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EXPERIMENTAL ANALYSIS OF THE TRANSIENT BEHAVIOR OF AN ENGINE COOLING RADIATOR

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Abstract. *The aim of this work is to study the behavior of an engine cooling radiator in a transient state, with circulation of heated water. An experimental apparatus was constructed with the radiator inside a wind tunnel. The water is pumped from a small water tank to a heater, passes through the heat exchanger, and returns to the tank. The tests were carried out with constant water and air flows, and the heater was set on for some time. The temperatures of the radiator, the air and the water were measured into several places with thermocouples and a thermal camera, besides the flows of water and air. The temperatures increase very fast just as soon as the heater is turned on. After that, the temperatures increase slowly while the whole system is getting warmer. The steady state is reached after 15 min. These results might be useful in the project of a vehicle cooling system under transient conditions.*

Keywords: *heat exchanger, radiator, heat transfer, transient analysis*

1. INTRODUCTION

Any electric or internal combustion engine in operation releases heat, generated by the friction between the components, by the passage of electric current, combustion, among others. This heat must be rejected to the environment, either by the exhaust gases and by a subsystem which contains the heat exchanger known as radiator. Basically, the radiator is a cross flow compact heat exchanger that is composed by flat tubes with louvered fins between them. The flow of air from the vehicle displacement passes through the radiator, which has fins positioned transversely to the airflow. The fluid after exiting the engine loses heat as it passes through the tubes that are in contact with the fins, and returns to the engine.

The process for designing an automotive heat exchanger is similar for passenger, freight or competition vehicles, but there are important peculiarities in each project that need to be observed, as well as the presence of turbocharged, automatic transmission or air conditioning, and the maximum and minimum ambient temperatures.

The study of a radiator in a transient state is important because a vehicle is usually changing its state, such during acceleration, resulting in different heat rejections and air flow conditions. Besides, due to the nonuniformity of the fluids temperatures on the transient state, the radiator performance and the heat transfer coefficients are affected as well.

Most of the studies of the transient behavior of heat exchangers deal with models for simulation (Mishra *et al.*, 2006; Korzeń and Taler, 2015; Vaisi *et al.*, 2011). The transient analysis is often used to obtain heat transfer design data (Krishnakumar *et al.*, 2011). In experimental studies with air, the heat exchanger is generally placed inside a wind tunnel (Wang *et al.*, 2015; Glazar *et al.*, 2015). Experimental analysis of automotive radiator were carried out by Cuevas *et al.* (2011).

The aim of the present work is to study the transient behavior of a radiator inside a wind tunnel, when subjected to a sudden increase in the heat supplied to the circulating water.

2. EXPERIMENTAL PROCEDURE

The radiator used in the tests is a typical model used in the automotive industry. It is made of aluminum with fins. It has 35 tubes with external area of 0.229 m^2 and 36 rows of fins. Its main dimensions are presented in Fig. 1.

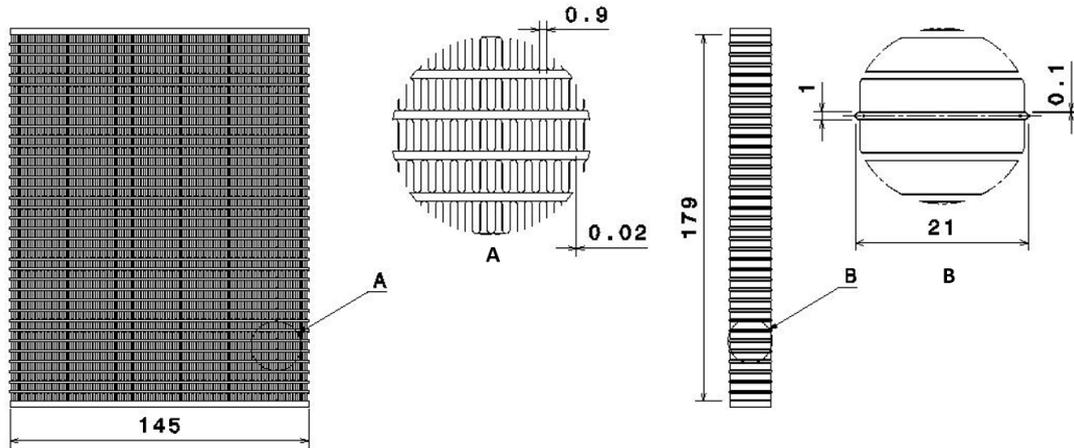


Figure 1. Details of the studied heat exchanger.

The radiator was placed inside a wind tunnel, ensuring that all the air passes through it. Figure 2 shows the experimental apparatus. The test section was made of acrylic to allow visualization, with holes for the insertion of the measuring instruments. The wind tunnel was manufactured at the institution. Without the radiator, it allows controlled air velocities of up to 34 m/s.

Water flows through a submerged pump inside a small water tank to a water heater, and then to the radiator. After leaving the radiator the water returns to the tank. The volume of water in the whole system (tank, radiator and pipes) was 3.5 L, and the flow was set to $(4.751 \pm 0.008) \times 10^{-2} \text{ kg} \cdot \text{s}^{-1}$, measured by the time to fill a certain volume.

The power of the water heater was obtained by measuring the current and voltage with a multimeter (Minipa ET-3702A, True RMS, $\pm 2\%$ accuracy).

The air flow was measured with a hot-wire anemometer (TESTO 405-V1, accuracy of 0.1 m/s + 5% of the measured value) at several points before the radiator. For the tests an air flow of $0.181 \pm 0.010 \text{ kg} \cdot \text{s}^{-1}$ was selected.

Type T thermocouples (diameter 0.0762 mm, limit of error 0.7°C , verified at 20, 40, 60 and 80°C) were placed to measure the inlet and outlet of water and air of the radiator, the water inside the tank, and the radiator surface. Due to the non-uniformity of the air after passing through the radiator, a net of 15 thermocouples was used (based on the works of Wang *et al.* (2015) and Glazar *et al.* (2015)). The acquisition of the thermocouples was performed by a National Instrument CompactDAQ with 6 modules NI 9211. A thermal camera (FLIR T450sc) was also used during the tests to measure the radiator external temperature.

A test with constant flow rate of water and air was carried on applying a heating step until the steady state, and then recovery to the initial conditions with the heater off.

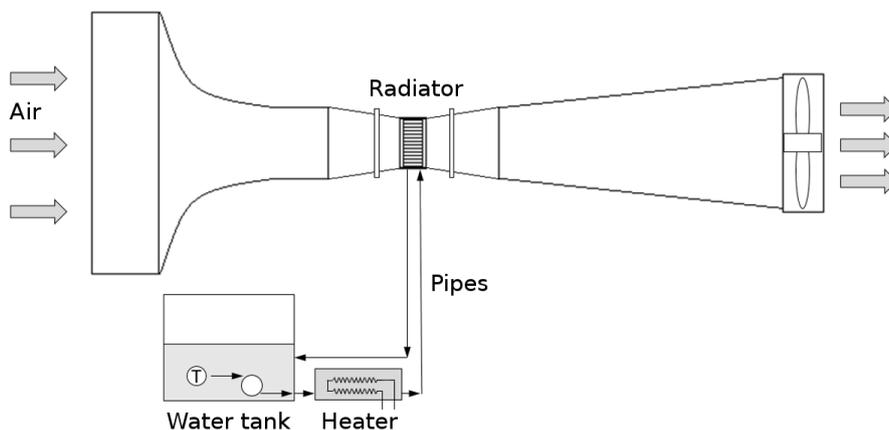


Figure 2. Experimental apparatus.

3. RESULTS AND DISCUSSION

In this test the heater was set to (2.73 ± 0.08) kW after 66s. Fig. 3 shows the behavior of the water and air temperatures in the inlet and outlet of the radiator, the heat exchanger average temperature and the water tank temperature.

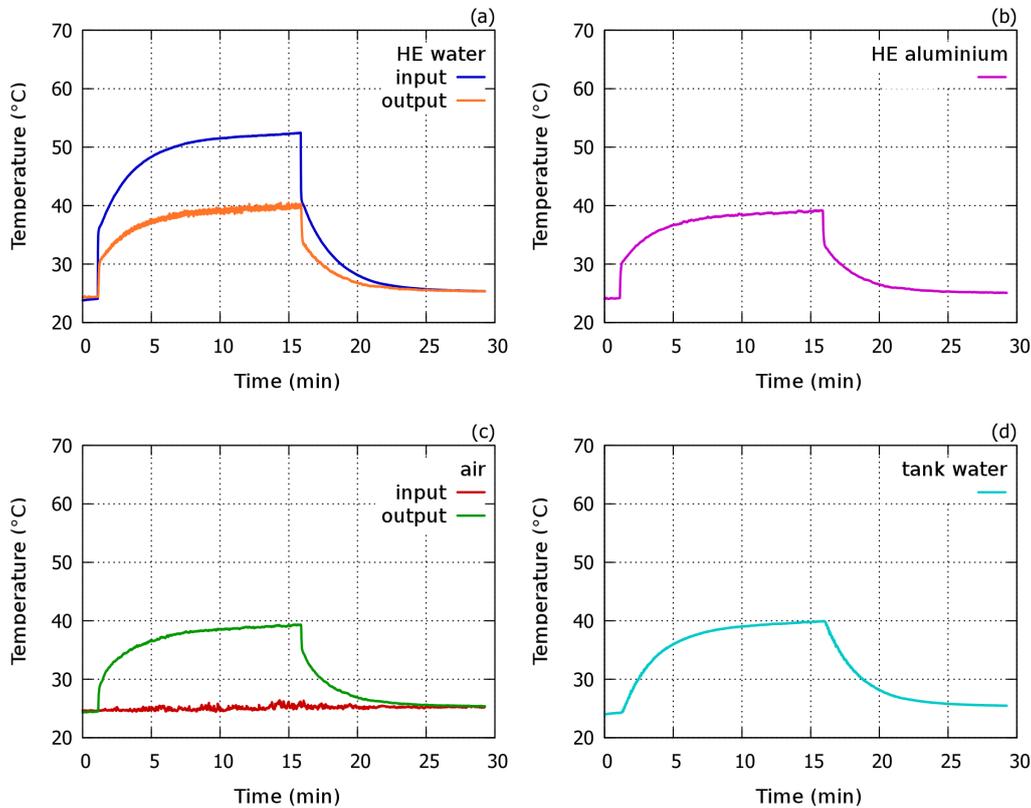


Figure 3. Water (a), aluminium (b), air (c) and tank (d) temperatures during the test.

It may be noted that the water temperature at the radiator inlet had a fast increase of 11°C in the first 7s seconds, and then they increased slowly until the steady state with 52.4°C . After turning off the heater, the temperature dropped fast reaching 40.4°C in 4s, and then continued to drop moderately to ambient temperature. The water temperature at the radiator outlet had a similar behavior, but with a delay of about 2 s due to the passage across the radiator, reaching 40.3°C in the steady state.

The fast temperature increase happens because of the fast dynamic of the radiator heat transfer, and the slow temperature increase happens because at this moment all the water, including the part inside the tank, is getting warmer. A similar behavior is found when the heater is turned off. Another observation is that the temperatures of the outlet water and the outlet air are almost the same, due to the high efficiency of the radiator.

Figure 4 shows the temperature distribution of the radiator during the test. It is clear the temperature difference from the right, where the hot water enters the radiator, to the left, where the water leaves the radiator. Also, it may be noted that the radiator reaches the steady state nearly to 15 min, corresponding to the values of the graphics on Fig. 3.

4. CONCLUSIONS

The experimental results showed that the radiator has a fast response when the water temperature is increased. If the heater remains on, the whole system starts getting warmer. The temperature of the water and the air leaving the radiator are very similar. The difference in the temperature distribution of the radiator is observed from the water inlet side to the outlet side.

5. ACKNOWLEDGEMENTS

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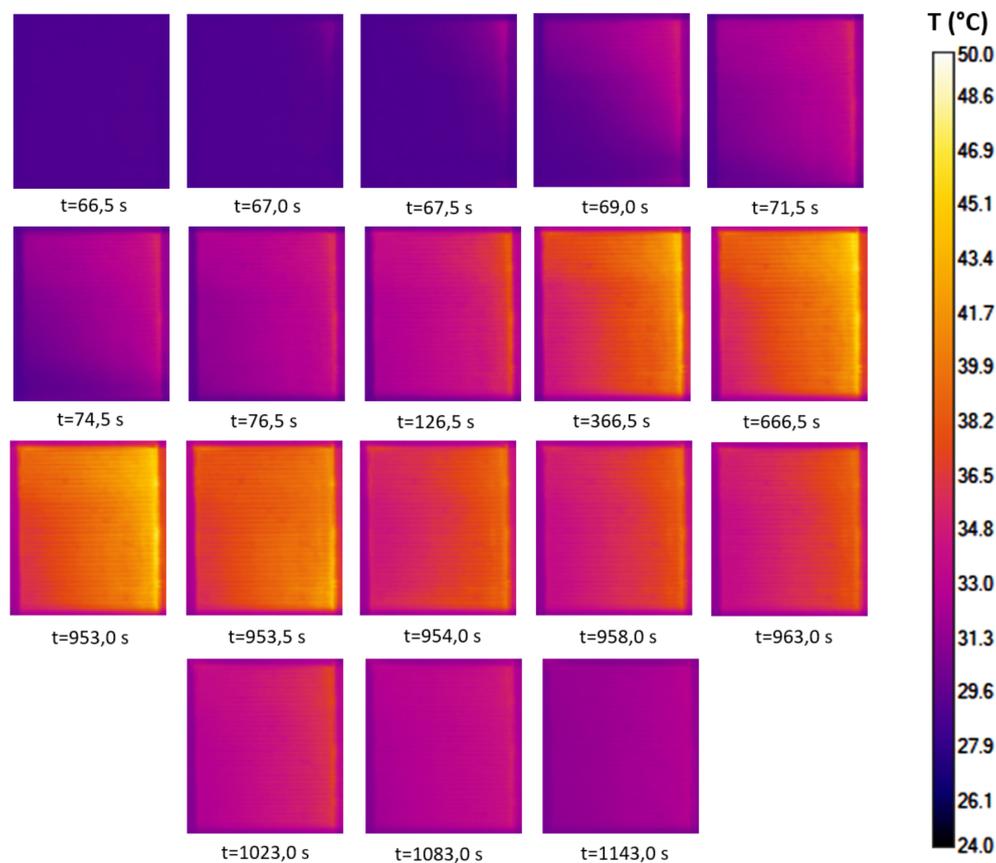


Figure 4. Radiator temperature distribution during the test.

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