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Design of Radiator for Internal Combustion Engine with Tubes in Distribution of Sierpinski and Fins with Fractal Convolution

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Design of Radiator for Internal Combustion Engine with Tubes in Distribution of Sierpinski and Fins with Fractal Convolution

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Abstract- Introduction: Fractal geometries have demonstrated their efficiency in nature, for that reason a fractal geometry will be implemented to improve the transfer in a heat exchanger. This paper presents the design of the radiator for an internal combustion engine, where the location of the tubes through which the fluid passes are given by the distribution of Sierpinski and the perforations of the fins were made with fractal convolution. The outlet temperature respect to inlet temperature is studied and analyzed through a CFD software. This document shows theory fundamental used to design the radiator, with the implemented methodology, its results and conclusions.

Objective: Verify that a radiator with fractal design improves heat transfer in comparison with a commercial radiator.

Methodology: For this study, the design of the radiator in matlab was made, then the CAD design and the corresponding simulations in Ansys were performed. The numerical analysis was carried out. Finally, for the case of the common radiator, the data was adjusted to the Newtonian cooling function and for the radiator with fractal design it was performed as a function of Mittag-Leffler.

Results: The designed radiator cooling temperature curve falls faster than the commercial radiator curve, which is an indication that the radiator with fractal geometry improves heat transfer in the exchanger.

Conclusion: The Mittag-Leffler function best approximates the temperature curve of the Fractal Radiator. To estimate a fractal object under the condition of thermal conductivity, when making the estimation it is suggested that it must relate to the Fourier equation of fractional type in fractal medium.

Keywords: fractal convolution; sierpinski distribution; fins design; radiators.

I. Introduction

Since their appearance in 1975, fractals have been used in many areas related to engineering applications and have proven useful for increasing performance while using less volume. It has been shown that the self-likeness of fractal patterns could be used to create an effective distribution system over geometric surfaces.

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Originally, they emerged as geometric shapes that are repeated in an iterated manner at different scales and that are self-similar. In the first decade of its development its geometric properties and its possible connections with other disciplines were obtained. Subsequently from the work of Nigmatullin [1], it began to incursion with connections of the area with fractional or fractional calculation, and from this, in the 21st century the possible applications to the various engineering. This work is part of the fractal theory to heat transfer, through simulated constructions by computer, which are feasible to build, on fins whose surface is fractal.

The essential characteristics of fractals is the irregularity of surfaces that can be repeated at different scales, this allows to improve heat transfer, for instance the surfaces of the fins under Euclidean geometries have been used in a classical way [2], [3]. One of the applications of surface engineering with fins is the radiator. By attaching the metal sheet to the water pipes at a defined temperature, the area of the convection surface increases and thus increases the heat transfer rate [4], if this is changed from geometry to fractal geometry, the transfer efficiency should be markedly improved.

Due to the increasing use of methods to improve the design of the heat exchanger in the industry, Compact heat exchangers have been developed which ones have a high proportion of heat transfer surface to heat exchanger volume, considering the fractal capacity to increase heat transfer. These are divided into fin tubes and fins plates [5] [6], which allow a high heat transfer coefficient in the high turbulence flow as that offered by a laminar flow in a flat tube situation [7].

This project investigated a tube heat exchanger based on the use of the Sierpinski fractal pattern where the spaces are not square but circular, and those are given by an operation fractal operation called convolution. Using computer modeling software, this indicated that with fractal iteration, an increase in heat transfer is achieved. Another research interest involving fractals in engineering has been the effects of fractal on surface diffusion rates.

In reference to radiators, they can use any type of compact exchangers, for the purpose of controlling the engine temperature when the engine is too high [8]. Based on the different models of cooling systems manufactured in [9], [10], [11], it decided to analyze the behavior of the design of the radiator with convolution fractal distribution fins, because in heat transfer fractal designs have shown better results than common geometries [12], [13].

The following simulations presented was made through CFD software since it allows us to study trends and properties [14].

II. Methodology

This project methodology is divided in four parts: fin calculus, fractal distributions, CAD and simulation.

a) Radiator Design

A radiator has four parts: inlet tank, outlet tank control cap and diaper (figure 1). The principal parameters are the diaper dimensions [15] which includes fins and tubes, these last parameters are those that will be considered to implement the fractal geometry.

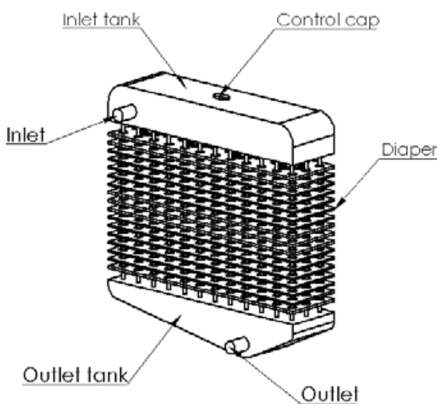


Fig. 1: Parts of a radiator

Tubes design: The chosen parameters to realize the tube design were: Cross section (1), total internal perimeter (2), and hydraulic diameter (3).

$$A_{tube} = N_t\left[t_{hi}\cdot(t_{wi} - t_{hi}) + \frac{\pi}{4}t_{hi}^2\right] \tag{1}$$

$$P_{tube} = N_t\left[\pi\cdot t_{hi} + 2\cdot(t_{wi} - t_{hi})\right] \tag{2}$$

$$D_{htube} = \frac{4\cdot A_{tube}}{P_{tube}} \tag{3}$$

Where N_t is the radiator tubes number, t_{hi} is height of the tube, t_{wi} is the internal width of the tube.

Fin design: To design the heat transfer area on the side of the tube Aefect, tube and the area Ac, these can be expressed as:

$$A_{efect,tube} = N_t\left[2\cdot(t_{wi} - t_{hi}) - \pi\cdot t_{hi}\right] \tag{4}$$

$$A_c = (N_t\cdot t_{ho} + N_c\cdot c_h)\cdot L_t \tag{5}$$

b) Design using the Sierpinski distribution

Considering the values obtained of (4) and (5), it was necessary to find an efficient distribution, for this reason it was decided to use the Sierpinski distribution to locate the tubes.

To determine the location of the centers of the holes, we considered the dimensions of the fin, because the fin has a rectangular form, this one was divided into four squares, and in each one we applied the Sierpinski distribution. Finally, we made a Matlab program which calculates the center and the location of the holes, the result of the algorithm is illustrated in figure 2.

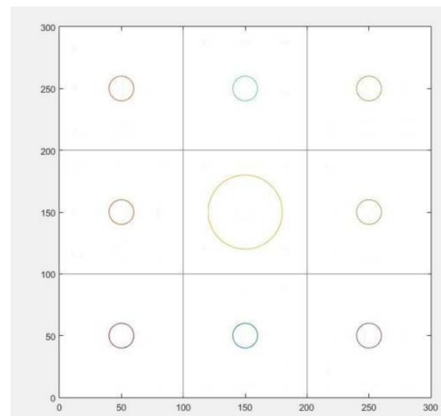


Fig. 2: Result obtained from Matlab

c) Fractal Convolution

In 2015, Cotton, McLeman y Pinchock proposed process to combine two fractals [16], one into each other and they explored the combined effect on fractal dimension. This project explores that effect over a radiator and its effect calculated through a simulation. The construction follows the parameters exposed in [16], except that apart from the Sierpinski we build a new fractal (figure 3) and the result of the convolution between Sierpinski and the fractal designed will be determinate the radiator perforations.

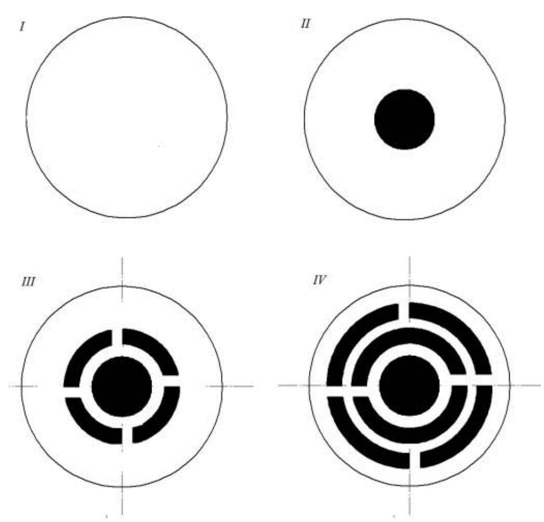


Fig. 3: Fractal figure construction

The contribution in this project was the use of these ideas to simulate the behavior of the radiator. The figure 4 shows the result of the fractal convolution that was made, and the fractal dimension was calculated through HarFa v5.3.33 software [19], its result was illustrated in the figure 5.

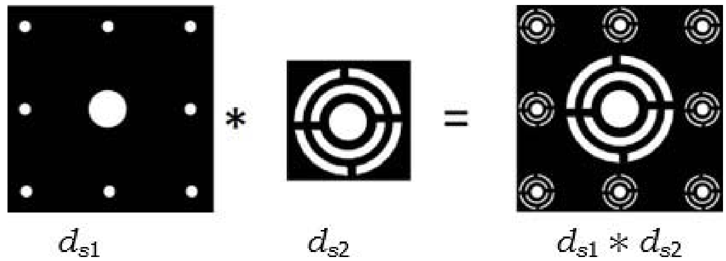


Fig. 4: Fractal convolution

Where, $ds1$ corresponds to the tubes distributions dimension, $ds2$ to the fractal figure designed dimension and DF is the product of the convolution between those fractals.

To calculate the fractal dimension, we used Harfa software and the operator form proposed by Cotton, McLeman and Pinchock, and these are:

$$ds1 = 1.8927$$

$$ds2 = 0.7392$$

$$DF = ds1 * ds2 = 1.3991 \tag{6}$$

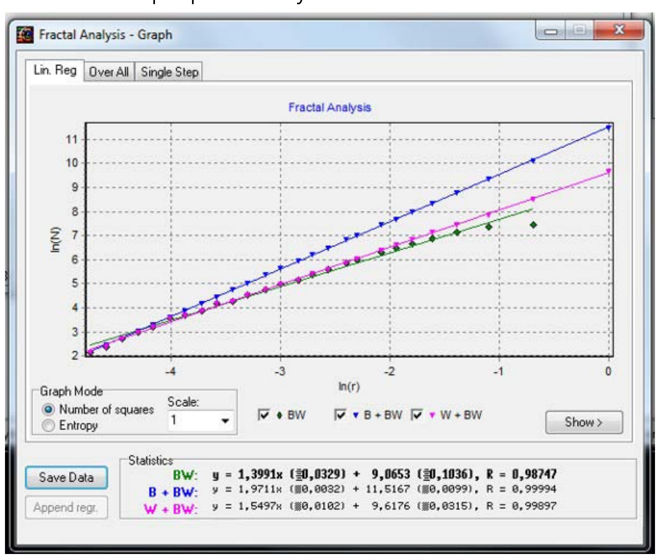


Fig. 5: Harfa Results

d) Simulation

CAD: This model was made through a 3D software. With the values previously found, the measurements of the drill bits are determined for the diameters of the holes and tubes passing through them, which corresponds to 1⁄8 "for the small hols and 3⁄8" for the central holes. The figure 6 shows the result of the convolution implemented in a fin design.

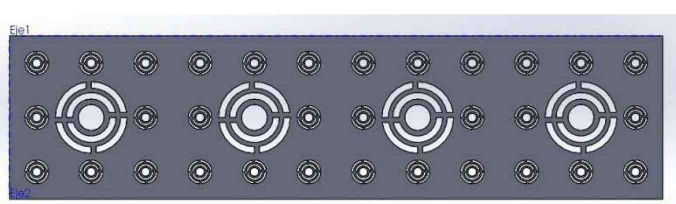


Fig. 6: Fin design in CAD

Meshing: Because the geometry radiator had 36 tubes and more that 500 perforations, it was necessary to use a mesh with the right size to analyze in CFD study and skewness coefficient that was less than 0.86 to be compatible with Fluent. Table 1 shows the mesh parameters implemented.

Table 1: Mesh Characteristics

Size Function	curvature
Size	3.3208 e-2 mm
nodes	3409535
number of elements	2835588

Parameters of CFD simulation: The computational model was set to a laminar model, with temperature and flow parameters shown in Table 2. The initial values of velocity and pressure was setting with SIMPLEC algorithm.

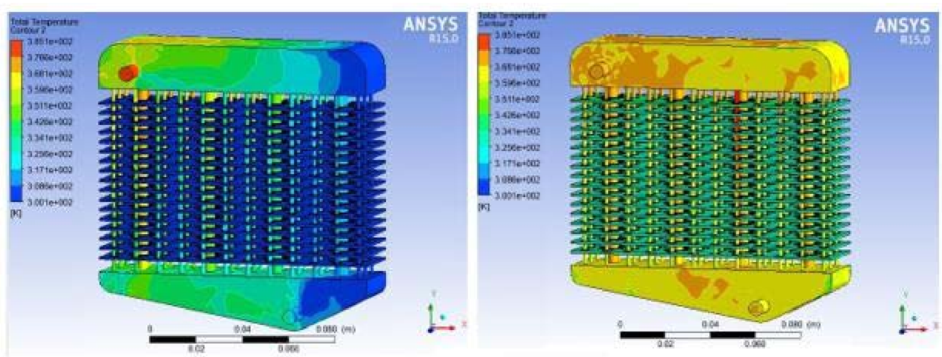
Table 2: Simulation Parameters

Convection (forced)	80 $W/K.m^2$
Fluid inlet temperature	385 K
Ambient temperature	300 K
Initial mass flow	0.1 Kg/s

III. Results

a) CFD

Simulation was performed in Ansys, it was made in order to analyze the temperature in the radiator in a time of 30 seconds. Figure 7 shows the difference between temperature at time t=1s and final temperature at time t=30s.



a). t=1s b). t=30s

Fig. 7: Radiator temperature

The obtained results show a reduction of 7K with regard to the initial temperature of the fluid. Considering that the analysis of the figure 8 is the temperature analyzed at the radiator outlet, where $T(0)Outlet = 300K$ is the ambient temperature.

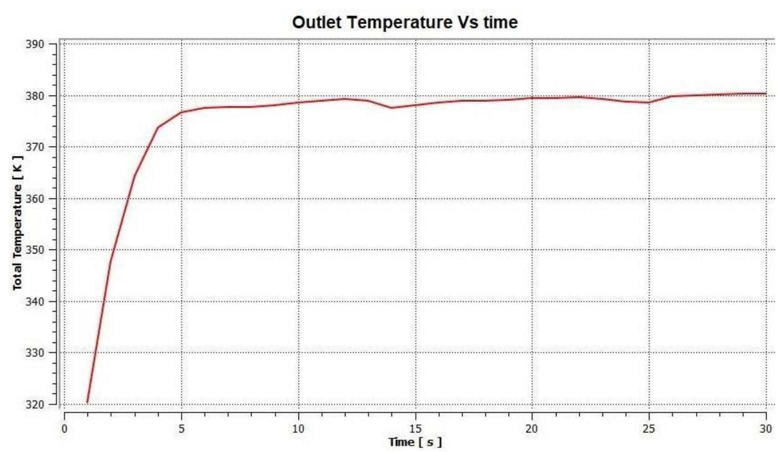


Fig. 8: Ansys results

b) Data processing

The data processing in this radiator has the purpose to find the function that fits better to fractal design. The first step consists in taking a temperature model and adjusting to a Mitag- Leffler function. To realize it, it was necessary to analyze the temperature decreasing, taking as reference the fluid initial temperature at the inlet radiator as T (0)inlet= 385K.

Figure 9 shows the change of temperature at the outlet of the radiator.

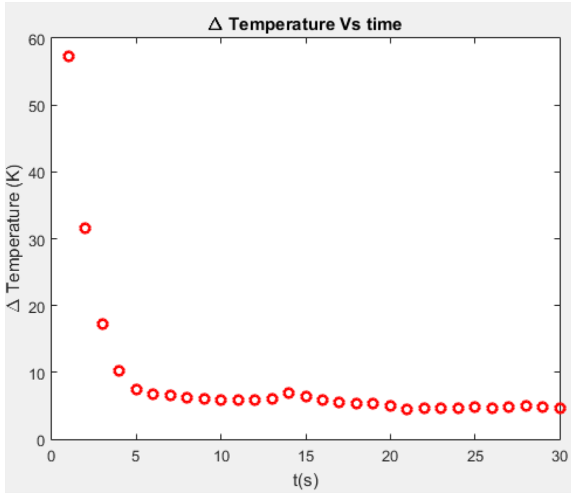


Fig. 9: Temperature drop at the radiator outlet

With the obtained data from figure 9, it proceeded to looking for Newton temperature classic model as the form:

$$\frac{dT}{dt} = K(T - Tm) \tag{7}$$

When estimating the model purchased with (7) we find that:

$$T(t) = 6 + 70e^{-0.47t} \tag{8}$$

When the adjustment analysis of the regression is performed, we find that:

$$R^2 = 0.8456$$

Square root of the middle square = 9.87 Con valor $p = 9,\ 09X10^{-18}$

Figure 10 illustrates the classical model (red line) and the points plot the data obtained from the simulation.

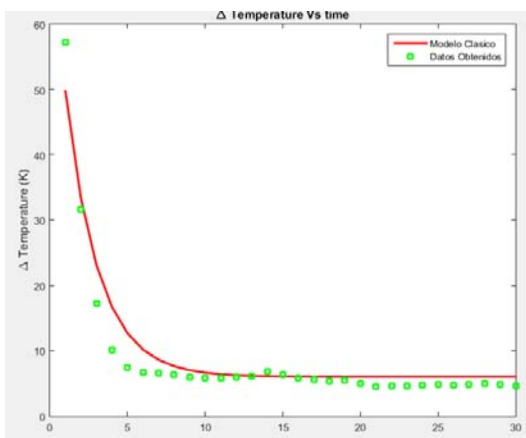


Fig. 10: Estimated classic model and simulation data

This is a lumped system, which temperature varies with the time, but remains unformed around the system at any time. The temperature of a lumped body of arbitrary shape with a mass m, volume V, surface area A_S, density ρ and specific heat C_P, initially at a temperature Ti, that is exposed to convection at a time t = 0 at a medium temperature $T\infty$, with a heat transfer coefficient h is expressed as:

$$\frac{T(t) - T_\infty}{Ti - T\infty} = e^{-bt} \tag{9}$$

Where,

$$b = \frac{h \cdot A_s}{\rho \cdot V \cdot C_p} = \frac{h}{\rho \cdot L_c \cdot C_p} \tag{10}$$

For the design of this radiator, the parameters of table III were considered.

Table 3: System Characteristics

h	$80\ W/\ (K.m^2)$
C_p	$4{,}1813\ J/\ (Kg.\ K)$
V	$0{,}000137\ m^3$
ρ	$2700\ Kg/m^3$
A_S	$0{,}003732\ m^2$

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Because the fractal form used is a fractal one and before the estimation by means of the calculation of Mittag- Leffler, definitions will be proposed that seek to link the parameters with the fractal dimensions, as follows:

Definition 1: We will call fractal dimension of convection ($dF\ c$) to: Being the natural logarithm of the coefficient of heat transfer coefficient h and the natural logarithm of the product of $\rho \cdot L_C \cdot C_p$. This definition can be expressed as:

$$a_F = \frac{ln(h)}{ln(\rho \cdot L_c \cdot C_p) + D_F} \qquad (11)$$

Where D_F is the fractal dimension of the convolution made in (6)

Replacing the equation 10 with Tabla 3 data, we obtained the value of $dF = 0,\ 4084$

Calculate the α value: However, since the construction is fractal it is suggested to adjust the classical model to a Mitag- Leffler function with a value of α

To find the value of α, it was taken as a reference the value of dF found in (11), and considering some observations given by Tatom [18] with some modifications appropriate to the project:

$$\alpha = \frac{1}{2} \cdot \left(\frac{1}{2 - d_F}\right) \qquad (12)$$

Which value of $\alpha = 0,\ 31$.

If Mitag-Leffler function with a value of $\alpha = 0.3$ is presented in the form of a Fox H-function, we get:

$$E_\alpha(z) = H^{1,1}_{1,2}\left[-z\left|\begin{matrix}(0,1) & \\ (0,1) & (0,\alpha)\end{matrix}\right.\right] \qquad (13)$$

As Haubold, Mathai and Saxena [17] indicates, when we performed the adjusting analysis with $\alpha = 0.3$, we find that: R^2decreases to 0.23, the square root of the average square decreases to 5.17 and $p = 4,\ 59X10^{-5}$, as shown in figure 11.

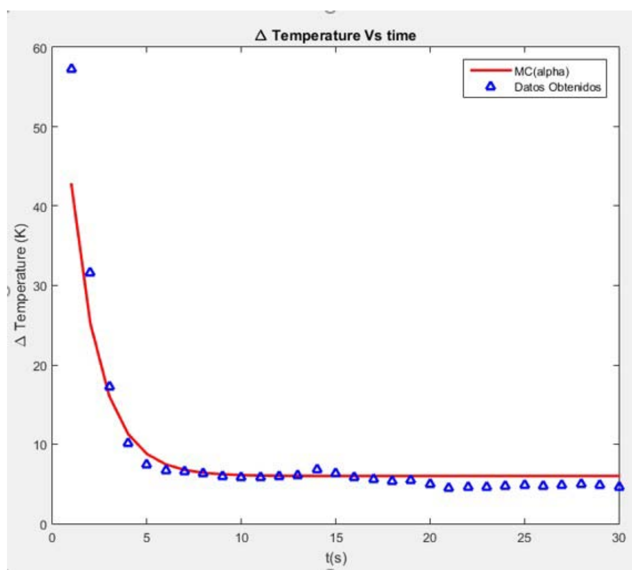

Fig. 11: Mittag-Leffler Function with $\alpha = 0.3$

The linearity is lost, but the adjustment is improved, which is in accordance with the fractal model, in a fractal geometry. When calculating the classic model obtained in term of the Fox H-function, we obtain:

$$T(t) = 6 + 70 \cdot H^{1,0}_{0,1}\left[Z|_{(0,1)}\right] \ para\ Z = -0,47t \qquad (14)$$

While Mitag-Leffler adjustment is:

$$T(t) = 7 + 70 \cdot H^{1,1}_{1,2}\left[-Z|^{(0,1)}_{(0,1),(0,\alpha)}\right] \ para\ Z = 0,47t\ \alpha = 0,3 \qquad (15)$$

The improvement of the adjustment suggests that there must be a connection between the value $\alpha = 0.3$ and the fractal dimension of the proposed design convolution ds1* ds2 = 1.3991.

When making the adjustment, it resembles the theoretical calculation of [18]. However, the values proposed by Zhao should be changed by the values of the model adjusted for this case of the radiator, in the following way: $\mu^2\omega$ is the thermal conductivity of the fractal material designed using the Sierpinski distribution, $\rho\omega$ its density, $c\omega$ specific heat, for the authors these values must be changed by their natural logarithm and the corresponding ω of the fractional order of the equation must be changed to the value α of this model.

IV. Conclusions

The simulation has shown that the fin surface in heat transfer and fractal shape and the yield of the fractal fins improve heat transfer or flow by improving fin efficiency.

The fundamental hypothesis on which the authors of the project are based is that since the fractals are self-similar objects and work at any scale, it is feasible to apply them at any scale of the engineering.

The Mittag-Leffler model with $\alpha = 0, 3$, fits much better than Newton's classic model because it changes from a distribution of a Euclidean geometry to a fractal geometry, in the design of fins in a radiator and the distribution of tubes.

To estimate a fractal object under the condition of thermal conductivity, when making the estimation it is suggested that it must relate to the Fourier equation of fractional type in fractal medium as we saw in [18]

This simulation further suggests that the reconstruction of the fins not in the form of the classical geometric euclidea but fractal and with operations of convolution between fractals markedly improves the behavior of heat transfer. It is further suggested to explain these phenomena with the possible connection with fractional calculation, which allows innovation within heat transfer and its associated engineering, we will therefore say that we have a promising future through these ideas.

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