COMPUTATIONAL ANALYSIS OF TEMPERATURE DISTRIBUTION IN A STIRLING ENGINE PROTOTYPE

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Abstract. *This paper presents an analytical and computational temperature distribution study in a prototype configuration Beta Stirling engine manufactured using recycled materials. Convection heat transfer and thermal conduction processes are evaluated. Conduction problem process assesses energy and heat loosed by convection in outer prototype walls. Computational results obtained with commercial software COMSOL Multiphysics 4.3b being compared and analyzed with one obtained using mathematical equations.*

Keywords: *Thermodynamics, Stirling Engine, Computer Simulation, Heat Transfer.*

1 INTRODUCTION

The computer simulation of thermal issues is an important tool for prior recognition of heat transfer processes that occur in simple models and, especially, in complex geometry. It is widely used in organizations to perform analyses and improve the quality of products and projects. A large part of these analyses is carried out by means of commercial software that use of mathematical methods in order to solve various engineering problems.

This work will be conducted two analyses based on a prototype of a Stirling engine Beta model manufactured, showing simulated computer results. SolidWorks software was used to build the geometric model of the prototype. The model was imported directly to the COMSOL Multiphysics 4.3b which is responsible for shaping and simulate the thermal behavior in the wall of the prototype. The simulated results are compared to results of mathematical models and has as purpose, allow a better understanding of the distribution of temperature in the prototype. So, a possible solution to the problem as the efficiencies found the engine heat exchanger. The results of this work will allow the advance of research for the construction of a second prototype. This study covers any scale of construction for a prototype Stirling engine.

2 BUILDING THE PROTOTYPE

The prototype created before the development of research, consists of 2 aluminum soda cans 0,3 L, 1 can of powdered milk 0,4 kg, 1 balloon 0,1778 m, 2 CDs, 5 light wire connectors 0,004 m, 1 steel wool, 2 coins of 25 cents (R$), 1 can of chocolate powder 0,2 kg, 1 PET bottle cap, 2 metal clips, 1 steel rope of musical instrument, high temperature sealant glue.

All the material was assembled by hand with the aid of tools, based on the design of a Beta Stirling engine model. The result was a totally handmade prototype that plays properly your function. It uses cold water in the low engine temperature and fire produced by flames of candles in the bottom of the cylinder. The piston is made of steel wool stuck on connecting rod of instrumental string. The difference of temperature and pressure shifts the balloon positioned in the cylinder head causing the rotational movement of the crankshaft moving so the flywheel of inertia, putting the motor is running. The cycle is repeated as long as the flame of the candle (hot spring) or reach the thermal equilibrium between the hot and cold part. Thermal equality is due to the limited capacity of the water tank (cold part).

Figure. 1 Prototype of the Stirling engine completed

3 METHODOLOGY AND RESULTS

First step consists in development of simplified mathematical equations to calculate temperature distribution at area defined as control volume (C.V). This C.V. was defined as the external walls of the prototype, cylinder and motor's heat exchanger (radiator) (Fig. 2). To calculate temperature distribution, control volume was divided in 7 equal parts on y-axis orientation, as show in Fig. 2. The distribution allows to calculate the thermal load of the convection in the wall of the cylinder.

Second step consists in use commercial software to simulate temperature distribution at the same control volume (Fig. 2). Parameters were considered as, steady state temperature, fine mesh geometry and control volume constituted by aluminum 1060 (UNS A91060) from the software catalog. The results are used to compare the computational and mathematical temperature results.

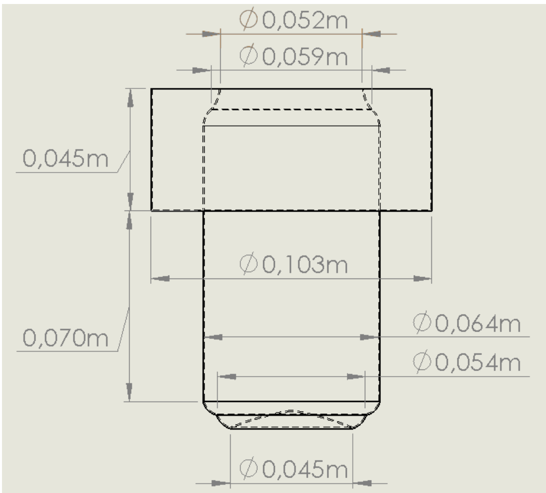


Figure 2. Technical drawing of the control volume adopted

3.1 MATHEMATICAL MODEL

The equations used for thermal mapping of the surface, are found in Arpaci and Kao (2000), described, vertical length, such as:

$$T(y) \ = \frac{T_{S2} - T_{S1}}{H} \ y + T_{S1} \tag{1}$$

Where $T(y)$ is the temperature positional, T_{S1} the temperature of the flame, T_{S2} the temperature of the water, y the vertical shift and H is maximum height of the volume control.

The mapping of the temperature variation in the control volume in Fig. 2 was carried out using experimental data, being $T_{S1} = 623{,}15\ K$ to the bottom of the cylinder, whose position is called power supply and $T_{S2} = 283{,}15\ K$ located at the lowest point of the cooling system located at the top of the cylinder.

To set the temperature variation of volume control was divided into seven parts along the length H, distributed vertically. The Table 1 shows the result of temperature by applying Eq. (1) in each of the seven parts of the volume control.

Table 1. Temperature calculated by Eq. (1) in each of the seven provinces of control volume described by the Fig. (2).

Nº	(y)	ºC	K
1st	0	350	623,15
2nd	0,01	301,43	574,58
3rd	0,02	252,86	526,01
4th	0,03	204,28	477,43
5th	0,04	155,71	428,86
6th	0,05	107,14	380,29
7th	0,06	58,57	331,72
8th	0,07	10	283,15
Average	-	180	453,15

With the temperature distribution, the next step is to estimate the heat loss by convection in the volume control. The calculation of the coefficient of natural convection parsed on the outside of the cylinder uses the templates found in Incropera and Dewitt (1998), being:

$$Ra = \frac{g\beta\left(T_{sup} - T_{\infty}\right)L^3}{\nu\alpha} \qquad ,\beta = \frac{1}{T} \tag{2}$$

$$Nu = 0{,}68 + \frac{0{,}670Ra^{1/6}}{\left[1 + (0{,}492/\mathrm{Pr})^{9/16}\right]^{4/9}} \qquad ,Ra \leq\ 10^9 \tag{3}$$

$$Nu = \frac{hL}{k} \tag{4}$$

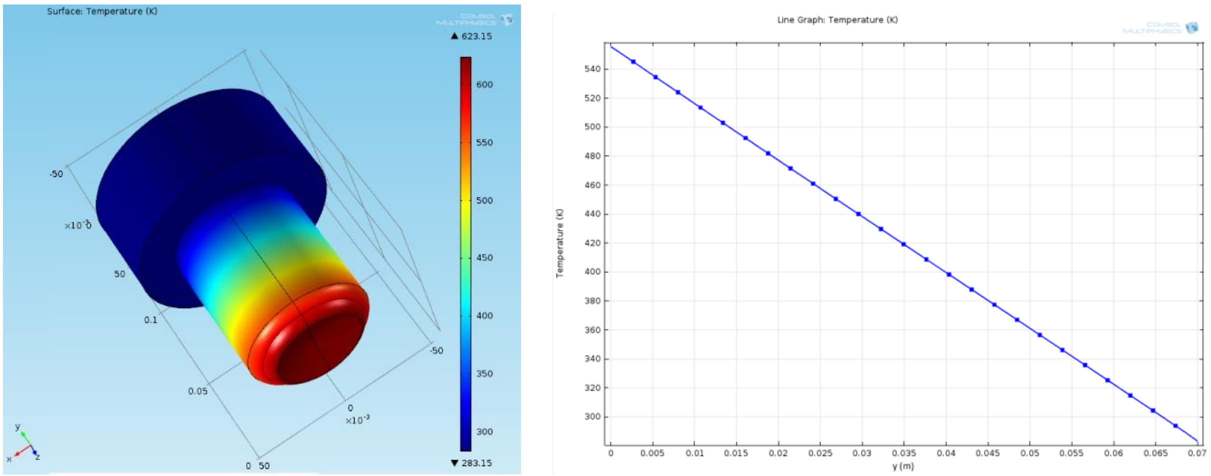
$$q = hA\left(T_{sup} - T_{\infty}\right) \tag{5}$$

The variables used are $g = 9{,}8\frac{m}{s^2}, \beta = 1/400$, $T_{sup} = 453{,}15\ K, T_{\infty} = 298{,}15\ K, \nu = 26{,}41 \times 10^{-6}, \alpha = 38{,}3 \times 10^{-6}, Pr = 0{,}690$. The flow of heat dissipated at the borders of the volume control, using the Eq. (2-5) was $q = 18{,}91w$.

3.2 COMPUTATIONAL MODEL

The simulations developed in this study were carried out using the software COMSOL Multiphysics 4.3b. For the computer simulation of the temperature distribution in the prototype was adopted the control volume shown in Fig. 2. The boundary conditions used in the simulation were the same temperatures $T_{S1} = 623{,}15\ K$ and $T_{S2} = 283{,}15\ K$ experimentally and measures used in the mathematical model.

The study of the model uses parameters for external temperature, which is adopted the value of $T_{ext} = 298{,}15\ K$, because this is the value measured in the experiment. The software was able to map the distribution of temperature as a function of the mesh generated, all prototype housing, as shown in Fig. 3.



(a) **(b)**

Figure 3. (a) Distribution in 3D; (b) Distribution in 2D

The Figure 3. (b) shows the temperature distribution in the control volume to the computational and mathematical models. Temperature distribution along the volume control in the computational model has relative errors of 6.28% in relation to the mathematical model. This difference there is because the mathematical model used only 7 subdivisions of control volume while the computational model used subdivisions of the finite elements, which takes the variations in the accuracy of each model.

4 CONCLUSION

Through the results obtained, the comparison between the mathematical model and the computational model satisfied. Concluded that the proposed methodology presents consistent results through implementation in commercial software, like the COMSOL Multiphysics 4.3b.

The data obtained, your problem based on the heat exchanger, has a solution with insulation between hot and cold parts, so preventing heat transfer and thermal equilibrium.

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