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# ANALYSIS OF RADIATORS IN VEHICLES COOLING SYSTEM OF SAE FORMULA

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***Abstract.*** *In order to ensure the safety of the pilots and oblige team members to develop different designs every year, the use of pure distilled water as a coolant, rather than a mixture of water, is mandatory in the cooling system of a SAE vehicle. with ethylene glycol as it is used in commercial vehicles, this change in the fluid circulating inside the engine for its cooling makes it impossible to use much of the data of the engine manufacturers for the selection of a competitive cooling system for the engine, so in that work we monitor important parameters of a cooling system used in a vehicle SAE formula with a CB600F 4-cylinder engine, DOHC command, used by the team Racing Phoenix SAE with the use of water as cooling fluid. The tests were done with the car stopped, due to the impossibility of collecting the data with the car in motion. First the cooling system of the year 2015 was set up and 3 internal thermocouples and an anemometer were placed in the system in order to collect the data, the thermocouples were placed in the entrance and the exit of water of the radiator and the exit of air, and the anemometer was placed in the air outlet, the motor was turned on for 2 minutes at each rotation, starting at 1000 rpm up to 11000 rpm, varying the engine speed in four more intermediate rotations. The data were all collected using the equations described in the methodology it becomes possible to evaluate how much the cooling system is able to extract heat from the engine in each rotation range, reaching the maximum extraction of power of 75 kW, in addition to global transfer coefficient of heat equal to 0.3 kW/m²K and water flows 1.2 kg/s for higher engine speeds.*

***Keywords:*** *Cooling system, radiator, heat exchanger.*

## 1. INTRODUCTION

It is known that; due to the maximum thermodynamic efficiency of a thermal machine, which is explained by the second law of thermodynamics and equated by the yield of a Carnot cycle; more than a third of the energy produced by the internal combustion engine is transferred to the cooling system and sent to the environment by the radiator. According to the US National Renewable Energy Agency - NREL, one liter of gasoline produces about 1.6 kWh in its combustion, the amount needed to evaporate 400 liters of water. In this way, the cooling system must be able to remove this amount of heat from the engine efficiently without overheating the cooling liquid, so as not to compromise the systems present in the vehicle (QUIM, 2007).

If the engine cooling system is not able to extract the extra heat provided by the performance limitation of the system, there will be a decrease in combustion efficiency, as well as an increase in the working temperature, shortening the engine life. To avoid this, the electronic power stations, responsible for supplying fuel to the combustion chamber of the most modern cars, cut off the engine turning it off when the engine temperature is exceeded. According to Choi (2006) a w ell-done cooling system can also contribute to better engine economy.

The engine's temperature increasing is bad for its operation, but an engine that is operated at very low temperatures also presents a problem, such as increased fuel consumption and pollutant emissions in the atmosphere. In order to avoid this problem, the actual vehicles, besides presenting a water pump to the flow of fluid in the cooling system, also present a thermostatic valve, which regulates the amount of cooling fluid destined for the radiator.

A thermostatic valve is regulated by the temperature of the fluid present in the engine ducts. If the fluid in the engine has low temperature, this valve allows a minimum or no flow of fluid to the radiator, reducing the heat dissipation of the engine, and when this temperature is high, this valve allows a maximum or near passage of fluid to the radiator, so there is a gradual aperture or obstruction of the fluid passage.

For this reason, an overheating analysis of the system becomes more important, which can lead to the engine turning off, than an analysis of the supercooling that, due to this valve, is a rare occurrence. As a matter of regulation, the cooling fluid used in the engine is pure distilled water, different from commercial vehicles, which forces us to make a different design from that manufactured by the commercial assemblers; since we have the limitations that the use of additive would allow us work around. This change in the fluid circulating inside the engine for cooling makes it unfeasible to use much of the engine manufacturer's data to select a competitive cooling system.

Therefore, knowing how much heat the cooling system be able to remove from the motor, heat for each rotation is an important parameter, both for a present quantitative analysis and a future optimization analysis.

Studies involving water circulating inside radiators as a cooling fluid are rare, being work using a solution water-ethylene glycol, such as Cuevas et al (2011), more common. Some works involve study of nanofluids as cooling fluid, Leong et al (2010). Bibliographical research to obtention of parameters for selecting a radiator for a Formula SAE car is scarce.

Thus, in this work, we propose a simple experiment that with data extraction of easy acquisition allows us to quantify this power capacity withdrawn from a cooling system of a SAE Formula vehicle (used by the Fenix Racing team, which uses the CB600 4-cylinder engine) varying the rotation of the engine.

## 2. METHODOLOGY

The water flow $(\dot{m}_q)$˙ in the cooling system is provided by a rotary pump present in the system, which is rotated by an axis coupled to the crankshaft of the engine. Taking into account that during the tests there is no change in the aspects of the hoses or the water path along the cooling system for each radiator, we can consider that the water flow $(\dot{m}_q)$˙ is a function of the radiator type being analyzed, since each radiator presents a different pressure drop, of the rotation of the motor, since for each rotation of the motor we have a different rotation of pump, and of the degree of closure of the thermostatic valve, since the thermostatic valve regulates the flow of water that is destined for the radiator.

The airflow $(\dot{m}_f)$ for a stopped car is supplied only by the fan behind the radiator. This fan has a fan-like function, rotating and pulling the air axially against its propellers, causing the mass of air to pass through the radiator. The power directed to the fan is supplied by the vehicle battery and has a constant value. Therefore, the airflow $(\dot{m}_f)$ is dependent only on the radiator that will be used.

This airflow rate can be found by obtaining the mean air velocity after the fan output, shown in Figure 1, and the mass rate can be calculated as:

$$\dot{m}_f = \rho_{air} \bar{V} A_{flow} \tag{1}$$

where $\bar{V}$ is the average air velocity, $\rho_{air}$ is the air density and $A_{flow}$ is the airflow area of the fan.

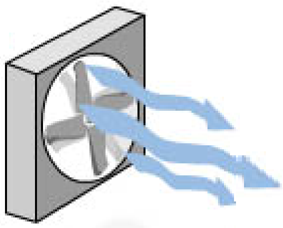

Figure 1 - Layout of the air flow in the fan. (Shopping dos Filtros, 2017).

Radiators are, according to Pabón, (2014), compact heat exchangers, combining a high heat exchange area with a small volume. Basically, they are constituted of special finned ducts with water circulating inside them and air passing around them. Thus, the equation heat rate exchanged between the two fluid is of the form:

$$\dot{Q}_{radiator} = U A_t \Delta T_m \tag{2}$$

where $U$ is the overall heat transfer coefficient of the heat exchanger, $A_t$ is the total heat exchange area composed by the unfinned surface area of ducts plus the surface area of the fins and $\Delta T_m$ is a mean temperature difference. A typical arrange of finned ducts of a radiator is shown in Figure 2.

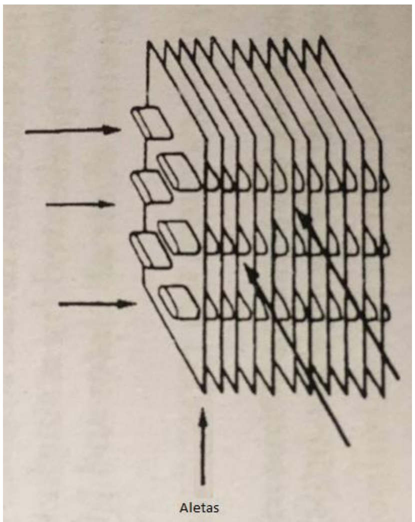


Figure 2 - Radiator heat exchange region (Kays and London, (1984)).

$\Delta T_m$, the mean temperature difference between the hot fluid and the cold fluid, can be found from the equation:

$$\Delta T_m = (\Delta T_1 - \Delta T_2) / ln(\Delta T_1 / \Delta T_2) \tag{3}$$

where:

$$\Delta T_1 = T_{h,out} - T_{c,in} \tag{4}$$

$$\Delta T_2 = T_{h,in} - T_{c,out} \tag{5}$$

$T_{h,in}$ , $T_{h,out}$ , $T_{c,in}$ and $T_{c,out}$ are respectively the inlet and outlet temperatures of the hot fluid (h) and the cold fluid (c).

The heat of the radiator $\dot{Q}_{radiator}$ can also be found through the energy balance for the hot and cold fluids, as follow:

$$\dot{Q}_{radiator} = \dot{m}_h c_{p,h} (T_{h,in} - T_{h,out}) \tag{6}$$

$$\dot{Q}_{radiator} = \dot{m}_c c_{p,c} (T_{c,out} - T_{c,in}) \tag{7}$$

The hot fluid in the case is distilled water and the cold fluid is air. $\dot{m}_h$ and $\dot{m}_c = \dot{m}_f$ are the mass flow rates of the hot and cold fluids respectively. $c_{p,h}$ and $c_{p,c}$ are the specific heat at constant pressure for the hot and cold fluids respectively. A schematic circulation of water in the radiator is shown in Figure 3.

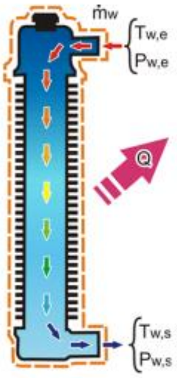


Figure 3 - Schematic of the heat loss from water (Pabón, (2014)).

Combining the Eqs. (6) and (7) the mass flow rate for water can be obtained as:

$$\dot{m}_h = \dot{m}_c c_{p,c}\left(T_{c,out} - T_{c,in}\right) / \, c_{p,h}\left(T_{h,in} - T_{h,out}\right) \quad (8)$$

Substituting the Eq. (6) in Eq (2), the overall coefficient of heat transfer can be obtained as:

$$U = \dot{m}_h c_{p,h}\left(T_{h,in} - T_{h,out}\right) / \, A_t \Delta T_m \quad (9)$$

## 3. EXPERIMENTAL PROCEDURE

The radiator used in the cooling system used by the Fênix Racing team is a radiator used commercially in the Volkswagen Gol car, shown in Fig 4 along with its dimensions shown in Tab 1.

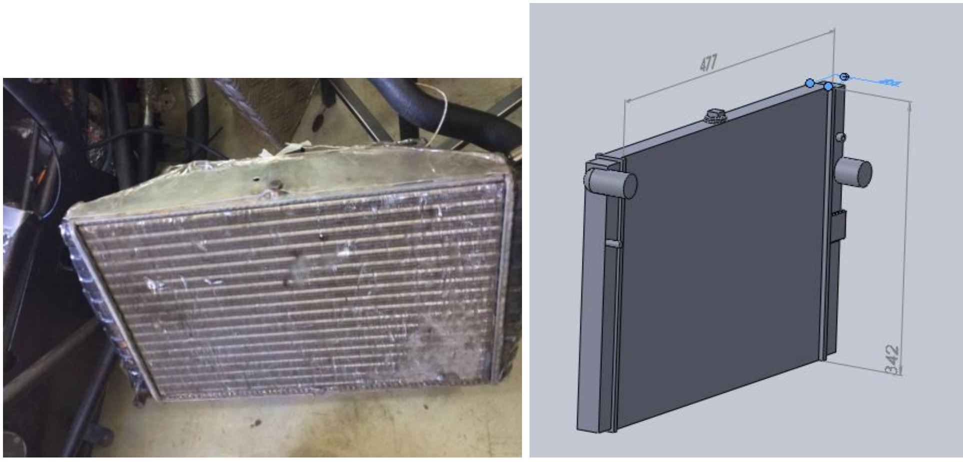


Figure 4 - Radiator used in cooling system in the year 2015.

The technical data of this radiator are shown in Table 1:

Table 1 - Geometric data of the radiator.

| | |
|---|---|
| Frontal radiator area | 477mm X 342 mm (163134 mm²) |
| Thickness of fins | 26 mm |
| Heat transfer area | 6,038 m² |

To obtain data such as inlet and outlet air temperature of the air were used two thermocouples: one thermocouple to measure the laboratory room temperature on the day of the test and another to pick up the radiator air outlet temperature, as schematized in Fig 5.

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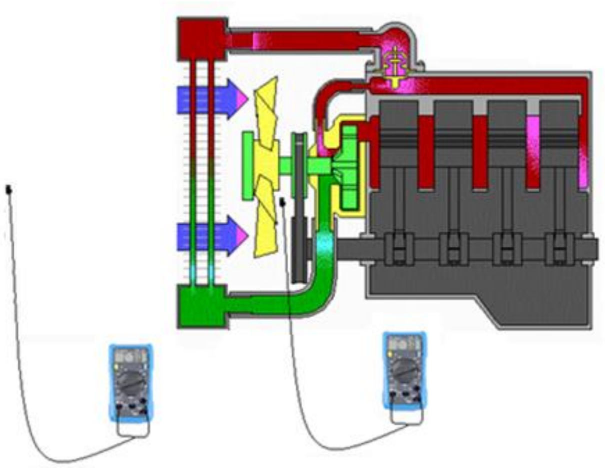

Figure 5 - Layout of thermocouples positioning (R19Club, 2017).

The thermocouples used were of type T, previously calibrated, with uncertainty of 1°C.

With the car stationary and the cooling system mounted with the thermocouples positioned internally, the engine was turned on and set at a speed of 1500 rpm (rotation was controlled by the air intake butterfly and checked in the electronic control unit). This engine rotation was maintained for 2 minutes and the temperatures on the thermocouples were checked and recorded over those 2 minutes every 10 seconds. The same procedure was repeated for a further 7 rotations (2500, 6000, 7000, 8000, 9000, 10000, and 11000 rpm).

In order to obtain data for the flow of air passing through the radiators, after the end of the tests performed with the engine running, an anemometer was placed in the air outlet of the radiator, with motor at low speed and with the fan in operation. The anemometer used had a diameter of 103 mm and had an accuracy of 0.1 m/s.

As the fan used had a constant rotation for the same electric voltage of the electrical motor. The fan was moved by the battery of 12 V and constant electrical current. In this way, the airflow rate was the same for all motor rotations. The air flow area was based on the design data of the fan.

## 4. RESULTS AND DISCUSSIONS

For the FORMULA SAE competition, each year the design of the radiator is changed. The results here presented are for the radiator the year 2015. With the radiator connected to the car and the thermocouples placed internally to the system, the temperatures of the water $T_{h,in}$ , $T_{h,out}$ and the outlet temperature of the air, $T_{c,out}$ , were measured, during 2 minutes with 10 seconds between two measures, for eight rotations: 1500, 2500, 6000, 7000, 8000, 9000, 10000 and 11000 RPM. These temperatures measured over period of time are presented graphically in Figures 6, 7 and 8.

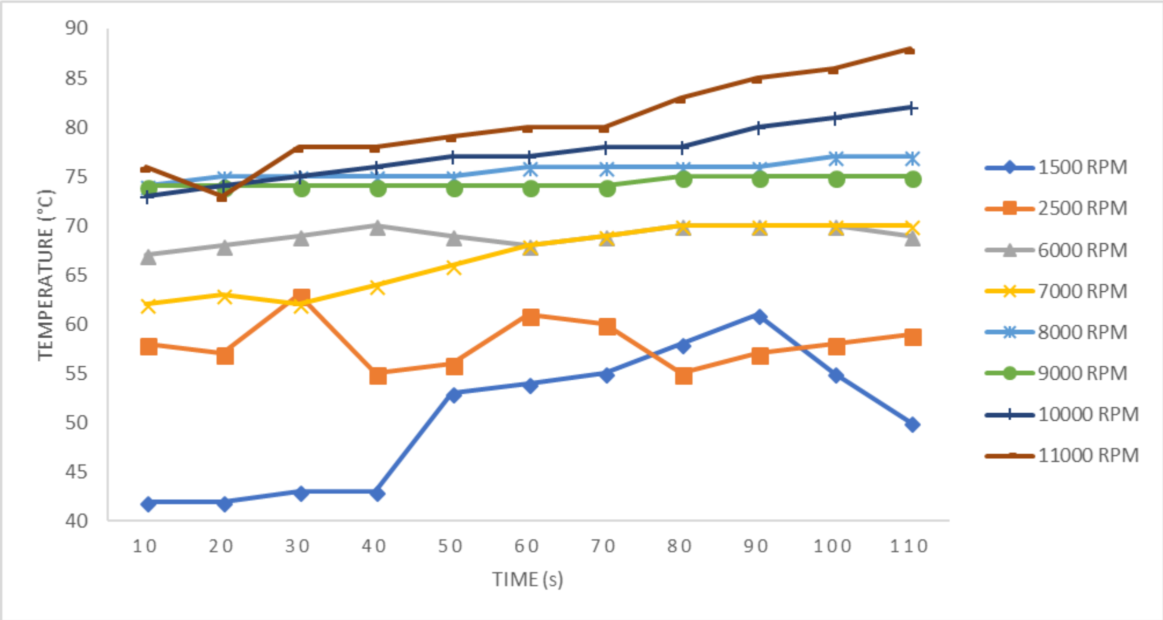


Figure 6 - Water outlet temperature of the radiator.

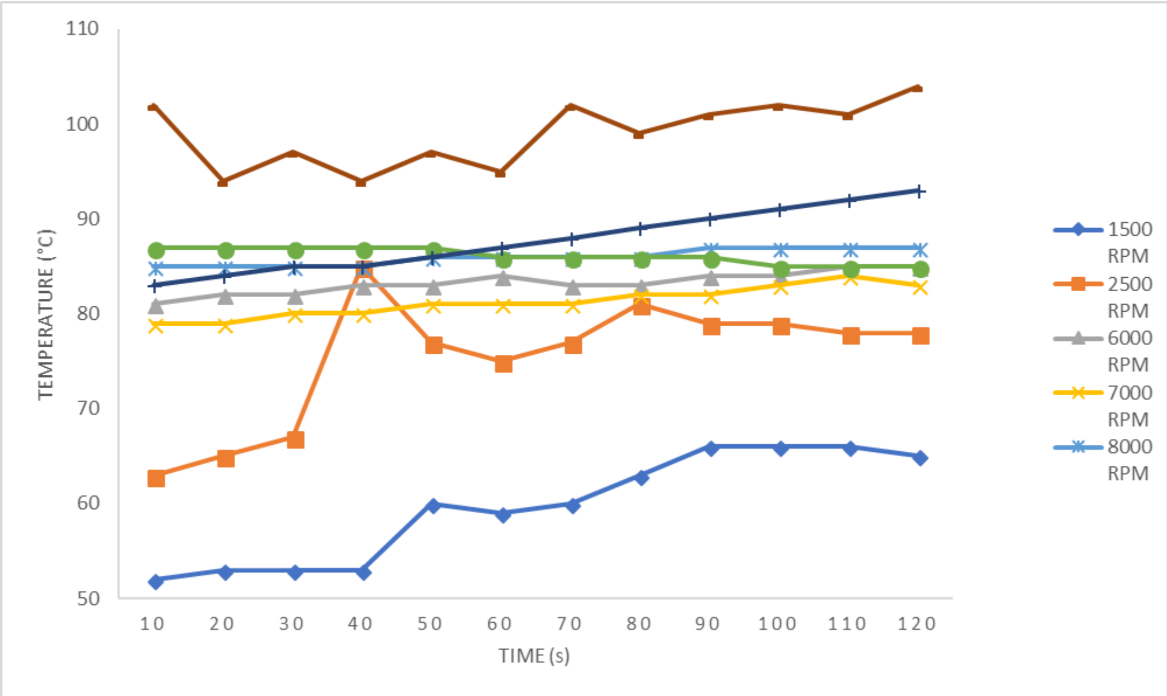


Figure 7 - Inlet air temperature of the radiator.

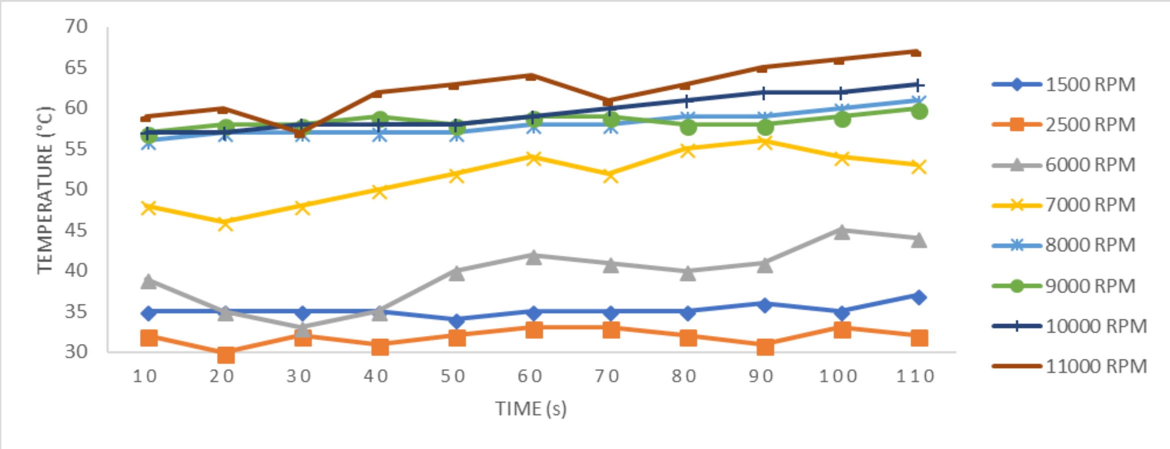


Figure 8: Outlet air temperature of the radiator.

By analyzing the Figures 6, 7 and 8, it is evident that none of the system temperatures are constant, they variate along the time. An average value of the outlet temperatures seems to be increased as the engine speed increases. The fluctuations of the 3 measured temperatures shown in Figures are more pronounced for low engine rotations, periods when the heat supplied by the engine is small, so there is a greater influence of the thermostatic valve in the system, increasing and decreasing the heat withdrawn by the radiator during these 2 minutes, such effect being visible at the measured temperatures.

After the fluid inlet and outlet temperature data be recorded for all rotations, an anemometer was placed in the radiator air outlet to achieve the flow of air, $\dot{m}_f$, through the heat exchanger. Dimensional values of the radiator and fan were also checked for the same purpose, which are necessary for calculations to be made later. The results obtained by the anemometer and the checked design data are presented in Tab 2, together with the air flow calculated by Equation (1).

Table 2 - Airflow and dimensional radiator data.

| | |
|---|---|
| Air outlet speed | 10,3 m/s |
| Fan Area | 0,0408 m² |
| Air Density | 1,225 g/cm³ |
| Cp of air ($C_{pf}$) | 1,014 kJ/kg.K |
| Calculated air mass flow ($\dot{m}_f$) | 1,92 kg/s |
| Room temperature ($T_{fe}$) | 28,4 °C |

This variation of parameters with time can be explained by the opening and closure of the thermostatic valve during the 2-minute test, and this, as expected, has its action diminished at higher engine speeds when the heat exchange in the motor is larger and therefore the radiator needs maximum power (i.e. fully opened thermostatic valve) to be able to remove any extra heat from the engine.

With the data obtained in the experiment and shown in the graphs: Fig 6, Fig 7 and Fig 8 , together with the results measured and shown in Tab 2, using the Equations (7, 8 and 9) it is possible to calculate data for the radiator of 2015 such as: the water flow rate $\dot{m}_h$, the global coefficient of heat transfer $U$ and the heat extracted from the engine by the radiator $\dot{Q}_{radiator}$ for each rotation in which the test was performed and for each time that the temperature data were measured. The calculated results are present in the Figures 9, 10 and 11.

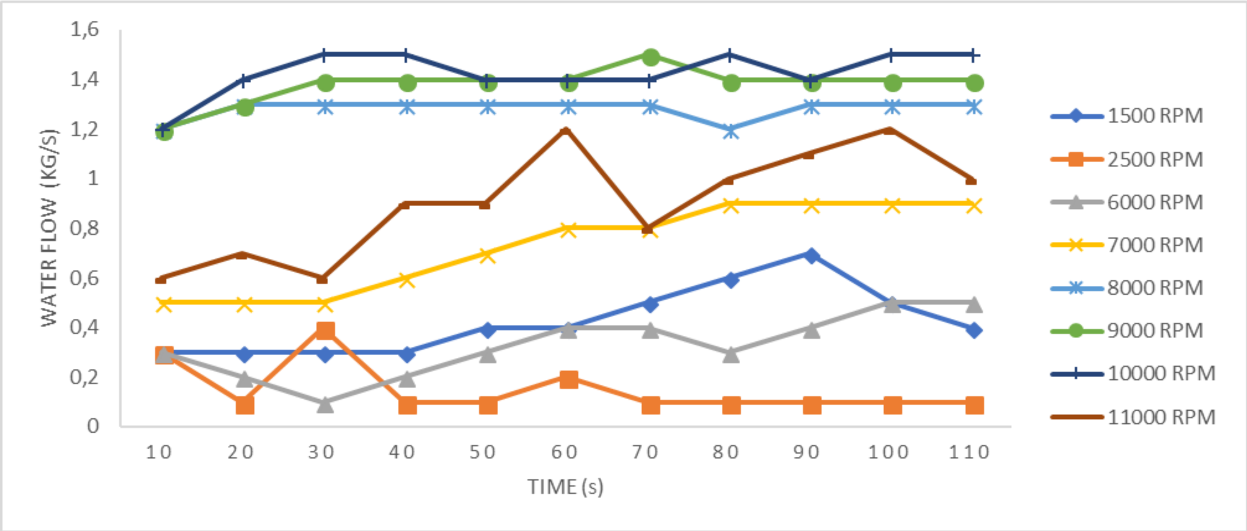


Figure 9 - Water mass flow rate of the radiator.

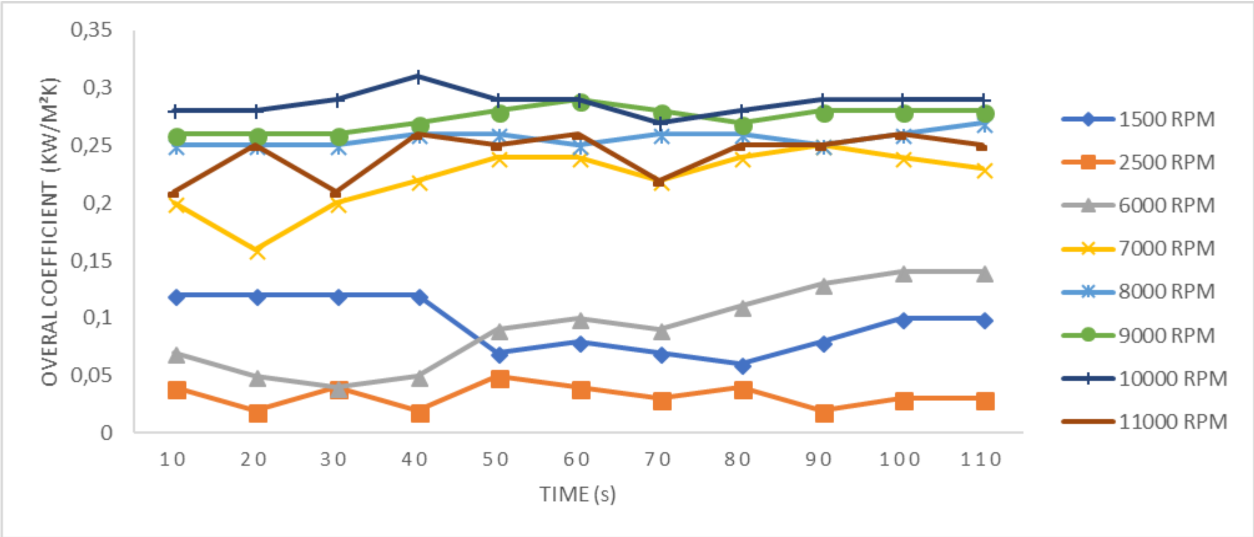


Figure 10 - Overall heat transfer coefficient *U*.

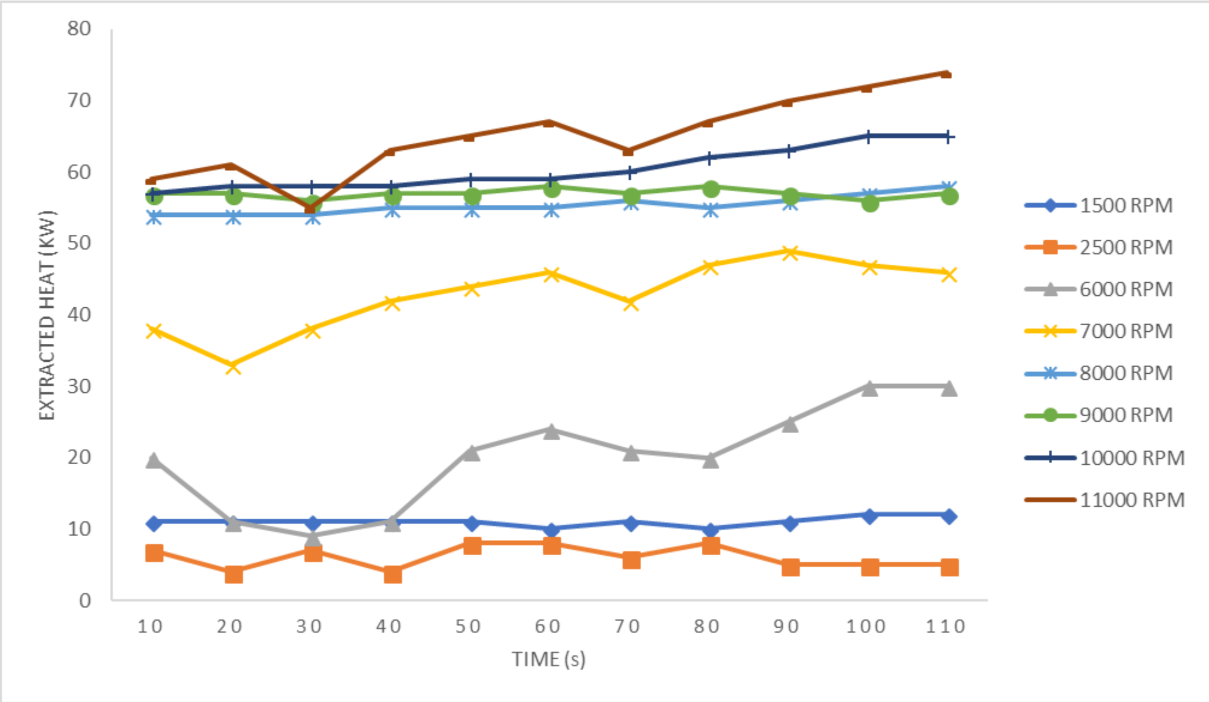


Figure 11- Heat extracted from the engine by the radiator.

In Figure 9 it is more evident the change in the water flow rate in the radiator for rotations bellow 8000 RPM. The other parameters influencing this flow variation, also, show oscillations over the time of test with the same engine speed. Like the measured temperatures, all the parameters calculated for the radiator exhibit variation along a mean, the average being increased with the engine speed.

Due to the variation of the water flow in the radiator during the test for a single rotation of the engine, it becomes complicated to analyze the parameters along the rotations, therefore the data presented in the last three graphs were separated in the moments of higher water flow (best performance moment of the heat transfer) for each motor rotation and these data were compared closely, these comparisons are presented in Figures 12, 13 and 14.

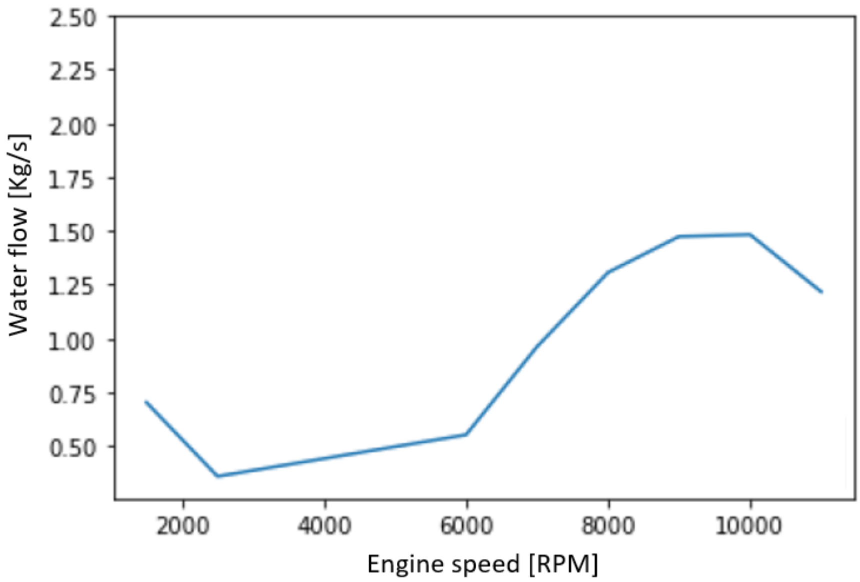


Figure 12- Radiator water flows in function of rotation.

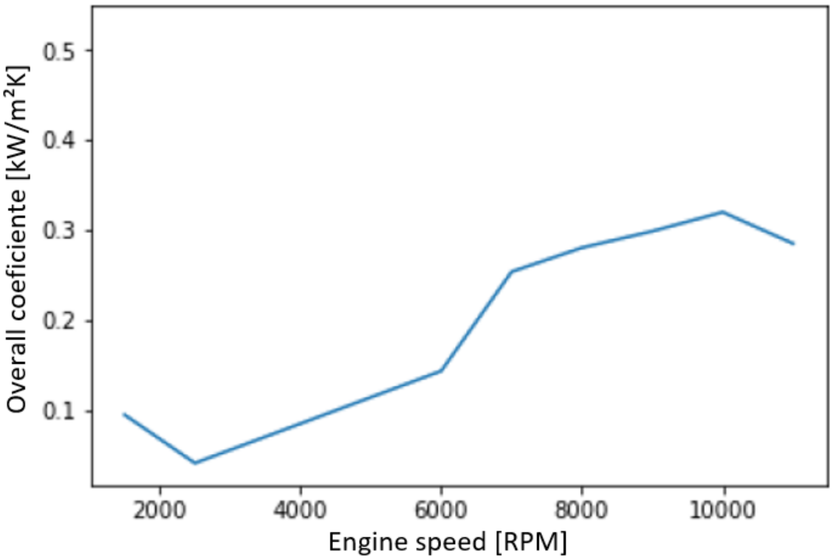


Figure 13 - Overall heat transfer coefficient in function of rotation.

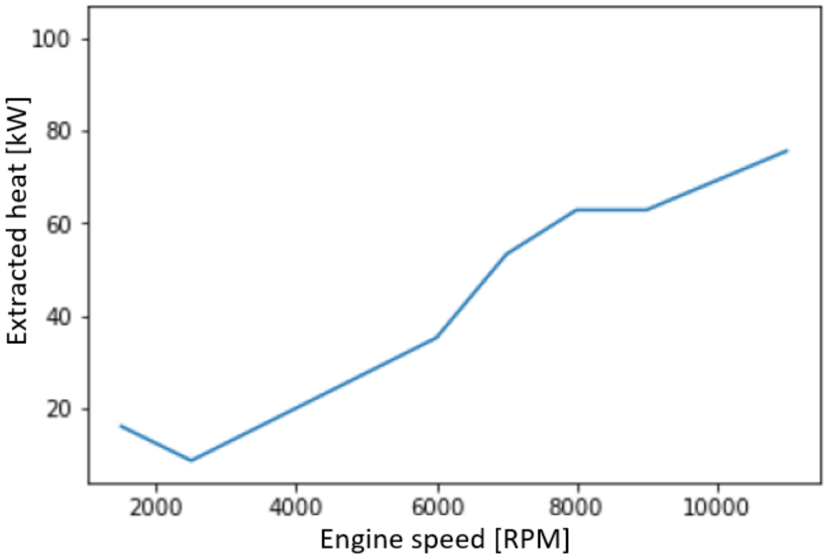


Figure 14- Heat extracted from the engine by radiator in function of rotation.

In these graphs it is easier to quantify the heat extracted by the radiator at each rotation, which increases with the rotation, except at the low rotations, where the idle control can interfere with the heat generated, having a peak value of 75 kW an 11000. RPM, the same value as the maximum engine power of the system, as expected, since the power used by the engine and the power drawn by the radiator show the same amount of energy generated by the combustion of the fuel.

A similar behavior of increasing in the intensity of the global coefficient and water flow levels, also, occurred at higher rotations, with values of order 0.3 kW/m²K and 1.2 kg/s respectively.

## 5. CONCLUSION

An experimental analysis of a radiator for a SAE vehicle has been done in this work. Some data obtained were air mass flow rate, water mass flow rate, overall heat transfer coefficient for several rotations of the engine. The results obtained are in according to the maximum power of the engine about 102 HP (75 kW). Different from the radiator of normal vehicles, where is used pure water or a solution of water and ethylene glycol for cooling of the engine, the radiator must use distilled water as cooling fluid. The tests have been done for the vehicle stopped due to the difficulties for do experiments with the car in moving.

Each year, the design of the radiator of a SAE vehicle must be changed, so, it is important to try optimizing the dimensions of the radiator as part of the project of the whole vehicle to get the best performance. This kind of design also serves to expose the students to real situations which an engineer will encounter in their jobs. A good design of a radiator impacts directly the performance of the engine, so, it is important an optimized project of the cooling system for the vehicle.

The data obtained in these tests alone says very little about the cooling system, but they are very important for comparisons of systems to be designed in future competitions.

In future works, it is necessary to obtain more data of this cooling system for better mapping of the system, besides the data withdrawal of another cooling system coupled to the same car, in order to make comparative between them.

The experimental data obtained also serve for comparison with data from theoretical or numerical results for design of more efficient cooling systems to vehicles.

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