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NUMERICAL SIMULATION OF THE ATB TEST

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Abstract. *The main purpose of the cooling system in internal combustion engines is to prevent overloading of the thermal engine by, maintaining the temperature under ideal conditions of operation. Our investigation was performed an experimental and numerical study of the Air to Boil (ATB) test. The numerical simulation of the behavior of the cooling system was performed by using commercial software (FlowmasterV7. The model was developed using the methodology of block diagram, based on the thermo-fluid-dynamics equations that govern the engine components. The one-dimensional model used is capable of analyzing several steady and unsteady behaviors typical of the cooling systems and thermal fluid dynamic of liquids pipelines. The validation of the mathematical model was performed comparing the experimental and numerical results. The temperature at the entrance of the radiator and the ATB test results were evaluated. The maximum difference between the numerical and experimental results was 8.2%. The behavior of the cooling system was evaluated by varying the selected radiator.*

Keywords: *cooling system, mathematical model, ATB*

1. INTRODUCTION

The engineering of internal combustion engines, developed in the end of the 19th century, has evolved greatly, creating more complex machines with modules to manage electronic systems that control most parts of the engine, including the cooling system, the main theme of this paper. The cooling system has the main task to prevent thermal overload engine, keeping the engine temperature under ideal conditions of work, maximizing fuel economy and trying to reduce the emission of pollutants to the air.

Previously, the focus of the cooling system was to maintain the engine temperature close to the ambient temperature, because it was believed that raising the temperature was not good to the engine operation. The process of controlling the temperature was denominated "cooling system" because its role was simply to lower the engine temperature. The technological developments have led the engine to run better, maintaining the temperature higher and uniform, in order to keep the material dilatation under control. The cooling system evolved from the basic purpose of lowering the engine temperature to increase the engine temperature as fast as possible, reaching the ideal operating temperature, maintaining it and distributing it throughout the engine.

In the design of a vehicle, several tests are performed in the cooling system to ensure that it works properly in all operation conditions. A test of fundamental importance is the test of Air to Boil (ATB), which represents the ability of the coolant to form bubbles. The maximum temperature supported by the system components until the coolant boils is determined through tests carried out in a climatic chamber with roller dynamometer.

In this work, the results of an ATB test will be predicted using the one-dimensional software Flowmaster V7. It was developed a mathematical model using a block diagram, based on the governing equations that describe the behavior of the engine components. This model was developed to a specific vehicle. It was necessary to define the dynamic behavior of each of its components, in order to establish the appropriate boundary conditions.

The validation of the mathematical model was performed through the comparison of the numerical results with experimental data. The use of the Flowmaster V7 software enables the assessment of the cooling system behavior under several operation conditions, like several radiators and fans, thereby avoiding repeated experimental and thus considerably reducing the costs of a project.

2. LITERATURE REVIEW

The air injected into the engine is mixed with the fuel injected and burns in the engine cylinders. Part of the energy of combustion produces power for the engine and the rest of this is transferred to the environment, the engine block, oil and coolant (Kwang, 2001). The cooling system helps to maintain the temperature of an engine under appropriate limits. It is composed of a water pump, engine, radiator, fan, expansion tank, thermostatic valve, coolant and hoses as shown in Fig. 1.

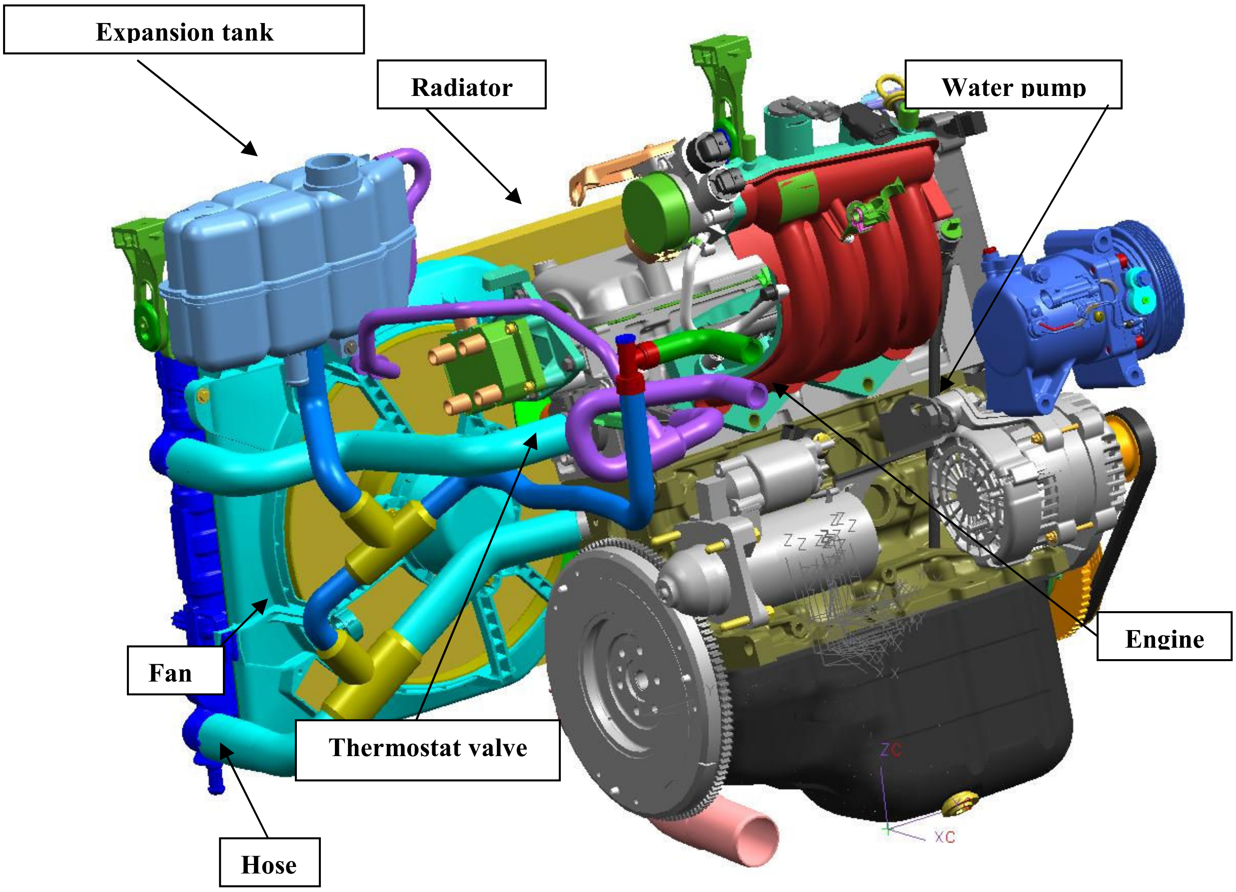

Figure 1. Cooling system.

Robinson et al. (1999) studied the cooling system in the engine. Several studies were performed in order to optimize the design of the internal passages of the coolant in the engine. The accuracy of refrigeration was defined as the least amount of liquid needed to achieve the optimization of temperature. They showed that the reduction of the coolant passages to smaller spaces close to the valves reduced the heat rejection by 18%. It also reduced the required power of the fan and the noise from the propellers. It allowed a considerable reduction on the warm up time of the vehicle, reducing the power of the water pump and lowering the heat stresses, thus reduction the cost of the components materials and the amount of coolant required in the engine.

Srun (1999) and Silva et al. (2008) developed simulations of the cooling system using simple models. Srun (1999) used a wind tunnel to determine the efficiency of the radiator. The velocity of the airflow through the radiator in the vehicle and the flow of the water pump were measured. With these values a simple simulation of the engine cooling system of was made allowing a study of the influence of each component and parameters of the vehicle on the performance of the cooling system. The results obtained in the wind tunnel were compared with the numerical results obtained by simulation. Expect for the fan, small errors were observed between the numerical and the experimental results.

In general, the control of the engine components is mechanical, because it is cheap and simple in design. However, this control is not able to achieve a deep optimization required for a drastic reduction of fuel consumption. In the cooling system, the evolution began with electronic actuators from fan. Perst and Jouannet (1999) developed a new type of variable fan called FANTRONIC™. The modeling fan was accomplished with the FLOWMASTER™. A generic approach allowed to modify any component of the system and to know precisely the consequences of such changes. Fig. 2 shows the system modeled by VALEO for the development of the proposed cooling system. P represents pressure in the system and DL represents a pressure drop between two sections of the pipe cooling system. Fig. 3 shows the comparison between the temperatures measured on the vehicle and the temperatures determined by the model. It can be seen that the results are very close.

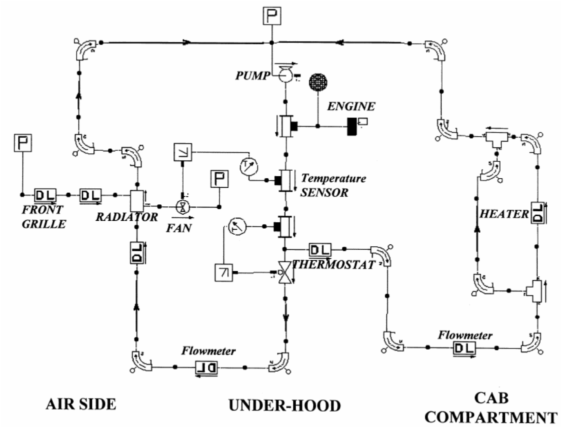

Figure 2. Network of the cooling system.
VALEO

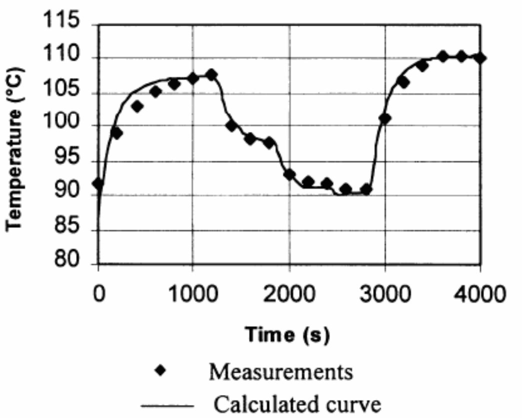

Figure 3. Comparison between calculations and measurements of the engine outlet coolant temperature.
VALEO

3. NUMERICAL METHODOLOGY

A one-dimensional model of the coolant in the engine was developed to estimate the airflow by the radiator. The model was developed using the software Flowmaster™ V7. This software is an advanced one-dimensional tool to model virtual systems. It allows the determination of the effects of the flow of fluids, predicting the internal flow and thermal effects through the use of mathematical and empirical relationships of pressure, flow and temperature. The characteristics of some components of the system were given by the components suppliers.

Fig. 4 presents the blocks diagram of the test ATB, modeled with Flowmaster V7 It can be seen that the software interface is user friendly. The main components are represented by the following numbers: 1 - water pump, 2 - engine, 3 – thermostatic valve, 4 - entry of air in front of the vehicle, 5 - radiator, 6 - fan, 7 – expansion tank.

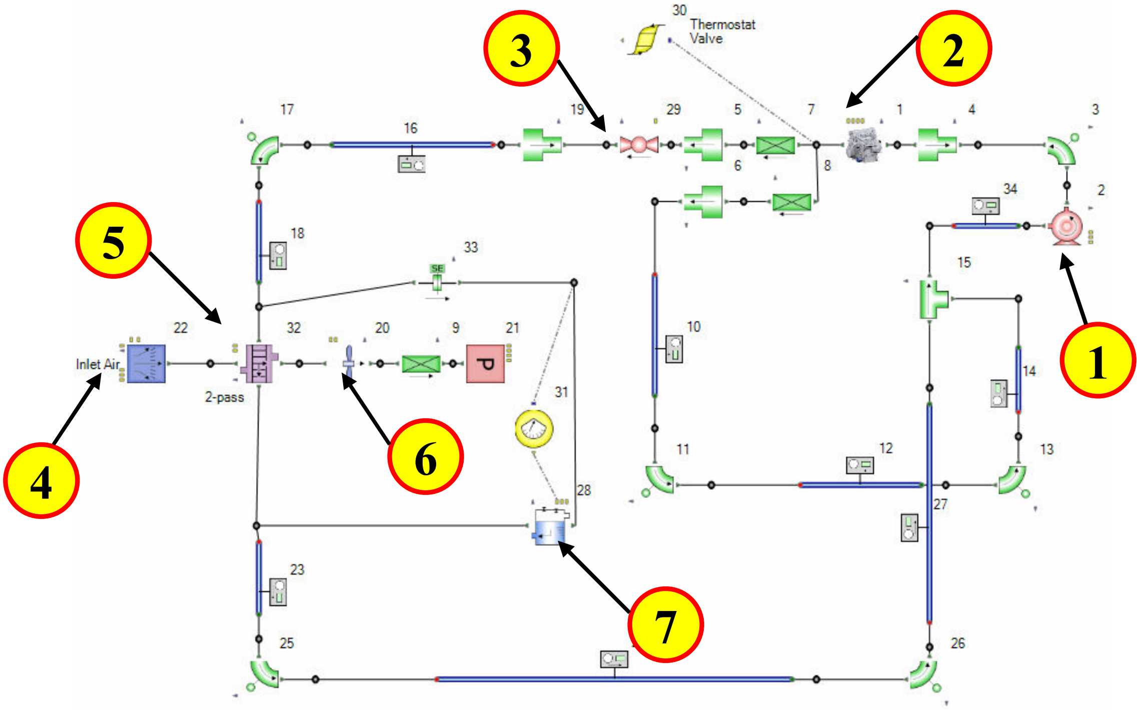

Figure 4. Network of the cooling system in Flowmaster V7 by Fiat.

Fig. 5 represents the curves of the pressure drop in the radiator versus the volume flow, on the water side (a) and on the air side (b), used to model the radiator. These curves were obtained based on the information supplied by the radiator manufacturer.

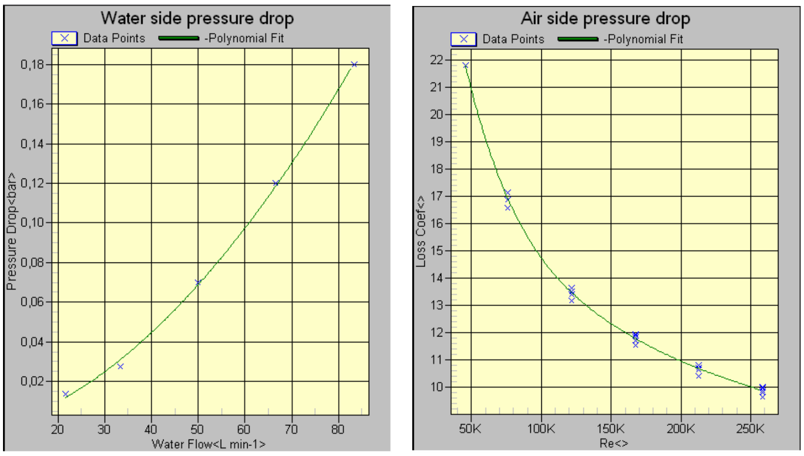

Figure 5. Pressure drop in the radiator: water side (a) and air side (b).

Fig. 6 shows the thermostatic valve opening curve, used to model this component. It was also supplied by the manufacturer.

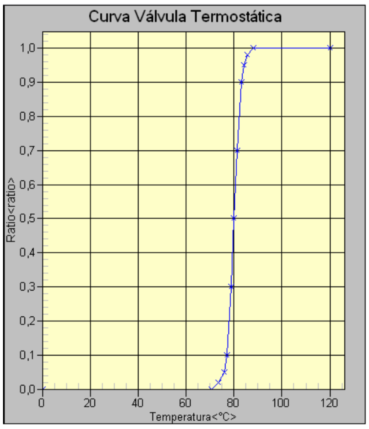

Figure 6. Thermostatic valve curve opening.

Fig. 7 (a) presents the pressure coefficient of the fan as a function of the flow coefficient. Fig. 7 (b) shows the radiator thermal performance.

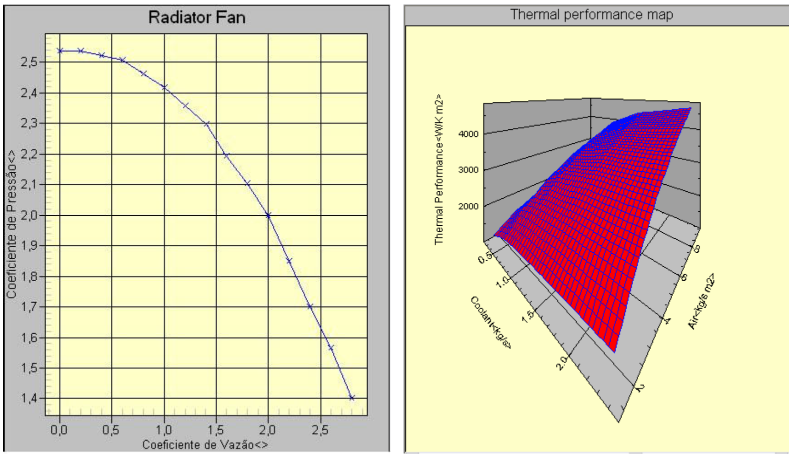

Figure 7. Fan coefficient pressure curve (a) and radiator thermal performance (b).

4. EXPERIMENTAL METHODOLOGY

To validate the numerical model, experiments were performed in a climate chamber with roller dynamometer (Figure 8). Environmental conditions such as temperature, solar radiation and humidity were controlled inside the chamber. The tested vehicle was a Fiat, 4 cylinders, 1000 Flex engine with 8 valves.

Figure 8. Climate chamber with roller dynamometer.

The main goal of the ATB test is to evaluate the maximum efficiency of the system. It is important, therefore, to define the vehicle characteristics such as motorization, weight, maximum load, and the place where this vehicle will be sold (due to the climate and altitude parameters). The ATB index represents the maximum temperature that the cooling system supports before the coolant begins to boil. If the temperature exceeds this limit, the cooling system should be better dimensioned or the maximum load of the vehicle should be reduced.

The instrumentation used on the experimental tests was composed of a transducer pressure of 1.5 bar with analogic output installed on the expansion tank (accuracy of 1%) and eight type K thermocouples. The main points of instrumentation with thermocouples are: inlet and outlet of the radiator, output head cylinder; inlet and outlet of the air filter and engine oil. Fig 9 presents the instrumented vehicle.

Figure 9. Instrumented vehicle to ATB test.

The ATB index is defined by:

$$\mathrm{ATB} = \mathrm{T_v} - \mathrm{T_u} + \mathrm{T_a} \tag{1}$$

Where Tv represents the boiling temperature of the coolant, Tu represents the temperature of the coolant in the radiator and Ta is the ambient temperature.

5. RESULTS

This work presents the ATB test results obtained through the software Flowmaster V7 and the comparison with experimental data obtained in a climate chamber. In order to run the numerical model, it was necessary to insert some input data, to develop the lay-out of the vehicle's cooling system proposed and to define the test parameters, like temperature, relative humidity, solar radiation, rotation of the engine, fan and water pump, rejection and heat engine for a given condition of proof. These data were obtained from tests performed at Fiat and with suppliers of components.

The ATB test is normalized by Fiat. The test must be performed under specific conditions. The velocities of the vehicle in the conditions are shown in Figure 10 (a). In the first condition, the vehicle has a velocity of 29 km/h; in the second condition, at 40 km/h; in the third condition, at 140 km/h. In the fourth condition, called idle, the vehicle is kept in rotation of idling. Figure 10 (b) shows the rejection of the heat engine to each situation, obtained from Fiat Auto SpA (Italy).

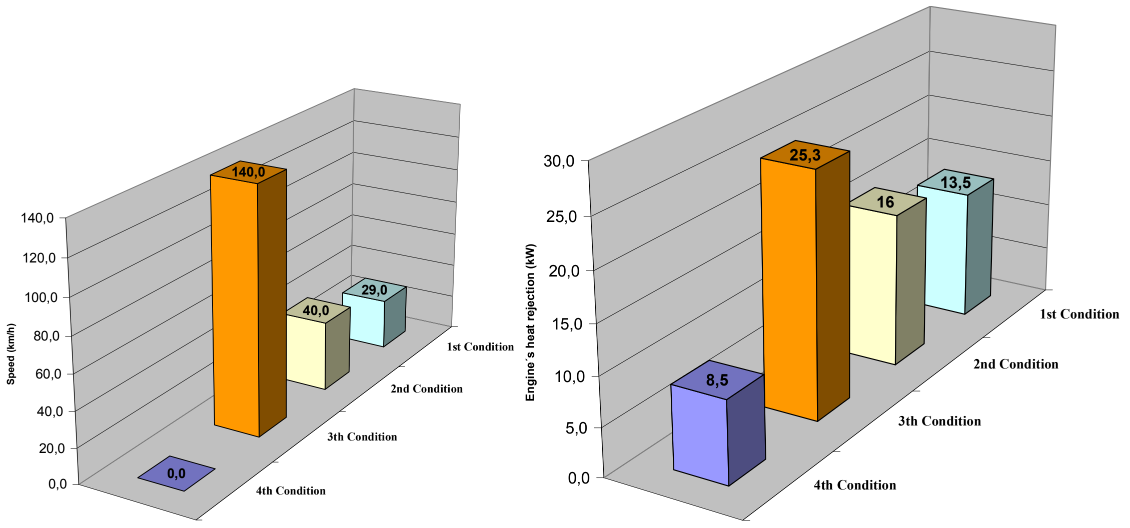

Figure 10. Speed X Test conditions (a) and heat rejection X Test condition (b).

The main result of the ATB test is the inlet temperature of the radiator, since the ATB index is obtained from this temperature. A proposed cooling system can be approved or not depending on this result. Fig 11 (a) presents the inlet temperature of the radiator temperature, numerically and experimentally obtained. Fig 11 (b) presents the experimental and numerical ATB indexes.

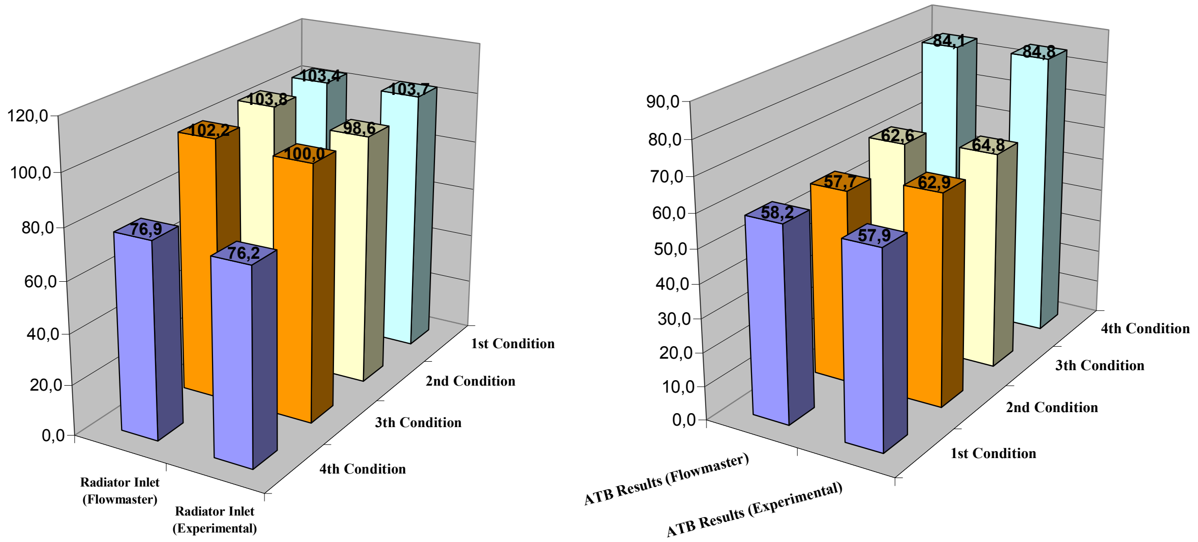

Figure 11. Radiator Inlet temperature (a) and ATB index (b).

It can be seen that the numerical and experimental results were close. In the first condition, the error between the results for the radiator inlet temperature was lower than 0.5%, and in the second condition, the error was 8.2%. Although the error was relatively high for the second condition, the analysis is still valid, because it indicates the possibility of use of a particular component in the vehicle.

For the ATB index, the maximum error was of 3.3%, in the third condition. The differences between the numerical and experimental can be explained by the uncertainty of the measurement instruments, by the variations of the climatic chamber conditions and by the input data (mainly the rejection of the heat engine).

The developed model was used to predict the performance of the cooling system with a different radiator and a different fan. The parameters of these components were obtained with the suppliers. Table 1 shows the radiator inlet temperature for these components, as a function of the test condition. The numerical results previously presented are referred as Flowmaster™ Vehicle. The numerical results for the new radiator proposed are referred as 2nd Radiator, for the new fan, 2nd Fan. The results obtained changing both the radiator and the fan are referred as Radiator and Fan together. Finally, the experimental results (previously presented) are referred as Experimental Vehicle. It can be seen change of the radiator reduced the inlet radiator temperature, indicating that this radiator is more efficient than the Flowmaster™ vehicle. The decrease of the inlet temperature was lower than 12%. The change of the fan reduced the temperature in (18% at maximum). The simultaneous replacement of the radiator and fan decreased the temperature in up to 28%. The results of the simulations indicate if the components can be used in a vehicle, without the need of experimental tests, reducing the design costs. It can be noticed, however, that the ATB test result cannot be solely used to define the components of the cooling system. Replacing both the radiator and the fan, it can be seen that the reduction of the temperature was very high. If these components were replaced, the engine would work in a temperature lower than the ideal, causing the engine to operate with higher fuel consumption and pollutants emission.

Table 1 - Inlet radiator temperatures after changing components

Inlet radiator temperature (°C)	Flowmaster™ Vehicle	2nd Radiator	2nd Fan	Radiator and Fan together	Experimental Vehicle
1st Condition	103,4	90,8	87,7	74,7	103,7
2nd Condition	103,8	93,3	93,0	79,4	98,6
3th Condition	102,2	92,1	83,1	78,7	100,0
4th Condition	76,9	73,0	71,0	62,2	76,2

6. CONCLUSIONS

A methodology was developed to predict the boiling temperature of the coolant of a vehicle allowing the determination of the ATB index. The numerical model was validated through the comparison with experimental data obtained in a climate chamber. The maximum error obtained was of 8.2%, which was acceptable. The model developed can be used in the design of cooling systems, helping the understanding of the effects of heat rejection of the engine, thermal efficiency of the radiator and fan performance in the cooling system of the vehicle.

A complete determination of the cooling system may also include air conditioning system in vehicles. Different designs can be simulated by changing the performance data in the component models and running additional simulation scenarios.It is important to mention, however, that the simulation helps the design of the cooling system, reducing costs and time, but does not eliminate experimental tests, which have crucial to the knowledge of the actual conditions of the vehicles on the streets.

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