	6878
4	Liner	9643	5782

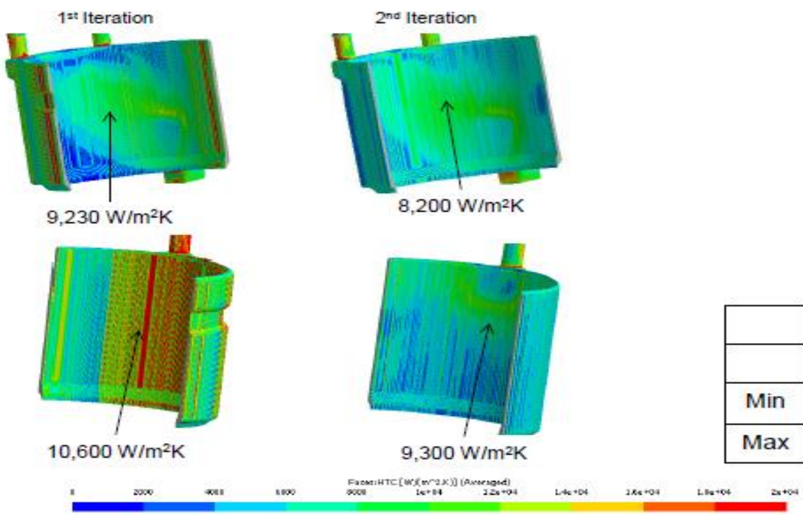
	HTC (W/m²K)	
	Iteration 1	Iteration 2
Min	0	0
Max	2,25,186	2,15,115

Figure 5(b)



	HTC (W/m²K)	
	Baseline	1st iteration
Min	0	0
Max	2,11,725	2,25,186

Figure 5(c)



	HTC (W/m²K)	
	Iteration 1	Iteration 2
Min	0	0
Max	2,25,186	2,15,115

Figure 5(d)

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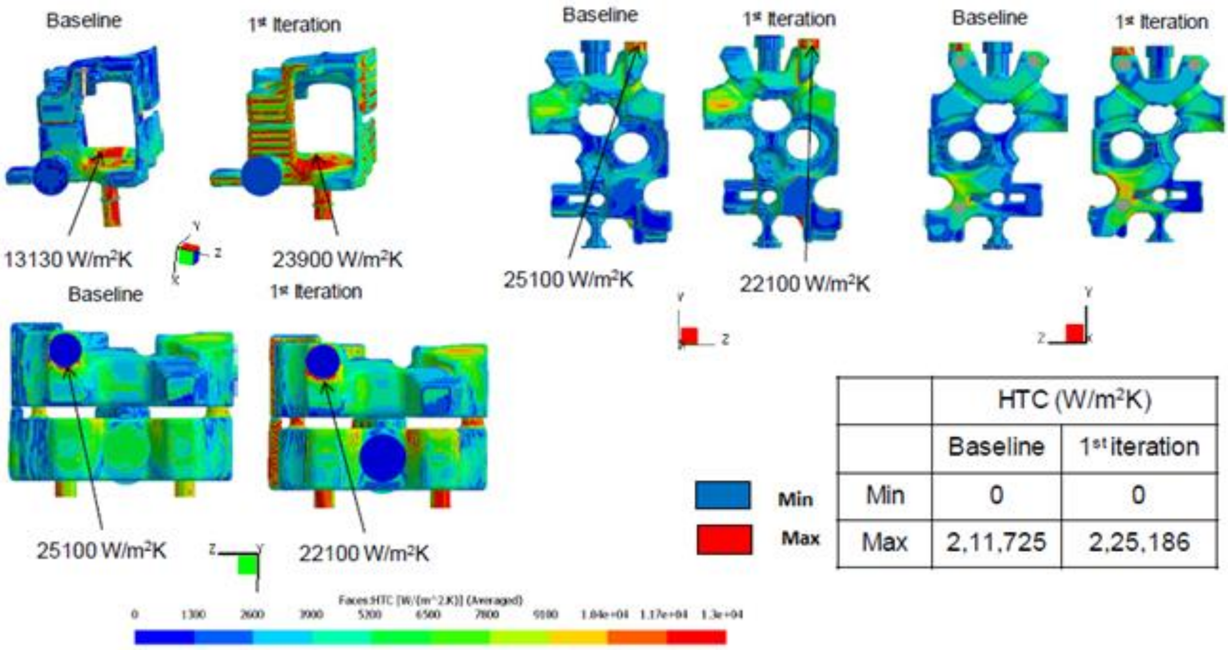
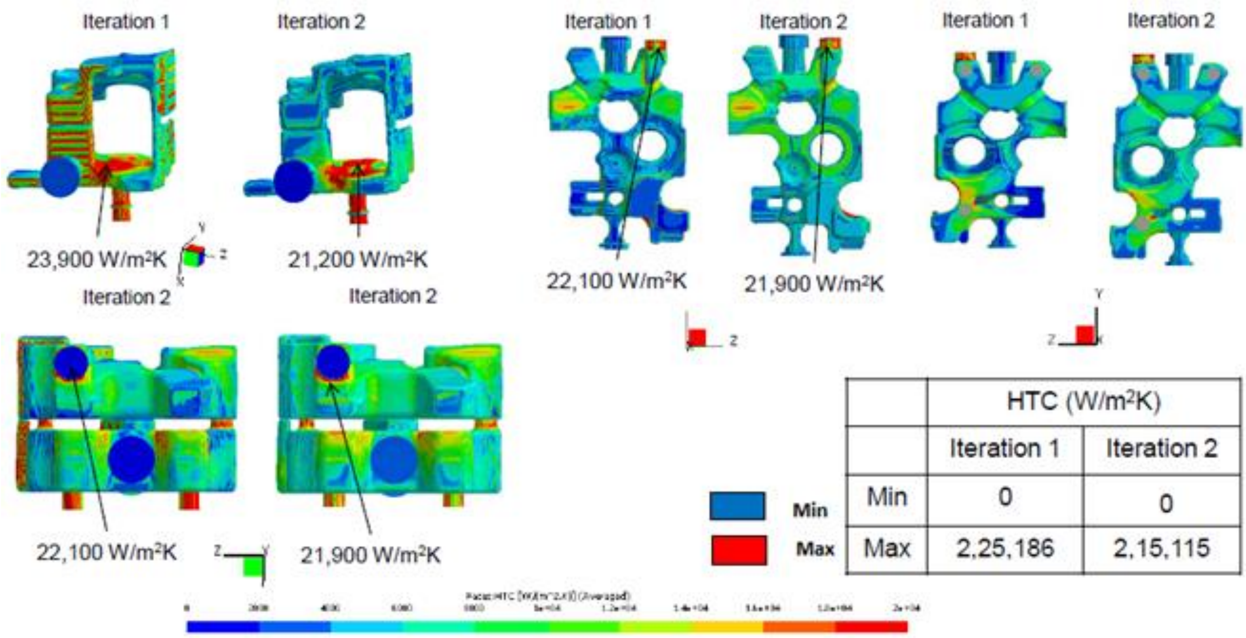


	HTC (W/m²K)	
	Baseline	1st iteration
Min	0	0
Max	2,11,725	2,25,186

Figure 5(e)



	HTC (W/m²K)	
	Iteration 1	Iteration 2
Min	0	0
Max	2,25,186	2,15,115

Figure 5(f)

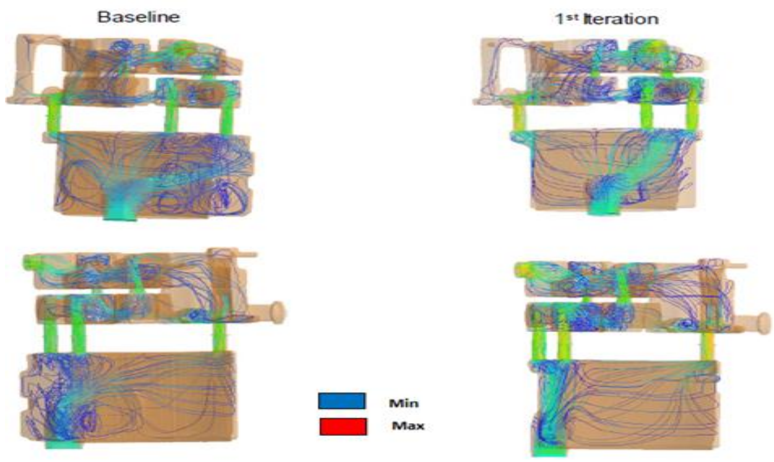


Figure 5(g)

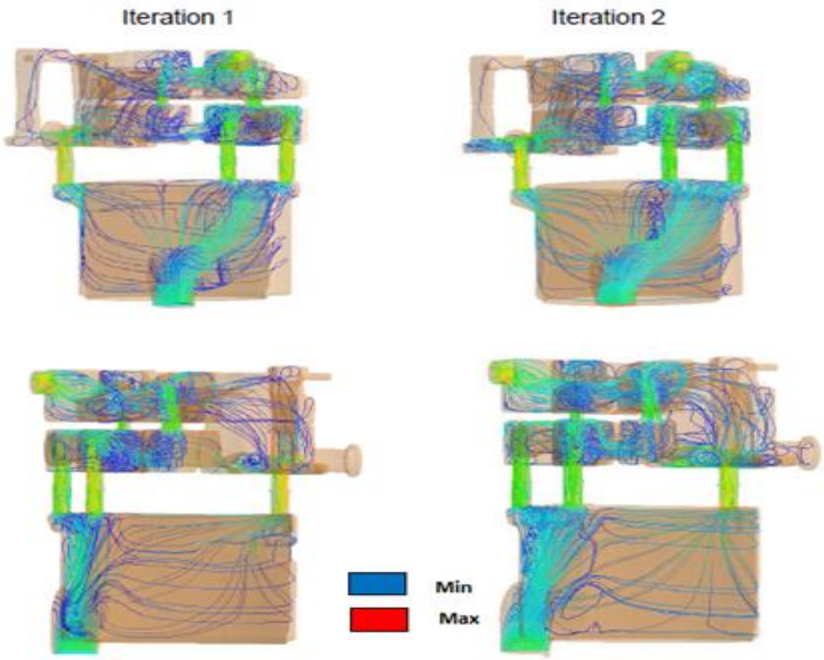


Figure 5(h)

CONCLUSION:

Some of the important advantages of the novel cooling system, considered to be noteworthy are mentioned below:

1. The engine has a water pump to ensure the flow of coolant through the engines coolant jacket.
2. Better cooling efficiency implies improved engine performance.
3. Improves durability of the engine.
4. Water changing frequency reduced.
5. The power tiller can be used in both Thermo siphon as well as forced cooling configuration with no additional machining required.
6. The power tiller has an integral volute in crank case (Engine block) for Water pump.
7. The water pump is driven within the engine gear train using Helical gear.
8. A weep hole provision is provided for early indication of any water pump seal leak and avoidance of water mixing with engine oil in the event of a failure.

   Although an efficient method of cooling an engine, thereby increasing the engine performance and durability has been described in language specific to the structural features, it is to be understood that the embodiments disclosed in the above section are not necessarily limited to the specific features or devices described. Rather, the specific features are disclosed as examples of implementations of an engine cooling system, implementing both thermo siphon and forced cooling method.