Comparative Numerical Study of a Co-Current Heat Exchanger

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Abstract: Heat exchangers represent equipment that is widely used in industry to lower, raise the temperature of a fluid. The problems related to thermo hydraulics concern above all the thermal dimensioning of the devices. In this work, we validate the results obtained with the use of the Comsol-Multiphysics software and that of the experimental and fluent code of a turbulent flow in forced convection for two hot and cold fluids to see the thermal behavior of the water in the coaxial exchanger. The numerical results obtained clearly show that the thermal performances are dependent on the value of the turbulence intensity and of the fluid used.

Key words: Coaxial heat exchanger, Turbulent flow, temperature, Finite element, Comsol-Multiphysics.

1. INTRODUCTION

The era of fossil fuels is nearing its end; according to oil specialists, they will run out within a hundred years at most, and given that the crucial demand for energy in all its forms has reached its peak, specialists are resorting to energy called renewable to meet energy needs; and without reciprocal, the mastery of these new procedures rests on a fundamental basis (Petitot, S. & al 2002): thermal exchanges, hence the knowledge of their different modes: conduction, convection and radiation, which proves to be more than a necessity for good dimension energy systems (Duinea, A. & al 2008).

Heat exchanges occur in many sectors of human activity. In most of these activities, heat transfer must take place without alteration of the media involved in heat transfer (Talbi, K & al. 2003). The use of specific exchange equipment is then necessary. This equipment is known as heat exchangers. These are thermodynamic systems present in all industrial units in which heat extraction processes take place(Elouardi, M. & al 2011). (Stein, R.P.& al1965).

The heat exchanger is a piece of equipment that ensures heat transfer from a hot fluid to a cold fluid without direct contact between the two. The same fluid can retain its liquid or gaseous physical state (Nunge, R.J. and Gill, W.N., 1966).

The major technological concern of heat exchangers is the improvement of the thermal exchange between the two fluids while generating the least pressure losses or reducing them to their lowest possible level (Taki, A.H. & al, 1988). (Hogg, S., & al 1989). We will first display a validation of our results with the experimental results found in the literature and a comparison with the Fluent simulation code (Benayad, N. & al 2009). Subsequently, we will treat some possible cases while carefully providing some interpretations.

2. DESCRIPTION OF THE PROBLEM

The Comsol-Multiphysics code was used to simulate flow transport and temperature evolution. The geometric configuration considered in the present work is illustrated in (Fig. 1).

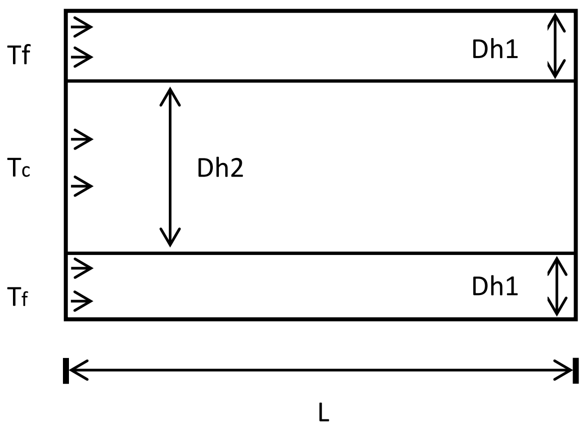


Figure 1. Studied geometry.

We will focus on the numerical study of the thermal behavior of the water flow in stationary turbulent forced convection in the co-current configuration in the coaxial exchanger.

The heat exchanger sizing data are taken from reference (Benayad, N. & al, 2009). The length of the exchanger: L=0.105 m;

Hydraulic diameter of the cold fluid channel: Dh1= 0.0032 m; Hydraulic diameter of the hot fluid channel: Dh2= 0.0079 m.

2.1 *Boundary conditions*

-The speed of the cold water at the inlet: Vf= 0.4 m/s;

-The speed of the hot water at the inlet: Vc= 0.3 m/s;

-The temperature of the cold water at the inlet: Tf = 288 °K;

-The temperature of the hot water at the inlet: Tc = 320.2 °K;

-The pressure at the outlet: Ps = Patm

2.2 Mesh

Mesh generation (2D or 3D) is a very important phase in an analysis given the influence of its parameters on the calculated solution. This menu allows you to mesh a particular line of geometry, i.e. arrange the nodes with particular conditions (use of a ratio to modify the weighting of the mesh, application of different mesh shapes).

2.3 Convergence test

Numerical simulations were tested by varying the number of calculation elements. Stability and convergence of the model were achieved for different meshes. The type of mesh chosen for the geometry studied is “user-controlled mesh”, with “free triangular” type elements predefined by “Normal” and a refinement in the wall.

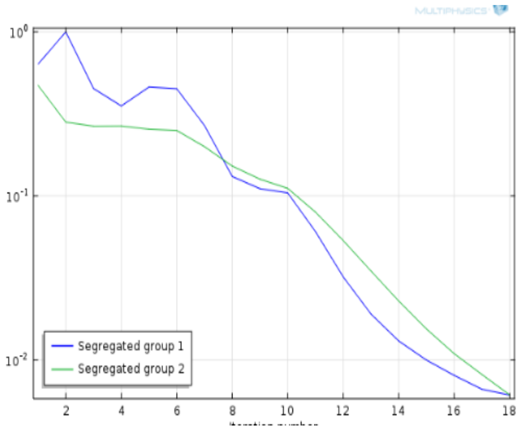


Figure 2. Convergence test.

Table (1) represent the results of the mesh

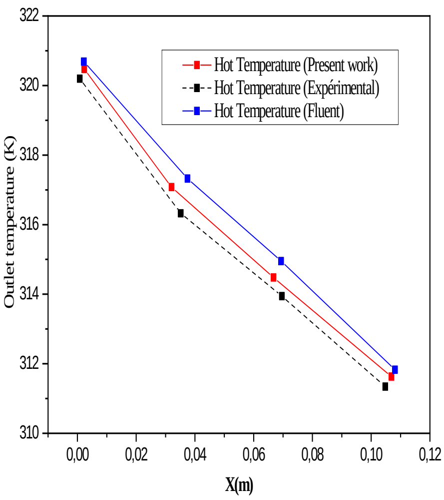
Table 1. Page margins

	Cas étudié
Elément vertex	8
Elément de frontière	902
Nombre d’élément	14288
Qualité minimal des éléments	0.8368
Nombre de dégrée de liberté résolu	53076
Volume de maillage	0.45 m^3

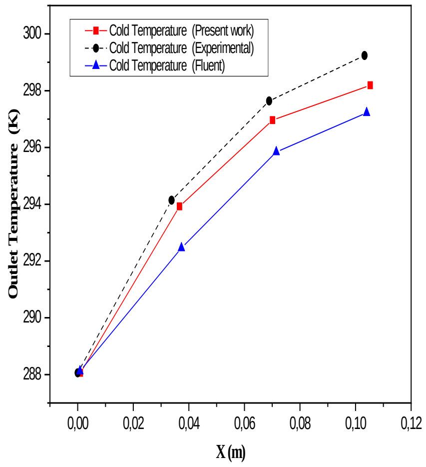
3. VALIDATION OF RESULTS

This part presents the different parameters which characterize the behavior of the co-current fluid along the exchanger. The results of the numerical simulation have been validated with the experimental work (Benayad, N. & al, 2009) and are compared with fluent simulation code.

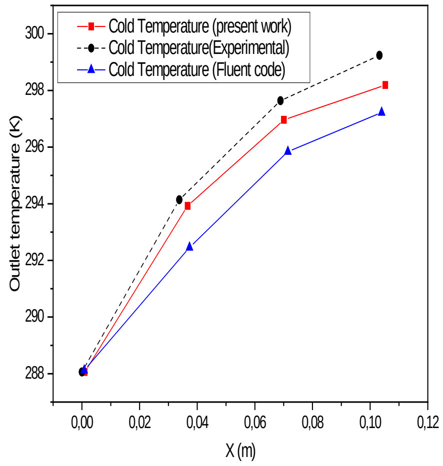
In (Fig. 3). we see a good agreement, we can say that the Comsol-Multiphysics software showed these qualities and these numerical performances.



(a)



(b)



(a)

Figure 3. Temperature field distribution (a) :hot and (b)cold, over along the heat exchanger

This simulation was validated by comparing its results with experimental data. This result confirms the accuracy of our approach as it aligns well with both sets of existing data. Good agreement between these results means that this issue can be examined numerically.

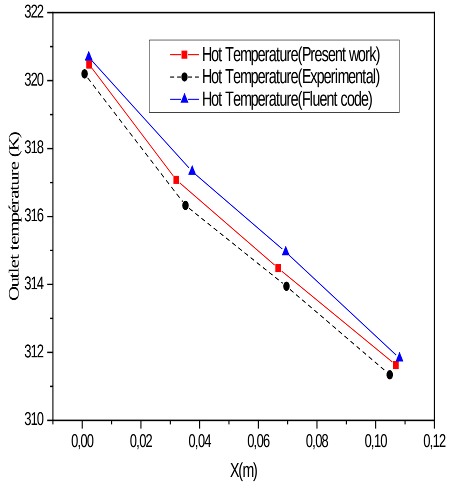
4. STUDY OF THE TEMPERATURE PROFILE

Figure 3 shows the behavior of the total temperature along the exchanger. The thermal field has the following characteristics: The temperature of the hot fluid in the central tube begins to decrease which is indicated by the gradual change in color. On the other hand, the cold fluid undergoes an increase in temperature. We say that the cold fluid gains heat and the other loses.

4.1 Temperature profile along the exchanger

The variation in total temperature for the two fluids (hot and cold) appears clearly on the contours. To carefully study this evolution, we traced temperature curves as a function of the length of the exchanger.

Figure 4 concerns the temperature profiles along the length of the exchanger. According to the following configurations we see that: there is a considerable increase in the cold fluid temperature which reaches 299 °K, on the other hand a decrease in the hot fluid temperature which reaches 311 K.



(b)

Figure 4. Long temperature profile of the coaxial exchanger (a) for the cold fluid and (b) for the hot fluid

4.2 Calculation of error bars

We take the data of the cold and hot temperature curves from the experimental study and our study by Comsol-Multiphysics software. We make a comparison between the two curves. The following table explains the calculation results.

According to the calculation of the error bars, we see an approach between the results obtained by the experimental study and the study by the Comsol-Multiphysics software (average ΔTf and average ΔTc are small). The plotted curves are almost the same, so a satisfactory agreement exists between the results.

4.3 Study of the velocity field

Figure 5 presents the axial velocity field distribution and the contour along the exchanger. We observe that : At the entrance to the exchanger, the speed of the cold fluid is maximum then it becomes minimum at the exit. On the other hand, there is an increase in the speed of the hot fluid.

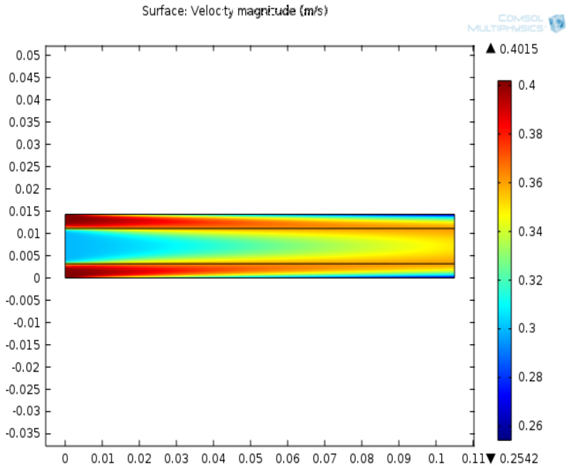


Figure 5. Presentation of the field and velocity contour

4.4 Axial speed profile

The speed variation appears clearly on the contours and their scales. To study this evolution of axial speed in the exchanger, we traced the axial speed curve for an axial position: x= 0.025 m.

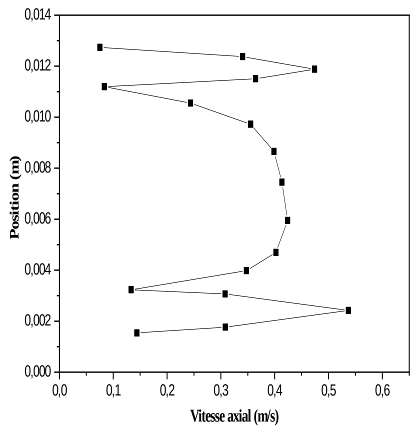


Figure 6. Axial velocity profiles at x=0.025m

Figure 6 present the progressive change in speed along the coaxial exchanger, it is minimum at maximum at the exit. It has a parabolic appearance.

4.5 Turbulent kinetic energy k

Figure 7and 8 presents the distribution of the turbulent kinetic energy lines K.

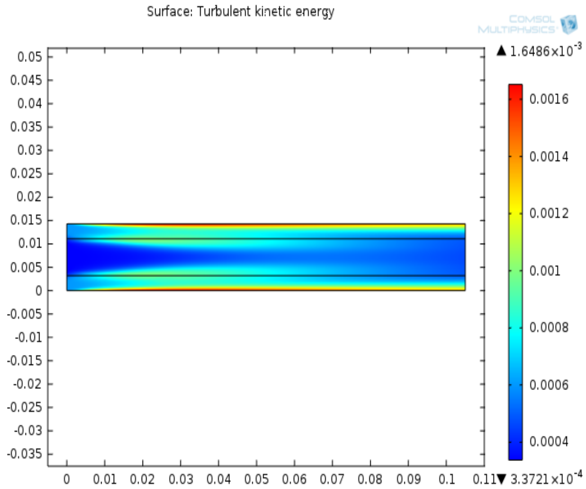


Figure 7. Presentation of the turbulent kinetic energy distribution K.

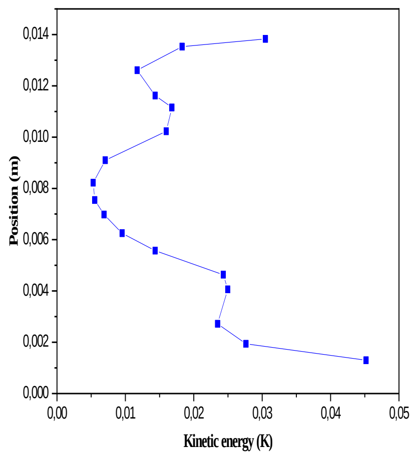


Figure 8.Profile of turbulence kinetic energy K

We observe that :

At the entrance to the exchanger, the turbulent kinetic energy is intense. And therefore the turbulence production term is important.

At the exit the production of turbulence is non-negligible.

A decay of turbulence transported by convection along the exchanger from the inlet to the outlet.

5. Case study

This part consists of taking some possible cases, it involves changing the value of the turbulence intensity, changing the fluid and adding roughness.

51. Change in turbulence intensity

When setting boundary conditions for a CFD simulation, it is often necessary to estimate the intensity of turbulence on the inputs. In high speed flow in complex geometries like heat exchangers and flow inside rotating machines (turbines and compressors). Typically, the turbulence intensity is between 5% and 20%.

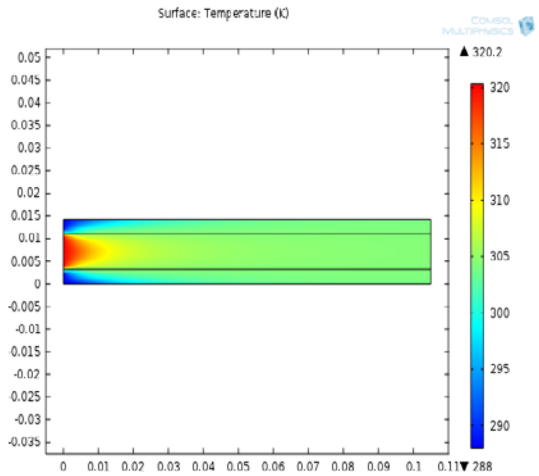
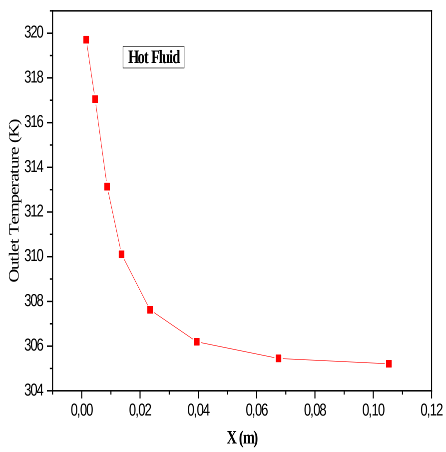
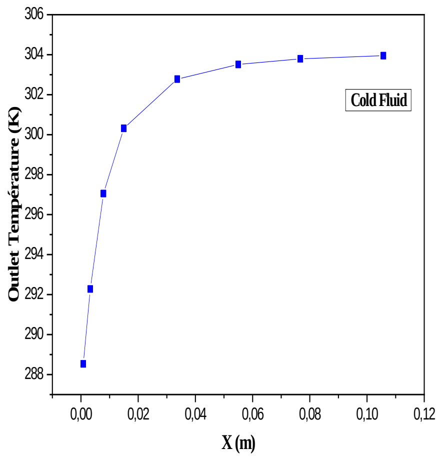


Figure 9. Temperature field along the exchanger.



(a)



(b)

Figure 10. Long temperature profile of the coaxial exchanger (a) for the hot fluid and(b) for the cold fluid.

Figure 10 shows the cold and hot temperature profile along the exchanger. We note that :

- The temperature of the hot fluid is reduced from the inlet rapidly to a value of 304 °K. On the other hand, the temperature of the cold fluid also increases rapidly until it reaches a value of 305°K.

- At a certain moment the two temperatures become equal, i.e. the heat exchange stops.

5.2. Fluid change (air, steam, propane)

In this part, we tried to change the fluid used which is water, it is: air, steam and propane. Figure 11 shows the variation of the cold temperature along the exchanger.

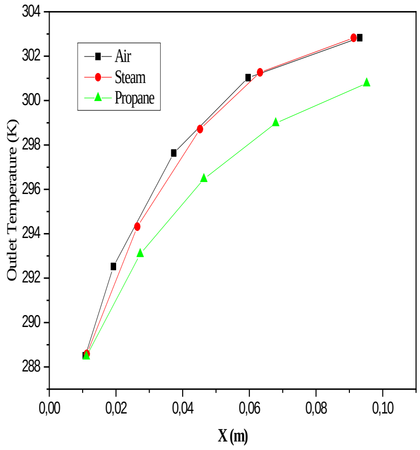


Figure 11. Cold fluid temperature profile

The observations that can be drawn from this maneuver:

- The three cases are similar, therefore of the same form.
- The air and steam temperature increases to a value of 303°K, on the other hand the propane temperature reaches a value of 301°K.

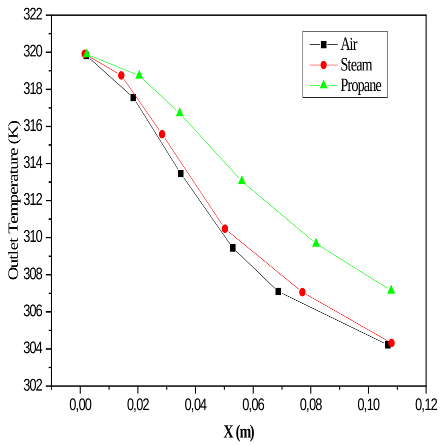


Figure 12. Temperature profile of the hot fluid

Figure 12 shows the variation of the hot temperature along the exchanger .The remarks that can be drawn are:

- Air and steam have the same appearance, which is different for propane;
- Propane reaches a temperature value of 307°K compared to air and steam which reaches the same temperature value of 304°K.

5.3 Adding roughness

In this part, we are going to play with the geometry, we add roughness to the central tube, to see its influence on the temperature profile. The boundary conditions and dimensions are the same as in the simple case.

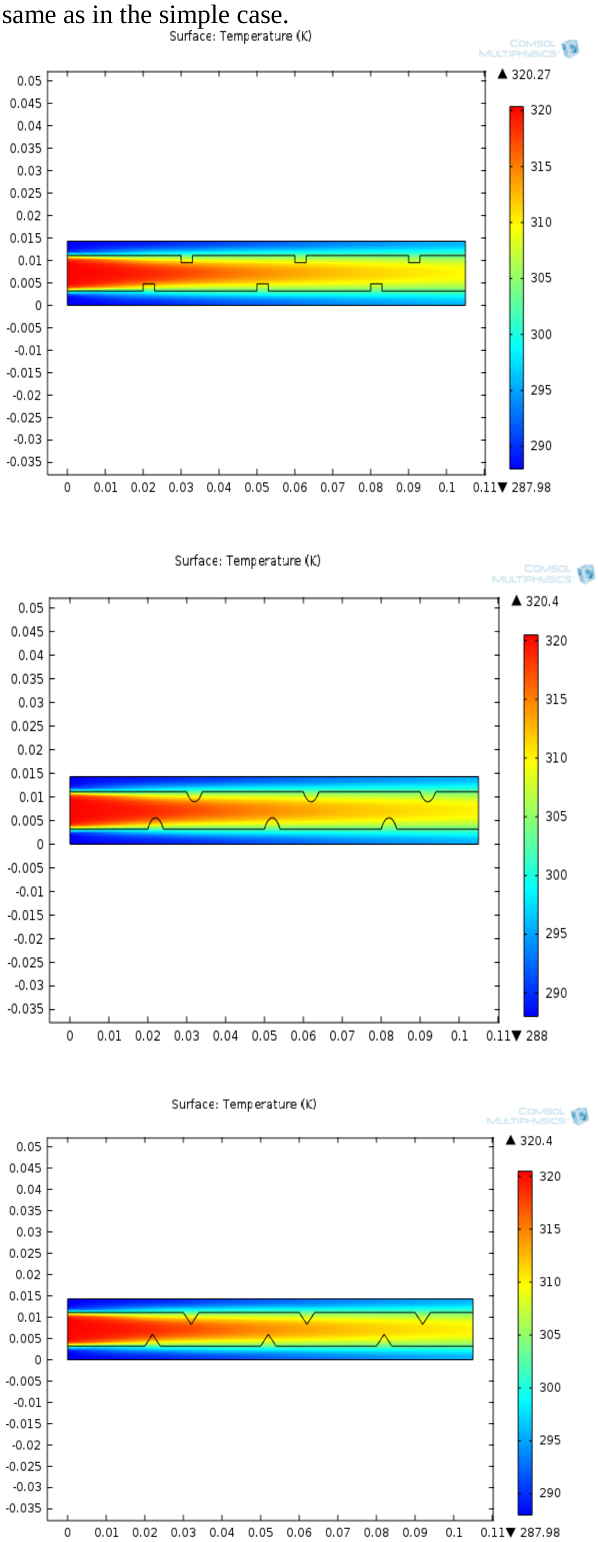


Figure 13. Cold fluid evolution profile

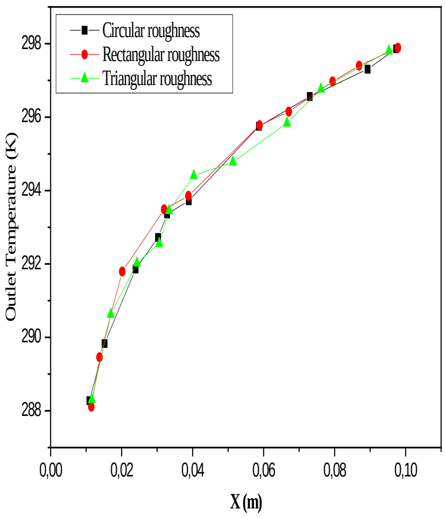


Figure 14. Cold fluid temperature profile

The remarks that can be drawn from figure 14 concerning the temperature profiles of the cold fluid along the exchanger are as follows:

- The three cases have the same appearance.
- There is an increase in the temperature of the cold fluid.
- The maximum temperature value for all cases is: 298 °K.

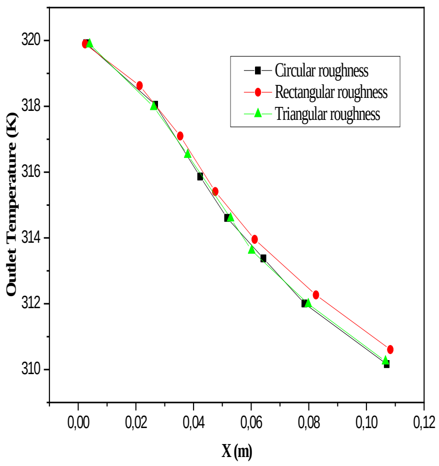


Figure 15. Hot fluid temperature profile

The remarks that can be drawn from figure 14 concerning the temperature profiles of the hot fluid along the exchanger are:

- All three cases are similar.
- A decrease in the temperature of the hot fluid for the three cases up to a temperature value of 310°K.

6. CONCLUSION

Through this chapter, we can say that the Comsol-Multiphysics software version 4.3, allowed us quite beneficial digital processing from the point of view of the results obtained from the different parameters compared to those found experimentally and by the Fluent software.

This step allowed us to see the fluid behavior and at the same time study the dynamic and thermal field along the coaxial exchanger. The variation in the value of the turbulence intensity influences the temperature profile which leads to a decrease and increase in the temperature of two fluids.

The numerical results clearly show that the thermal performances are dependent on the type of fluid used.

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