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COMPUTATIONAL SIMULATION OF AN INTERNAL COMBUSTION ENGINE BASED ON OTTO CYCLE TO IDENTIFY THERMAL LOSSES

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Abstract. *The thermal efficiency of Internal Combustion Engines – ICE - is associated with the burning of fuels in combustion chamber, where occurs the transformation of Chemical Energy in Mechanical. In this process, part of energy is dissipated as heat, which is not totally used, affecting machine efficiency. This article has the main goal analyze the thermal behavior of a single-cylinder internal combustion engine, model BRIGGS & STRATTON INTAKE 10, used to equip the Baja vehicle of Centro Universitário Newton Paiva. The analysis were made through Computational Fluid Dynamics – CFD – and simulations using a mathematical model based on Classic Equations from Heat Transfer. Two models were utilised to analyze the thermal losses in the cylinder and its fins. The obtained results through both simulations were compared between them and they show a misuse of order of 8.7% to temperatures calculated on superficial cylinder and 9.2% in tips of the fins. The distribution of temperature in the cylinder surface according to simulation, using CFD, showed points with temperature more elevated, that appointed regions where must not receive overweight once it will lead to cracks in cylinder surface.*

Keywords: *Computational simulation, Internal combustion engines, Computational fluid dynamic, Thermal losses, Heat Transfer.*

1. INTRODUCTION

Internal Combustion Engine (machine capable of produce heat internally through chemical transformation, fuel burning) is one of the most responsible for humanity development. Humankind has obtained huge gains in social and economics fields since Industrial Revolution, and its engines, developed. Registers show that in Century XVII, Leonardo da Vinci[1] idealized the first engine hypothesis, which it proposes to elevate a block using a flame in the bottle of recipient. After that, it is possible to find out a register of a hypothesis that accompanied fire arms development, Christian Huygens (1673), proposed utilize gunpowder explosion to move a piston in vertical way inside a cylinder. (MARTINS, 2011).

In Century XIX, there had been enough progress in ICE fields thanks to many inventors; one of them was Nikolas A. Otto (1832 – 1891), who developed a four strokes engine that induced combustion occurs after a spark triggered to a mixture air/fuel. Rudolf Diesel (1858 – 1913) developed a four-stroke engine where a spontaneous combustion occurs after the compression of the mixture air/fuel. Those two models are the most utilized by industry nowadays (PULKRABEK, 2004).

For decades, humankind has been developing engine improvements to achieve energy efficiency gains by better exploitation of the energy dissipated in combustion, reducing engine weight / power ratio, better fuel consumption and consequently a better performance (PULKRABEK, 2004). According to this author, due to the interest and performance of several researchers, many patents evolve and become consolidated projects, thus there are several types of engines. These engines can be classified in number of valves, basic drawing, number of cylinder, process of air admission, fuel, and cooling systems. However, the ICE is one of the most responsible of air pollution due to CO_2 emissions and others chemical compounds originated in fuel burning (MARTINS, 2011). Internal Combustion Engine is the most utilized motor in automobile industry; hence, it had a great evolution in sector since the beginnings of industry. Carl Benz (1844 – 1929) was responsible to the first vehicle equipped with an ICE. Its prototype had a single-cylinder internal combustion engine two strokes cycle. According to HEYWOOD (1988), internal combustion engines, in general, operates through fossil fuels, gas and diesel are the most utilized. The cycles show determinants characteristics in performance and applicability of engines. In this article will approach only the Otto Cycle working in four strokes cycle – Intake, Compression, Expansion and Exhaust, as shown in Figure 1.

[1] Leonardo da Vinci (1452 – 1519), was a polymath born in Italy, of the most important figures of the High Renaissance, who stood out as a scientist, mathematician, engineer, inventor, anatomist, painter, sculptor, architect, botanist, poet and musician. He is also known as the precursor of aviation and ballistics

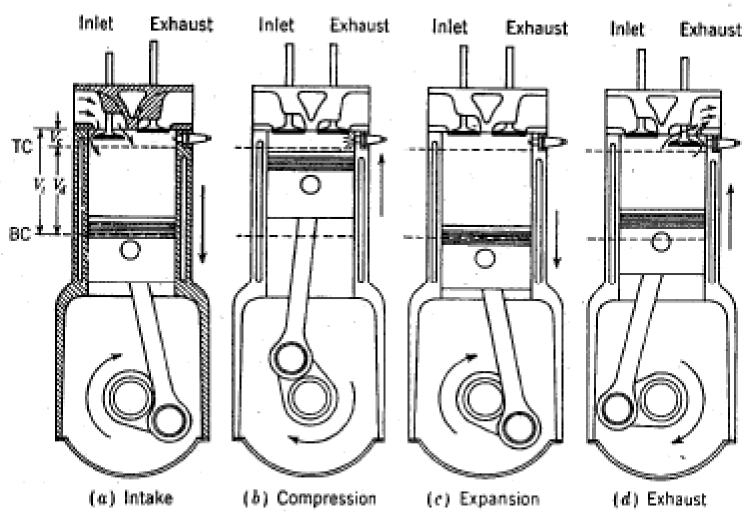

Figure 1 – *Working Cycle of a Four-Stroke Engine*.

Source: Heywood (1988).

According to MARTINS (2011), Otto Cycle of four strokes initiates with the piston in top dead center – TDC- and constant pressure close to Atmosphere pressure. Air temperature during intake course increases as the air goes through air collector. The mixture air/fuel is intake and the piston start to move towards bottom dead center – BTC – inducing half turn or a 180 º angle, at this moment, exhaust valves are closed and intake valves are open. This course is defined as Intake. Still according to MARTINS (2011), the second course is defined as Compression, the piston moves towards top dead center making a complete turn or 360 º, realizing the compression of gases inside the combustion chamber. The temperature and pressure increases brutally due to the compression and in the moment that compression starts intake valves must be closed, to preclude gases to escape from combustion chamber, making possible to compression occurs at constant volume. HEYWOOD (1988), explains that the third stroke initiates when compression finish, the piston is close to top dead center and in this moment a spark comes from spark plugs and start the fuel burning, causing an aggressive movement of the piston from top dead center to bottom dead center making another half turn, 540º. In this moment, intake and exhaust valves again are closed and this process of aggressive chemical transformation produces the driving force for the engine. To this course is given a name as Expansion or Combustion. Finally, occurs the exhaust of gases, where intake valves are closed and exhaust valves are open. The engine is at bottom dead center and move to top dead center making the second turn or 720 º taking with it the remnants of the burned mixture inside the combustion chamber, by the end of the course, occurs the initiating of a new energy transformation cycle as known as Otto Cycle (PULKRABEK, 2007). The angles reported by MARTINS (2011), in his explanation about Four Strokes Engine reflect the turns made by the crankshaft.

Over decades, Industry has been seeking for improvements in Internal Combustion Engines in order to obtain a better performance of energy dissipated in combustion, reducing of weight/power, better consumption of fuel, reducing of cost and consequently a better performance. The analysis of thermal losses in an Internal Combustion Engine – ICE- enables the possibility to obtain engines efficiency rates more elevated and general improvements in environmental and economic standards of Internal Combustion Engines (BASSI, 2012). Therefore, this article has the objective to analyze the thermal behavior of a single-cylinder internal combustion engine, model BRIGGS & STRATTON INTAKE 10, which equips the vehicle of Newton Paiva Baja`s Team. The analysis were made by fluid computational and through simulations using a model case on Heat Transfer Classic Equations. For this analytical simulation, in the engine studied was considered a presence of a finite number of annular fins with a cylinder made of aluminum. For this simulation was utilized the Software ANSYS®-Student Version.

2. THE MODEL OF ANALYTICAL SIMULATION

For the analytical modeling of the aluminum cylinder, it was considered the presence of a finite number of annular fins related to this cylinder. Making necessaries corrections in the dimension according to Fig. 2. One balance of energy was applied in the set, Cylinder - fins (Eq. 1) to the correct analysis.

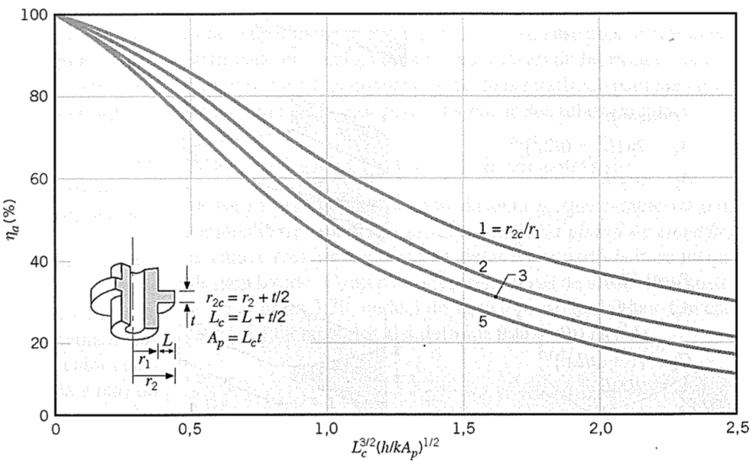

Figure 2 – Scheme for the efficiency calculus of annular fin with regular profile

Source: INCROPERA *et al.* (2011).

$$q_t = h\left[N\eta_a A_a + \left(A_t - NA_a\right)\right]\theta_b \tag{1}$$

In the Eq. 1, q_t corresponds to the heat transfer rate through the set; h refers to air convective coefficient that surrounds the set; N is the number of fins; η_a is the efficiency fin; A_a is the exchange thermal area; A_t is the exchange thermal area of entire set cylinder - fins; and θ_b is the excess of temperature in the bases calculated by Eq. 2.

$$\theta(0) = \theta_b = T_b - T_\infty \tag{2}$$

In the Eq. 2, T_b refers to bases temperature of the fin and T_∞ refers to air temperature of free airflow.

The presented equations, applicable in case of annular fins, were implemented in Software MatLab®. For a correct implementation of Conservation Laws, according to Incropera *et. al.*, (2011), were defined a proper finite control volume, a surface of control represented as lines or dashed lines; a time base proper, the relevant processes about energy identified and each process was considered in the control volume. After all considerations the conservation equation, was then written.

3. THE NUMERICAL SIMULATION MODEL

In order to compare the analytical calculus realized for the set cylinder – fins a numerical simulation was done. In this simulation, Software Ansys® – Student Version – was utilised. For this type of simulation was modeled a drawing of the set using the software Solidworks, then, the drawings were attached in the WorkBench® to mesh the domain in finite control volumes. After this step, the steady condition applicable were considerer and it started the beginning of simulation – Solver.

4. THE SINGLE-CYLINDER ANALYSED

In this article was used as subject of study the engine that equips the vehicle of Newton Paiva Baja`s team. This engine made by Briggs & Stratton model 10 has the following basic characteristics.

TABEL 1 –INTEK 10 Characteristics

Volume	305 cc
Power	10 hp at 3800 rpm
Fuel	Gas
Cooling	Air
Cycle	4 Strokes

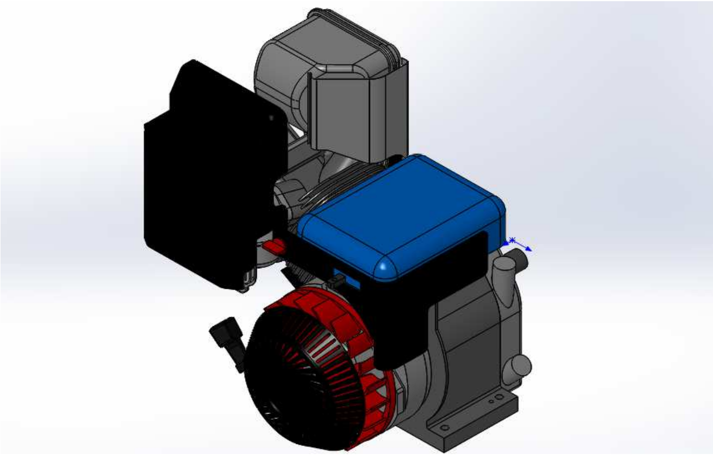

FIGURE 3 – Isometric view of a INTAKE 10 Engine using Software Solidworks®

5. RESULTS AND DISCUSSION

For this article was considered only the energy dissipated by gas combustion. According to Pulkrabek, (2004) gas has lower calorific value of 4700 kJ/kg. Thus, the energy dissipated by the combustion in the cylinder was calculated considering specific mass of gas as 0,720 kg/l, volume engine as 305 cc and compression rate as 15. With this database, the gas mass calculated was 0.022 kg and the energy produced, based on the gas LHV, was 1034 kJ. The engine is air-cooled. Thus, the convective coefficient to external air used was 50 W/m^{2}K, and environmental temperature was 27^o C (300K). The engine is made of Aluminum alloy with variable thermal conductive with temperature as shown in Fig. 4.

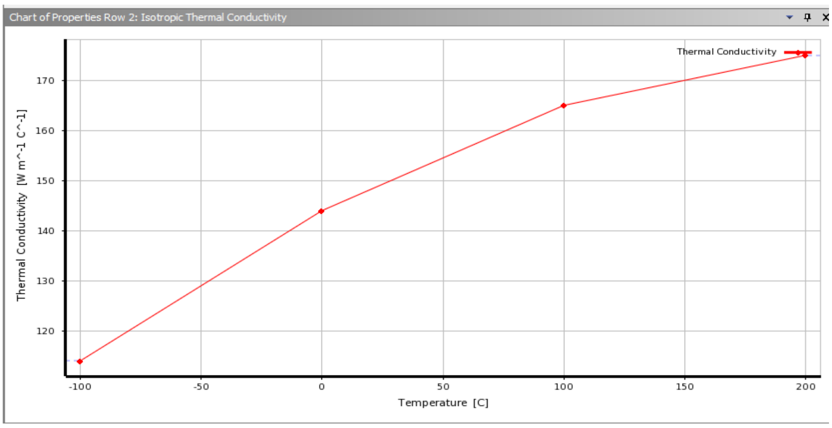

Figure 4- Graph refers to thermal conductivity of aluminium alloy

The analytical model considered, according to the methodology introduced by Incropera et al, (2011), for studying thermal losses in cylinder of the studied engine a stationary process was implemented, with one-dimensional heat transfer, constant proprieties and uniform convective coefficient in the external surface of the cylinder. After this definition of steady conditions the meshing process of the object was done. The software automatically makes this process, although it was added some refinements on the mesh to make it more refined with a small meshes in a way that results are more accurate and detailed. (Fig. 5).

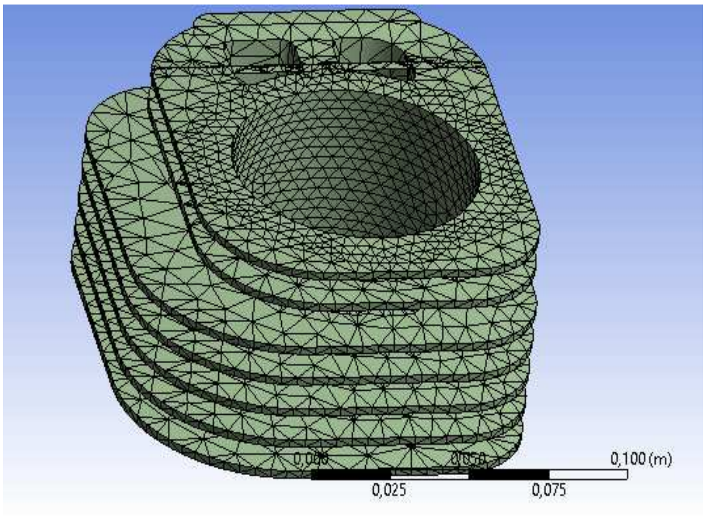

Figure 5 –Cylinder of the Engine divided into finite control volumes

Through Software Solver, program module that calculate all parameters and show the requested solutions, was possible to obtain the cylinder temperature of studied engine, flow rate and errors related to the calculus. The results of the numerical simulation are presented in Fig. 6 and 7.

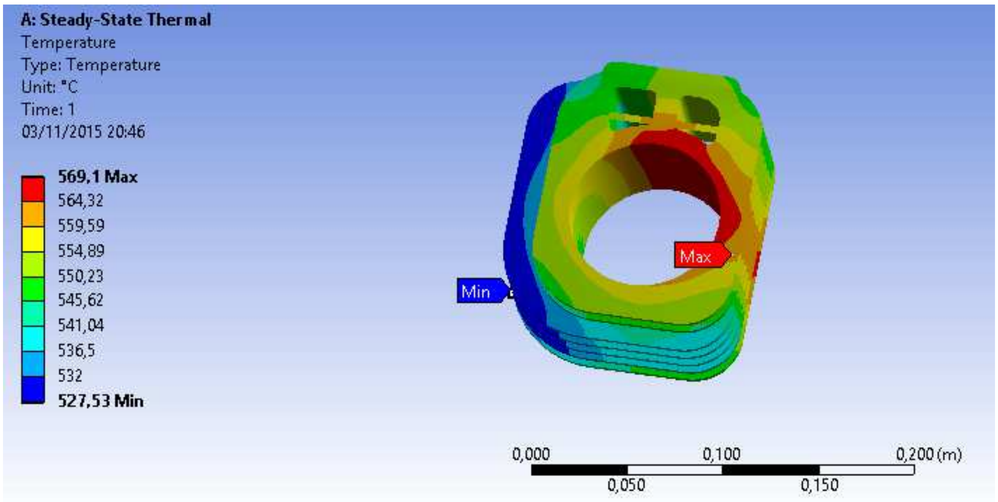

Figure 6 – Temperature distribution in ºC in cylinder of the studied engine

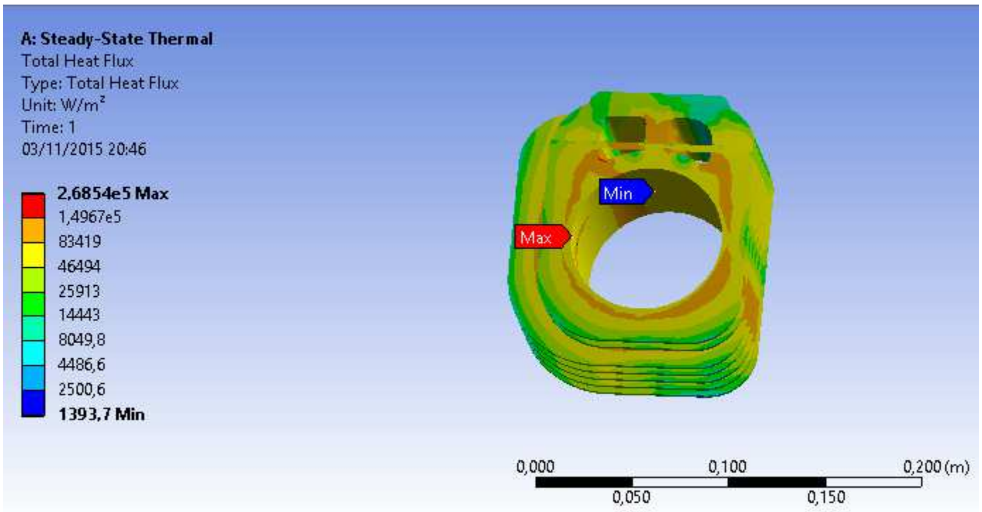

Figure 7 – Distribution of heat flow in cylinder in W/m^2.

After compilation of data made by the software, obtained the maximum temperature of 569 °C (Fig. 6 – temperature distribution). Another feature noted is that the point where the highest temperature module was obtained was around the piston skirt at the asymmetric side of the engine, which has no fins like the other. This is characterized by the fact that this asymmetric side has less material and also does not have fins which would help in the cooling process. Likewise,it is possible to see that the heat flow is symmetric over all regions of the cylinder (Fig. 7 – heat flow). However, it is noted that the value of the heat flow decreases very tenuously towards the tips of the fins.

For the analytical simulation, further the parameters already cited, others were necessary as cylinder height as 3 in; external diameter of cylinder (do not consider the fin) as 3.12 in; thickness fin as 0.1 in; number of fins as 7; length fin as 1.38 in. With all this data supplying the analytical model, the simulation was realized in Software MATLAB®. In figure 8, shown below, is the temperature variation at the base of the 7 fins associated with the cylinder. In this figure, the effectivity of the fin (comparable parameter to efficiency) was changed from 0.3 to 0.85. The results of Fig 7. – Heat flow were obtained with convective coefficient constant and equal to 50 W/(m^{2}K). By varying the value of this coefficient and of effectiveness, there is still a good agreement between the analytical and numerical analysis.

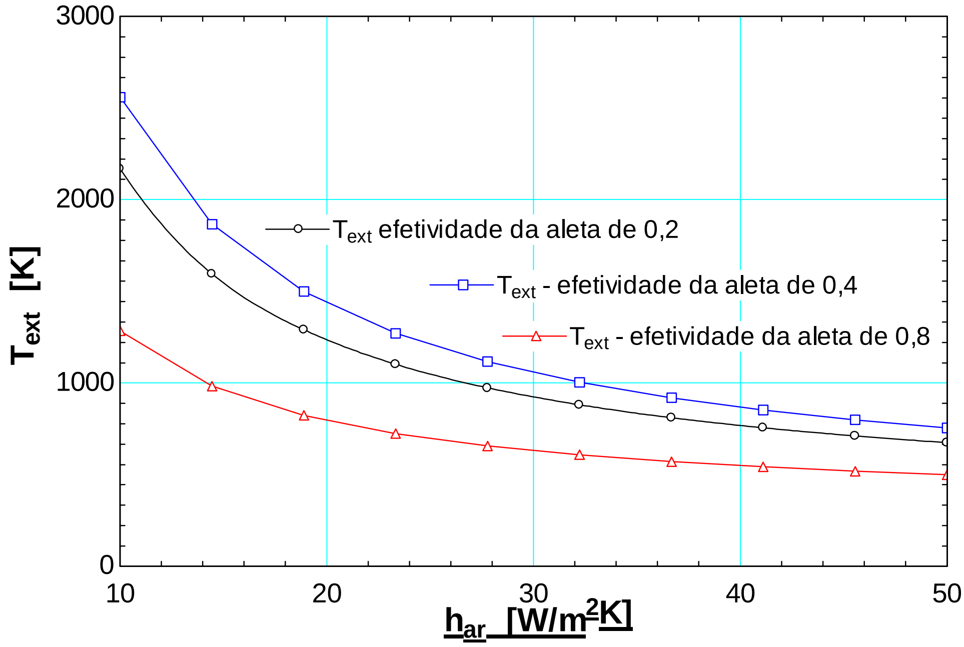

Figure 8 – Variation of temperature in the bases of fin in function of effectivity of fin and the convective coefficient

According to Fig 2 and the data utilized, the effectivity of the fin is situated between 0.6 and 0.8. For this gap, Fig. 9, related to temperature of the base fin was calculated. In these calculus was considered h = 50 W/ (m2.K) and a good correlation between Fig. 8 and 9 is observed.

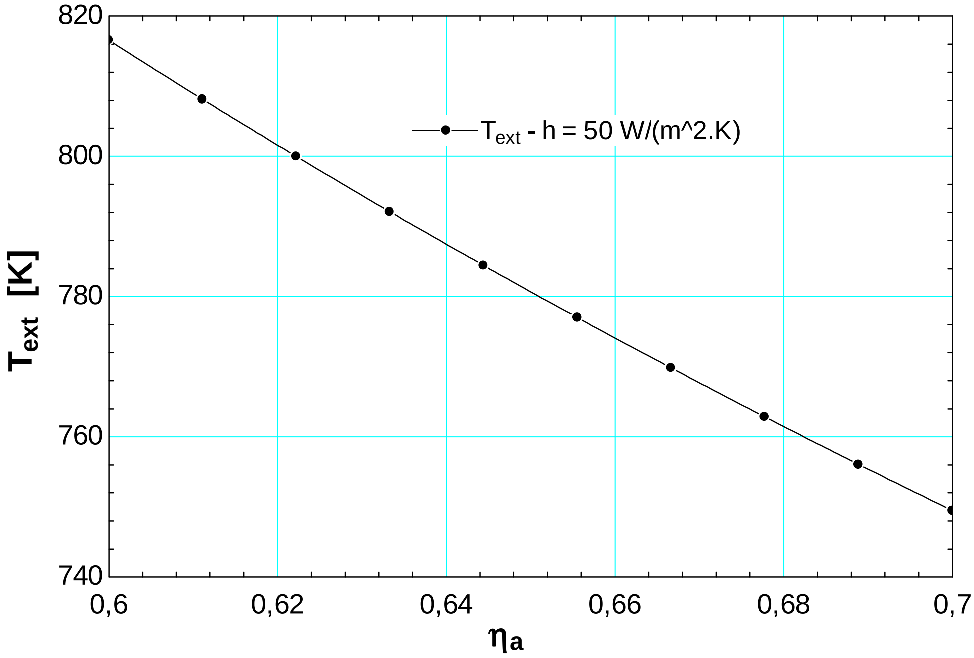

Figure 9 – Variation of temperature in the bases of fin in function of effectivity of fin in the gap between 0.6 to 0.7

Incropera *et al.* (2011) say that the number of fins increase the efficiency in the heat transfer rate of a body. Therefore was realized a simulation with improvements on the geometry of the cylinder studied in this paper. The original geometry had seven fins, where two were asymmetric. For purpose of study it was considered the originals dimensions of the engine, however, it was added two fins, becoming nine fins (Fig. 10). Thus, the new geometry was modeled on Software Solidworks. This new geometry proposes an improvement in heat transfer. This modification has the objective increase the contact area of the cylinder with environment.

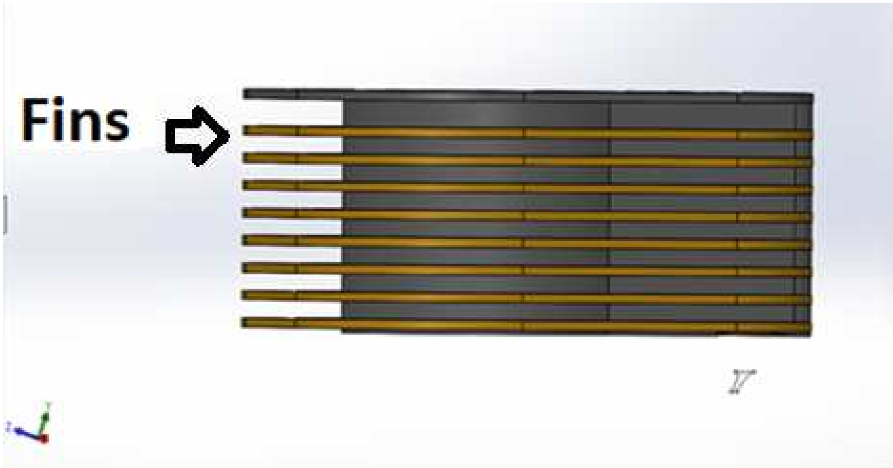

Figure 10 – Engine block with 9 fins

To analyse this proposed model of cylinder it were utilised the same steady conditions as in the previous analysis. After the data compilation by software the results are shown, (Fig. 11 e 12). The maximum temperature obtained dropped 7.5% as shown in Fig 11, settling at 529 °C. This can be considered a considerable decrease.

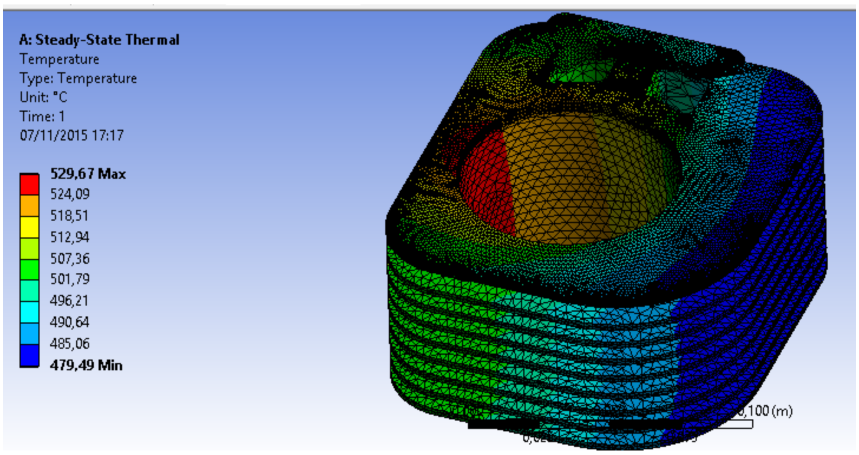

Figure 11 – Image with the new temperature distribution in cylinder

In the other hand, heat flow rate decreased 1.5%, settling at $2.46 x 10^5$ W/m^2. This percentage if compared to temperature can be considered low. However, it is not possible to affirm it, once in terms of magnitude the module of heat flow decreased almost 3.000 W/m^2.

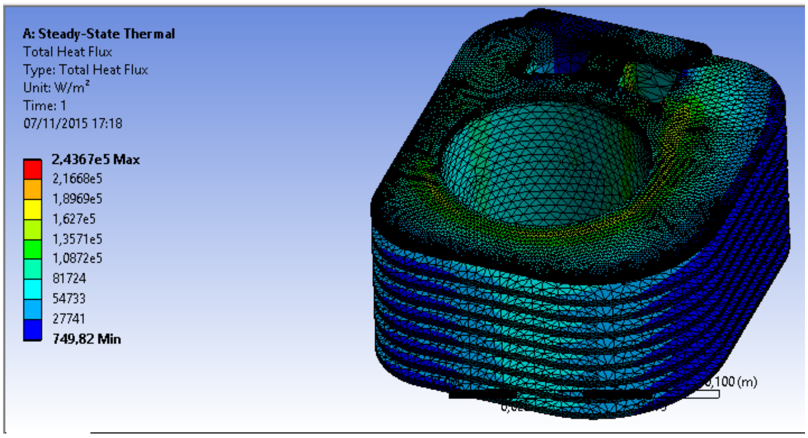

Figure 12 – Image with the new heat flow distribution in cylinder

Therefore, it has been proven through simulations performed that increasing the number of fins in a cylinder improves the capacity of heat transfer from the object. Nevertheless, it cannot affirm if this decrease of temperature would be a benefit for the engine and the vehicle, once the conditions of project are unknown.

6. CONCLUSIONS

The purpose of this paper was to analyze the heat loss that occurs during combustion of an engine BRIGGS & STRATTON INTAKE 10 through its cylinder. This engine is used in a vehicle of the Baja team of the University Center Newton Paiva. The analysis of heat loss was made through two computational simulations, analytical and numerical. For that, it was implemented a model based on Heat Transfer where it was analyzed the heat loss specifically in the cylinder of the engine. Once this heat flow hits the cylinder, it is controlled by the thermal resistance of the material, in this case aluminum alloy. One effect of heat flow passing through the material is the increasing of temperature in the cylinder. This increasing can be verified in this paper, by another computational simulation made on Ansys®. In addition, it was also possible to observe that as the temperature moves away from the heat-generating source, in this case the region of the combustion chamber, the temperature reduces gradually. This can be explained by the fact that as the heat flow goes through the cylinder the material makes opposition of that. Another characteristic was that the point that has the highest temperature was located around the piston skirt and in the asymmetric side of the engine. This is characterized by the fact of this side has less material and do not have fins which would help it in cooling process.

The results obtained by MATLAB® are not too refined as obtained by Ansys® - Student Version. However, this model offers to check the results obtained by Ansys® using Finite

Control Volume Method. Therefore, it is necessary a previous knowledge about Heat Transfer and conditions and functionality of engines.

Analytical simulation when compared to numerical simulations, made by software, tend to have a variation between 5 to 10% (Varella, 2010 e Merker, Schwarz, e Teichmann, 2011). This difference obtained on the two models proposed here settle inside this gap. This can be considered quite satisfactory, because there are small variations on the geometries proposed on Analytical model (Symmetric) and the original model of the engine (Asymmetric). Therefore, this paper can be considered appropriated.

It has been observed that the increasing of contact area with fluid obtained through adding two fins was effective in purpose of the initial goal that was a better heat transfer through the cylinder. However, it is not possible to affirm that this effect obtained is beneficial or not, since the project data of this engine are unknown. In addition, it must be considered that increasing the number of fins implies directly the increase in engine mass. Therefore, for definition of benefits all these factors should be considered.

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