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Performance Improvement of Cooling System in T72 Bridge Layer Tank

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ABSTRACT

Modern armoured fighting vehicles (AFVs) are provided with compact and efficient cooling systems. Any increase in volume warrants the protection which, in turn, increases the weight and size of the vehicle. In a combat vehicle, space is at premium. The AFVs (battle tanks) used by the Indian Army were found to be overheating when operated in deserts at very high-ambient temperatures of 323K (50 °C). This imposes severe restrictions in operating the tanks for prolonged time in deserts. The various subsystems of the cooling pack were investigated scientifically and an optimised solution was arrived at, implemented and proved successful in the subsequent desert trials. This paper deals with the details of investigations, modifications, and the results of studies on bridge layer tank (BLT–T72).

Keywords: Overheating, radiators, oil coolers, three-pass and single-pass radiators, bridge layer tank, armoured fighting vehicles, cooling system, combat vehicles

NOMENCLATURE

Nu	Nusselt number
Re	Reynolds number
Pr	Prandtl number
v	Velocity of fluid
μ	Viscosity of fluid
ρ	Density of fluid
d	Diameter of fluid flow
h	Heat transfer coefficient
$p.r$	Pressure ratio
p	Pressure of fluid
T	Temperature
T_1	Temperature of induction air
T_2	Temperature after compression
T_3	Temperature after combustion
V_1/V_2	Compression ratio
Q	Heat transfer
m	Mass flow rate of fluid
s	Specific heat
ΔT	Temperature differential
RTDs	Resistance temperature detectors
RH	Relative humidity

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1. INTRODUCTION

Unlike commercial automobiles, the armoured tracked vehicles (ATVs) have a different type of construction. It is essential to have heavy armour protection to meet the fighting option against the enemy's powerful attack by firepower. Then comes the fighting weapon systems and associated control systems. The propulsion unit is accommodated generally on the rear side. As battle equipment, tanks are subjected to attack from all sides, though the intensity of attack varies from very heavy in the front to indirect attack on the sides, rear, bottom and top. In this process, the engine and gearbox units get covered all-round and cooling airflow paths have labyrinth passages, leading to substantial restrictions for air movements. This reduces the quantity of air available for carrying away the rejected heat. In hot weather, this situation causes overheating of the engines[1].

2. CONSTRUCTION DETAILS

Figure 1 shows the general construction of a bridge layer tank of T72 vehicle. The engine, its cooling pack (oil coolers, radiators and fan) and airflow path are shown in Fig. 2. The engine is located transversely and power flow is through a gear train to change the speed gearboxes on right hand and left hand sides. In the horizontally placed cooling pack, radiators are kept below the oil coolers.

Figure 1. Typical bridge layer tank–T72.

The oil coolers and radiators are made up of aluminium plate and fin-type matrix with turbulators provided in water and air passages. The cool air

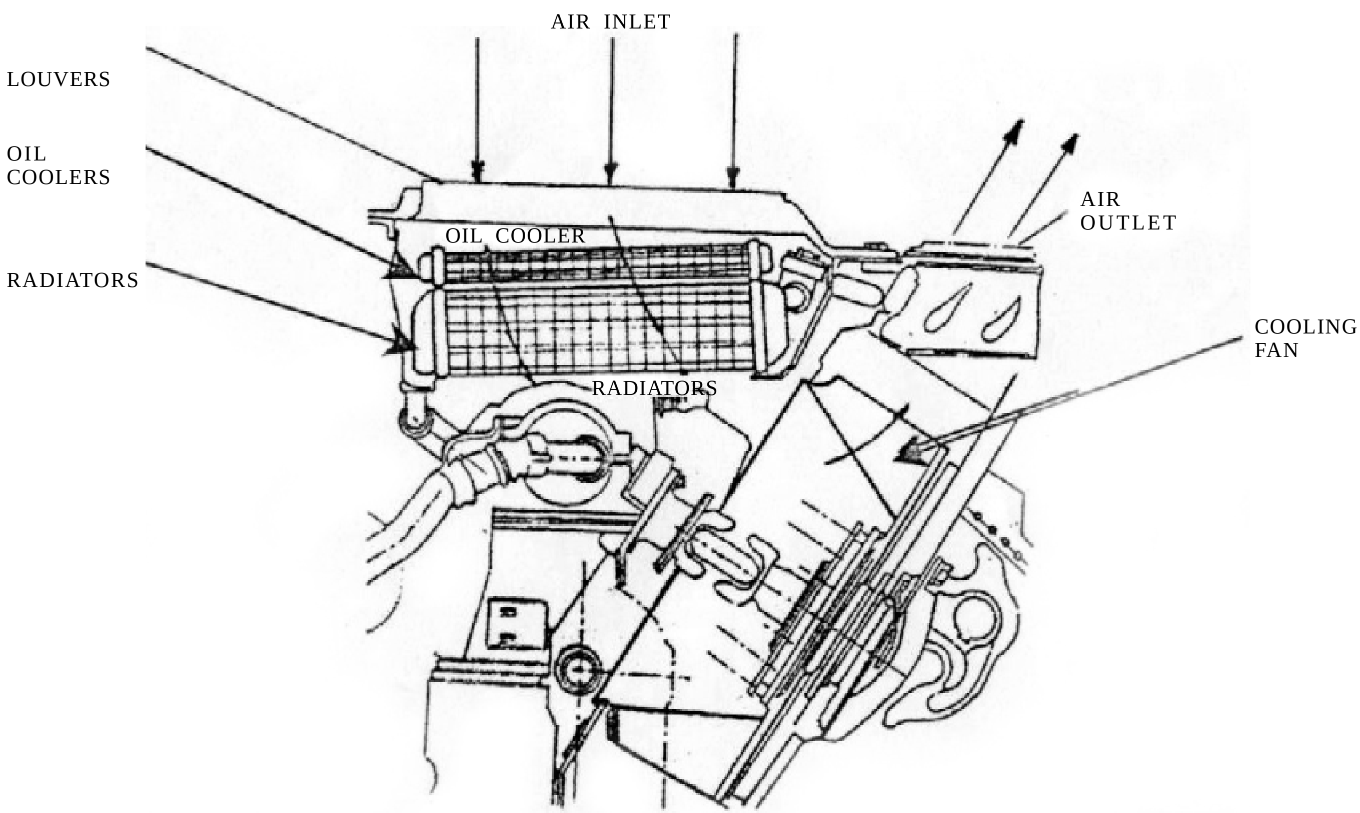

Figure 2. Cross-sectional view of cooling package and airflow path.

enters through the protection louvers, passes through the oil coolers, water radiators and then through the radial flow fan, exiting through another set of louvers.

These subassemblies have been arranged in a certain sequence to meet the specific requirements. The coolant is cooled by two radiators connected in series. On the water-flow side, it makes three passes each in two radiators as shown in Fig. 3. The free-space available has been kept to the minimum to keep the vehicle weight as low as possible. These tanks were designed to work efficiently within a maximum ambient temperature of 298K (25 °C), with marginal reduction in performance above 298K (25 °C). But when the ambient temperature exceeds 318K (45 °C), the performance falls steeply (approx. 33 % drop in power).

3. THEORETICAL ASSESSMENT

The power developed by an IC engine depends on inlet air temperature (T_1) . The maximum adiabatic temperature (T_3) developed in the thermodynamic process approximately increases with inlet air temperature as shown by the relationship:

$$T_3 = p.r^* \; T_2 = p.r^* \; T_1{}^* \; (V_1/V_2)^{(\gamma-1)}$$

For an increase of inlet air temperature from 293K (20 °C) to 323K (50 °C), it can be shown that the increase in T_3 is about 10 per cent, in case of naturally aspirated engine. In addition, it may be recalled that the increase in air inlet temperature reduces air mass inhaled. It can be shown that air mass reduces by 11 per cent causing reduction in excess air available for absorbing heat generated during the combustion process. In case of turbo-charged engine, the air temperature after the compressor is so high, charge cooling becomes inevitable to maintain the reasonable mass flow. Added to this if the air inlet temperature were to be quite high, the heat rejected to the coolant in the charge cooler becomes significantly high.

When the weight of the vehicle is increased, the power required to carry the excess weight is also required to increase. Hence, more amount of fuel is to be burnt to achieve the required mobility, which also increases, the thermal load on engine. Consequent to all of the above changes, the heat rejected to the coolant increases. As the coolant temperature increases the difference in temperature (ΔT) wrt cooling air gets reduced and hence the heat absorbed by the cooling air gets reduced.

The general equation describing the heat transfer coefficient (h), which is still accepted, is:

$$h = f(p^a T^b v^c)$$

This chain of events tends to increase the coolant temperature to a higher level and to stabilise

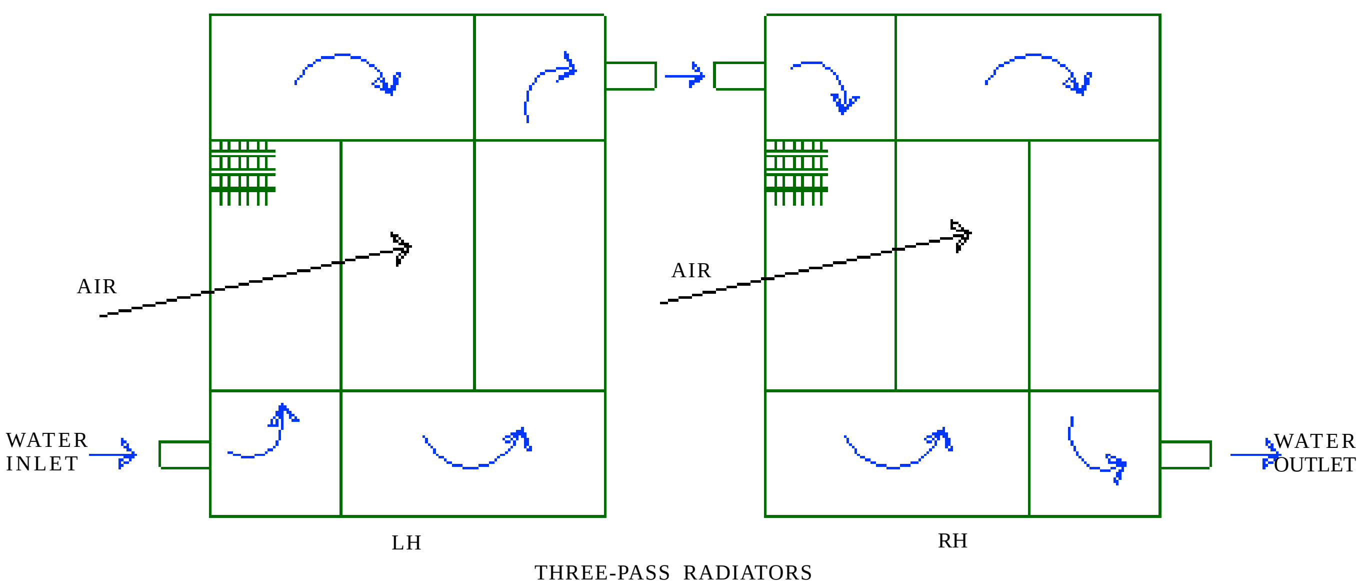

Figure 3. Water flow in original radiators.

the same, total heat rejected by the engine needs to be curtailed. This reduces the useful power available from the engine.

4. ASSESSMENT OF PARAMETERS

Before venturing into laboratory testing, the parameters affecting the performance of the engine, as installed in the vehicle, were checked. Also, the approximate design values were obtained. These input gave an idea about the range of variation of various parameters such as pressure, temperature, flow and velocity of cool air, water, and oil. The measurements were made in vehicle static condition using anemometer, pressure gauges, manometers and resistance temperature detectors (RTDs).

5. TEST ARRANGEMENT

The performance of the radiators and oil coolers were evaluated in a laboratory setup. The general arrangement of the rig was done as per FVRDE[2] Standard 1040. The test rig arrangement is shown in Fig. 4. Two separate test rigs of similar constructions were used, one dedicated to testing water-flow radiator and the second for oil coolers. In the test rig, facility was available to vary the water flow from 100 l/min to 650 l/min. Also, the water temperature can be varied in any step from ambient up to 368K (95 °C). The airflow velocity can also be varied from 3.5 m/s up to 20 m/s. Water-flow rate was monitored with a rotameter and airflow with a vane-type anemometer. The airflow measurements were made as per BS Standard[3] 1042. For oil cooler evaluation; oil flow can be varied from 80 l/min to 200 l/ min and temperature up to 393K (120 °C) and pressure up to 1.2 MPa. In both test rigs, temperature was measured using RTDs at different points. The pressure of water and oil at different points were measured with Bourdon-type gauges and for measuring low pressures, water and mercury manometers were used.

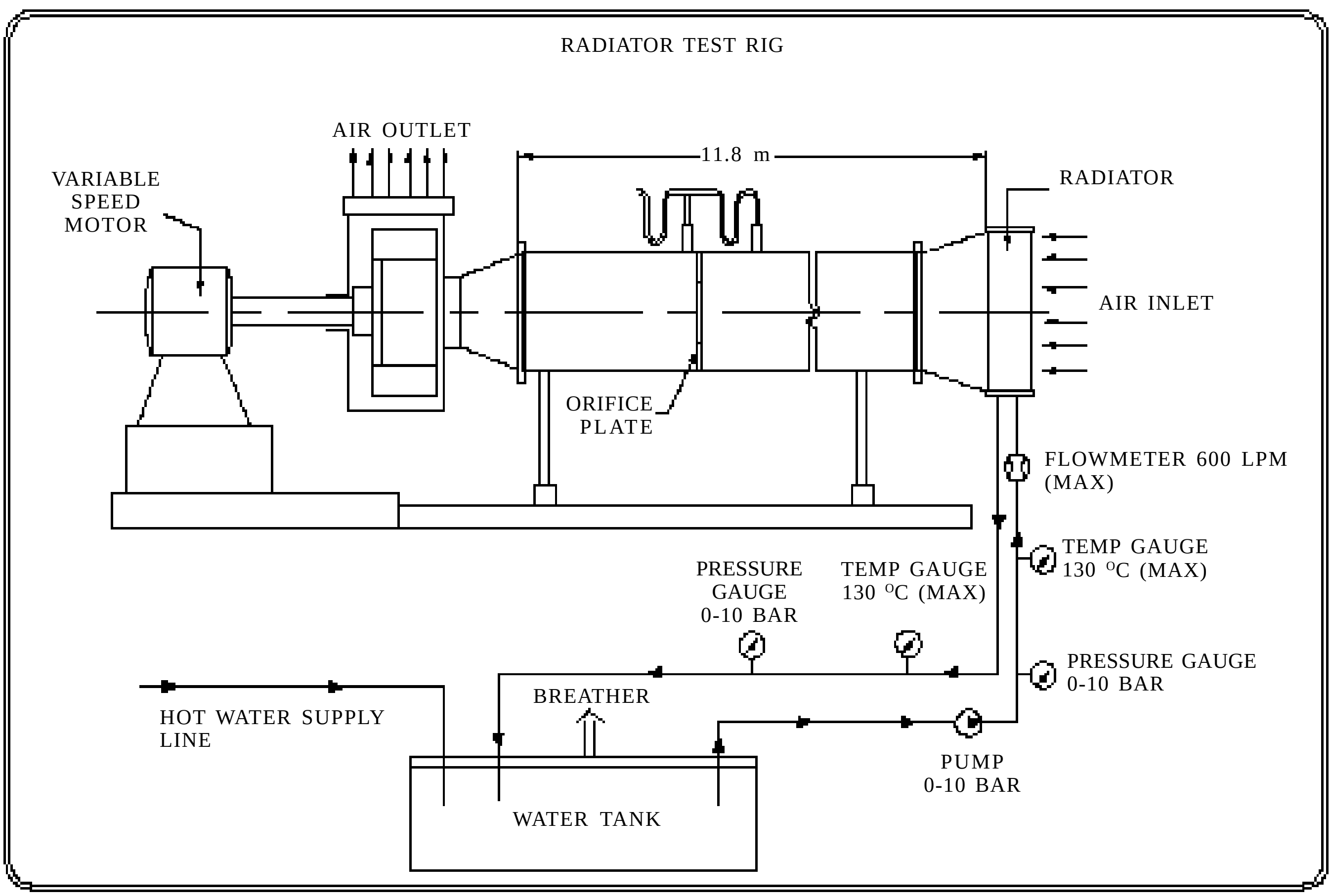

Figure 4. Test setup for radiator performance evaluation.

6. TESTING AND OBSERVATIONS

The testing was carried out with several alternate settings (repeated few times) to ensure consistent readings. The observations regarding temperature drop wrt different air/water-flow rates were measured with the existing water radiator. From these observations, the dependence of temperature drop wrt change in water flow and airflow are drawn and are shown in Fig. 5. It can be observed that the temperature drop varies significantly wrt increase in airflow rate than with the increase in water-flow rate. The transition from laminar to turbulent flow can be observed clearly in the characteristic curves.

7. INVESTIGATION AND FINDINGS

The above observations bring out the fact that if airflow is increased then the heat dissipation can be increased substantially. However, the means by which the airflow has to be increased should be studied indepth before implementing the same.

Similarly, the possibilities of increasing the water- and oil-flow rates were studied to obtain the maximum benefit in heat dissipation.

The existing radiators and oil coolers are plate and fin-types. The air paths have fins with louvers to increase the turbulence, and hence, the heat transfer coefficient. To provide a new airflow path, totally new construction has to be resorted to. The other alternative is to modify the source of airflow, viz., the cooling fan. By increasing the speed of the cooling fan at the expense of power, the airflow can be increased.

The heat transfer (Q) from the coolant to the surrounding air is mainly of convective nature and depends upon factors such as quantity of water flowing (m), specific heat (s), temperature differential (Δt), Reynolds number (Re) and Prandtl number (Pr), etc.

$Q = ms\ \Delta T$ and

$Nu = f\ (Re\ Pr)$[4]

A study of these equations shows that by increasing the mass flow of water for a given temperature differential and fixed specific heat, the quantity of heat transferred (to the ambient) can be increased.

$$Re = \frac{vd\rho}{\mu}$$

The above expression indicates that, when d, ρ, μ remain constant, Re increases depending on the velocity v, and hence, the mass flow. As the heat transfer increases when Re increases, it is preferable to increase the value of v. That is, if velocity of flow increases, the flow becomes turbulent, and hence, heat transfer also increases substantially[5].

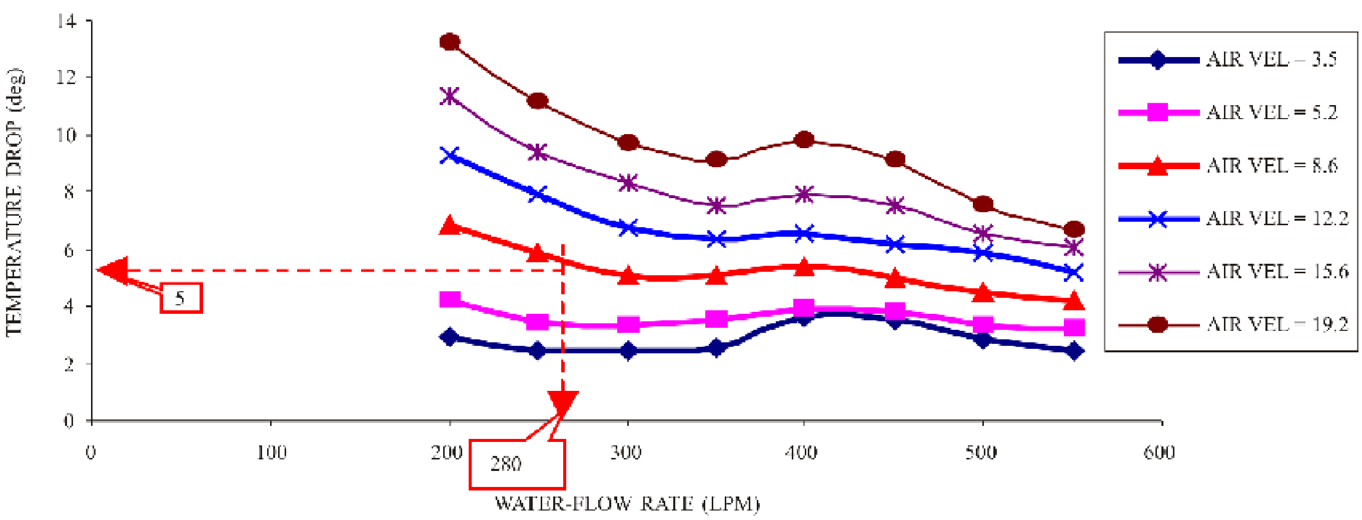

Figure 5. Water-flow rate versus temperature drop at different air velocities (existing radiator left hand three-pass).

It, therefore, becomes clear that if velocity of the coolant is increased, then considerable improvement in heat dissipation is achieved.

8. MODIFICATIONS

The water-flow passages are arranged as three-pass type as shown in Fig. 3, to provide longer flow paths and longer resident time for effective heat transfer. Since the water passages contain turbulators, the resistance (which varies directly as the square of fluid velocity) offered to the water flow increases substantially. Simply by removing the partitions at the headers and making the water to flow in a single pass [Fig. 6] has reduced the water-flow passage length to one-third of its original length, but has also reduced the pressure drop drastically (Fig. 7). This modification has enabled 60 per cent extra quantity of water to flow with the same pumping capacity. The comparative values are shown in Fig. 7.

These modified radiators and oil coolers were subjected to testing as before in the same test rigs. It can be seen from Fig. 5 that the values obtained from the testing show that for three-pass radiator for a flow of 280 LPM, the temperature drop achieved at an air velocity of 8.6 m/s was 5.5K. Corresponding (for same pressure drop) flow in a single-pass radiator (Fig. 7) is 450 LPM, for which temperature drop achieved was 9K. This shows theoretically an increase of 162 per cent in heat dissipation. This can be attributed to the fact that the flow pattern, which was laminar flow (Reynolds number 2190 for the above example) in the three-pass configuration has changed over to the turbulent flow (Reynolds number 3515) in a single-pass configuration (Figs 5 and 8) as the heat transfer is more effective in the turbulent phase than in laminar phase[6]. Similar improvements were observed in oil coolers also.

As the test result showed substantial improvement in the heat dissipation values with this modification (Fig. 9), it was decided to install the same in a vehicle and carryout extensive trials. Initially, trials were carried out at an ambient temperature of 308K (35 °C) in the test track available at CVRDE to validate the experimental findings. It was observed that the coolant temperature did not go beyond 368K (95 °C) (maximum permitted 115 °C) and the oil temperature reached a maximum of 378K (105 °C-maximum permitted is 120 °C) only. This confirmed the findings of lab-tests and encouraged further evaluation by field trials.

9. FIELD TRIALS

The vehicle was subjected to hot weather trials in the deserts along with a standard vehicle, which was using unmodified radiators and oil coolers. The trials in deserts extracted maximum power

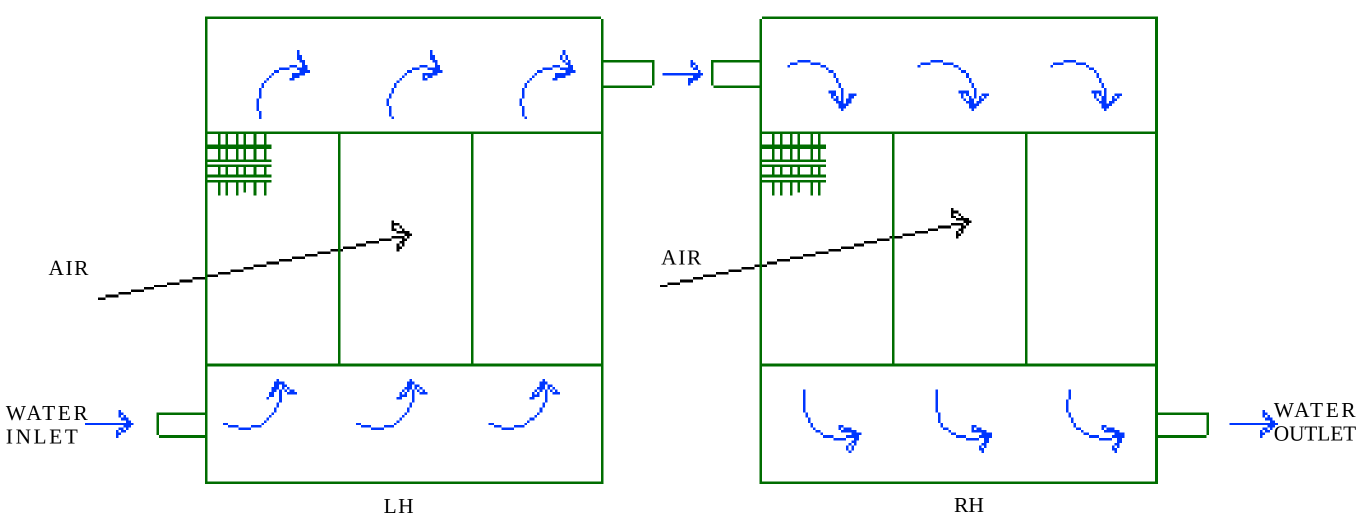

Figure 6. Water flow in modified radiators.

from the engine, due to difficult traction in sand. Coupled with this is the fact of very high, dry ambient conditions, viz., 323K (50 °C) and very low relative humidity of 20-30 per cent. The schedule of the trial was to cover 35 km of nonstop run in these conditions. The standard vehicle could cover only 25 km before reaching the temperature limit of 388K (115 °C) when it had to be halted. Whereas, the vehicle with modified radiators and coolers could complete the scheduled distance without any problem, with a maximum temperature of 381K (108 °C) only. This trial was repeated in a different location and the performance was observed to be identical.

The next trial was to run the vehicles in a very slushy terrain, which again extracted maximum power. In this case also, the trial vehicle with modified radiators and oil coolers performed excellently with maximum coolant temperature recorded being 378K (105 °C) only after covering stipulated 4 km, against 388K (115 °C) recorded by the standard

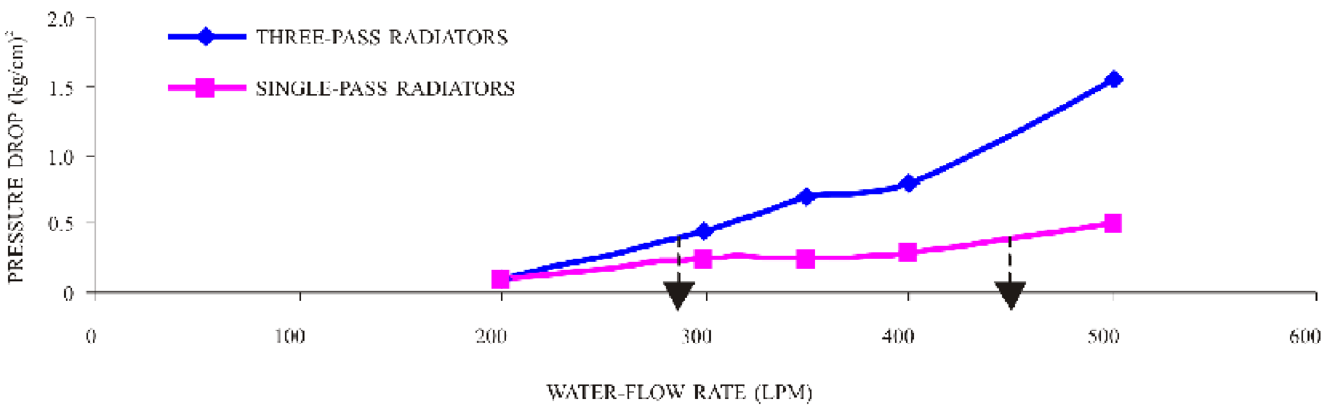

Figure 7. Water-flow rate versus pressure drop (three-pass and single-pass radiators).

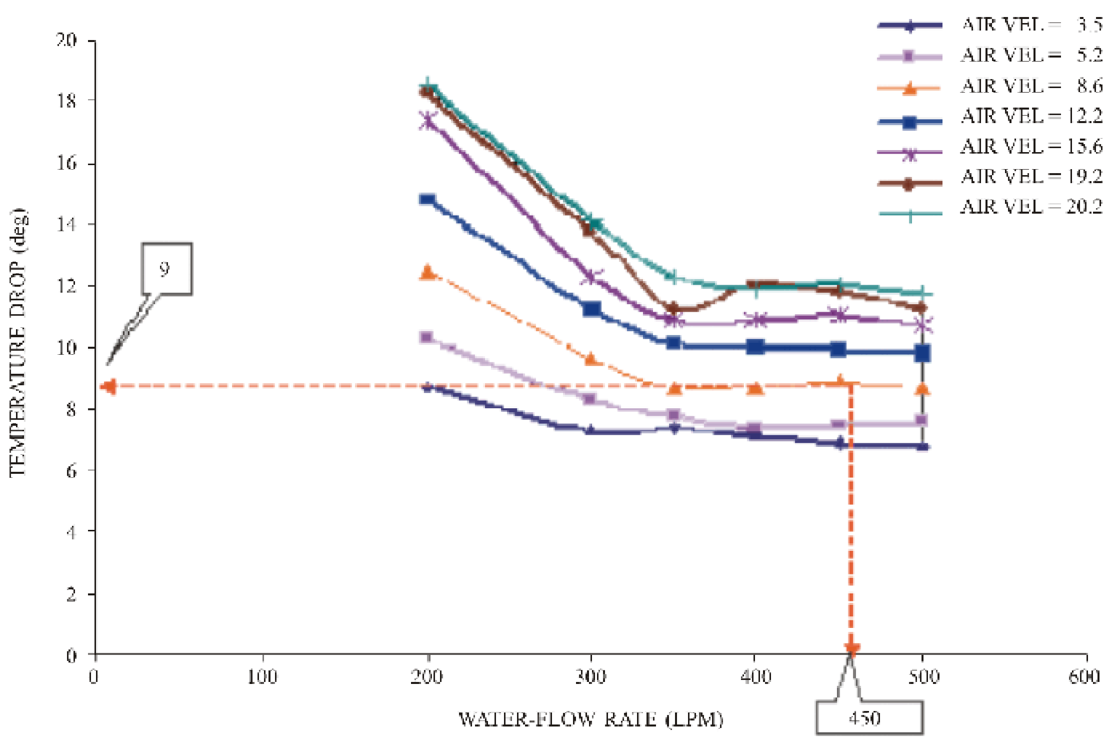

Figure 8. Temperature drop versus water-flow rate (modified radiator–single-pass).

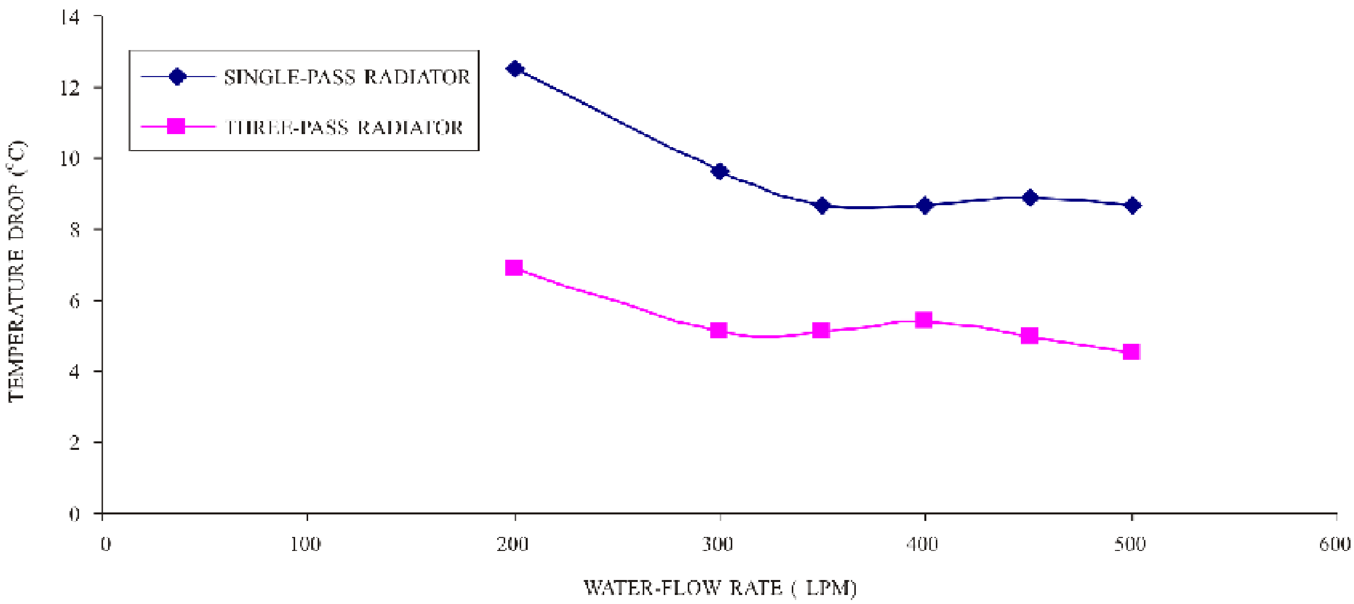

Figure 9. Comparison of water temperature, drop at 8.6 m/s air velocity.

vehicle covering less than half the distance (2 km). Subsequent to this, the vehicle was required to cross a river 500 m wide with 1m depth of water, flowing at a speed of 7 knot (approx. 3.6 m/s). The performance again was satisfactory with the coolant temperature remaining less than 373K (100 °C). The vehicle was subjected to a continuous reliability run of 70 km in the same desert terrain, i.e., running at an average speed of 20 km/h and providing for short halts to look after conveniences of the crew members. Again, the vehicle performance was satisfactory with coolant temperature remaining at less than 378K (105 °C).

10. CONCLUSION

Through systematic study and experimental evaluation, a simple modification of changing multi-pass to a single-pass was evolved to enhance the heat dissipation capacity of an existing radiator. The effect of such modification was evaluated in the test rig, which confirmed the enhancement of capacity by approx. 60 per cent. Further field trials in actual working environment validated this improvement and the overheating of the engine in critical operating condition could be eliminated.

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REFERENCES

1. Engineering design handbook, military vehicle power plant cooling, Ch. 6. US Dept of Commerce, (NTIS), Springfield, VA 22161.
2. Schedules for the testing of fighting vehicles. Fighting Vehicles Research & Development Establishment (FVRDE), UK.
3. Measurement of airflow. BS 1042.
4. Chapman. Allan, J. Heat transfer, Ed 4. Macmillan Publishing Co, New York, 1984. 189 p.
5. Frass. Arthur, P. *In* Heat exchanger design. John Wiley & Sons, 1989. pp. 44,45,53.
6. Isachenco, V.P.; & Osipova, V.A. & Sukomel, A.S. Heat transfer (Translated from Russian by S. Semyonov), Mir Publishers, Moscow, 1987. 210 p.

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