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EVALUATION OF CONVERGENT FLOW OF WATER IN A T-JUNCTION FOR DIFFERENT FLOW RATES IN THE SECONDARY BRANCH: NUMERICAL SIMULATION.

Helton Gomes Alves
Morgana de Vasconcellos Araújo
Wanessa Raphaella Gomes dos Santos
Antonio Gilson Barbosa de Lima
Severino Rodrigues de Farias Neto
Federal University of Campina Grande. Rua Aprigio Veloso, 882. Bairro Universitario. Campina Grande-PB. Zip Code: 58.429-900.
e-mails: helton.02@hotmail.com, morganamva@gmail.com, wanessa.raphaella@yahoo.com.br, gilson@dem.ufcg.edu.br, s.fariasn@gmail.com

Abstract. *The t-junction is an industrially common variation, with a simple construction and a low cost. Between of some many applications, stands out for its use as a fluid mixer, with or without chemical reaction, in a isothermal way or with changes in temperature. The fluctuations in temperature, pressure and in speed in the vicinity of the junction walls, if high, can result in vibrations that reach frequencies that cause damage to the structure of the material composing the product, such as cracks, for example, tracks resulting in financial loss for the industry. Aiming to give a contribution in the fluid dynamic parameters on the conditions that lead to fatigue, a numerical study of the convergent flow of water using Ansys CFX software was performed by fixing a value of velocity of flow of water in the main branch and varying values in the secondary branch. The conservation equations of mass and momentum are solved together with the turbulence model k-ε standard. The results of the pressure field and velocity are analyzed, emphasizing the regions most affected by the fluctuations of the mentioned variables.*

Keywords: *t-junction, water flow, pipe*

1. INTRODUCTION

The T-junction is an industrially common variation of simple construction and low cost which provides cross-flow jets used as a mixer, but is also found in application of phase separation or in a chemical reactor. One purpose of the use of the T-junction is to find the best geometrical and flow conditions, to provide, as soon as possible, a good homogeneity of the mixture and hence a more efficient chemical reaction.

Noteworthy is also the mixing of hot and cold fluid streams at T-junctions that, in many cases, can lead to large fluctuations in temperature in a short time. According to Ogawa et al. (2005), if these temperature fluctuations reach big amplitudes of temperature variation, can happen the thermal fatigue of the pipe structure, leading to the presence of cracks that will cause fluid leaks. Understanding this phenomenon is of great importance in assessing the structural integrity and safety of nuclear power plants and thermoelectric plants for power generation, for example.

It is clear, therefore, that the majority of the situations above listed the presence of a cross-flow fluid streams may engage stream fluid with one or more stages, or the presence of two or more chemical components. Accordingly, the understanding of the phenomena involved in single-phase, multiphase and/or multicomponent flow, or even combinations among them, has a prepoderante role in the use of T-junctions as separation devices, mixing or chemical reaction.

In the last thirty years has been reported in the literature the use of computational fluid dynamics (CFD) as a tool to get a detailed understanding of the process, which is essential in the design and selection of equipment (MONTENSEN *et al*., 2003; NAIK-NIMBALKAR *et al.* 2010; ŠTIGLER *et al*., 2012; ANDRADE, 2013).

This information, combined with the significant advances made in theoretical understanding of the fundamental processes governing the mixture, has increasingly made possible using a T-junction as mixer. Frank et al. (2010), for example, employed CFD to study non isothermal mixing of two streams of water (tap water and deionized water) at the same entry speed into a mixing "T", where the main and the secondary braches have the same diameter of circular cross section. The simulations were performed using the software Ansys CFX 11.0 applying the turbulence models SST (Shear Stress Transport) and the model BSL RSM (baseline Reynolds stress model). Frank *et al.* (2010) concluded that both turbulence models provided good results when compared with the experimental data. They also observed that after the connection, the upper wall of the duct undergoes major temperature fluctuations. Wang *et al.* (2014) evaluated experimentally the behavior of a turbulent mixing of hot and cold fluids in a T-junction filled with a porous ambient with 360 spherical particles composed of stainless steel with 28 mm in diameter, in order to determine the influence of spheres in temperature fluctuations. The results indicated higher instantaneous oscillations of temperature in the middle and upper part of the mixing zone. The increase of the flow rate decreased temperature fluctuations. Araújo (2014) realized a numerical study of the thermal fluid dynamic of the flow water-oil in pipe with a T-junction in the presence of leakage, evaluating three turbulence models (k-ε default, SST and RNG k-ε). Araujo (2014) concluded that the turbulence models have provided good results when compared with the experimental data.

Based on the above, the proposed work is motivated by the importance of confined crossflow in separation processes, mixing and reaction using T-junction. In order to make a contribution in the dynamic fluid parameters on the conditions that lead to fatigue, a numerical study of the convergent flow of water using ANSYS CFX software was carried out by setting a value of flow speed of water inthe main branch, changing the values in the secondary branch.

2. METHODOLOGY

2.1 Problem Description

In the Figure 1 is represented the experimental apparatus used by Naik-Nimbalkar et al. (2010). In this figure is highlighted by a dashed line the field of study adopted to numerically study the flow at the T-junction, aimed achieving the objective of this work.

The study area consists of a T-type pipe with the main extension 120 cm, 5 cm in diameter, connected to a secondary extension of 60 cm with 2.5 cm in diameter. Two branches are supplied with water at different temperatures characterizing a cross flow at the junction (mixing system).

In Figure 2 is shown the study domain regarding to the pipe with a T-junction, having two inputs and one output. The section A is fed with a cold flow and the section C with a hot flow. The geometry of the study area was created with the help of ICEM CFD software from creating points, curves, surface. Then, a mesh was made using the blocking strategy, which is formed by hexahedral elements 469340, as can be seen in Figure 3.

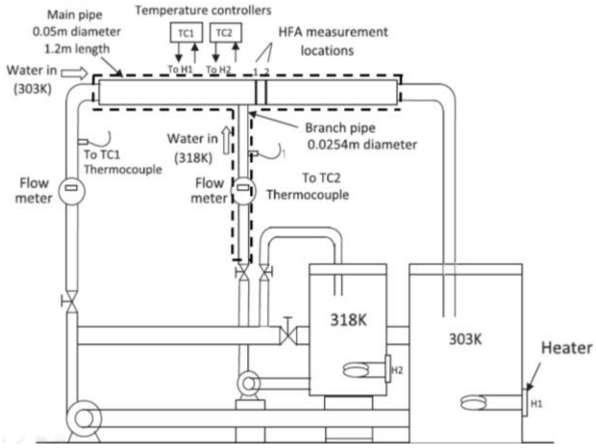

Figure 1. Schematic diagram of experimental setup for cross flow experiments
Source: Naick Nimbalkar *et al.* (2010)

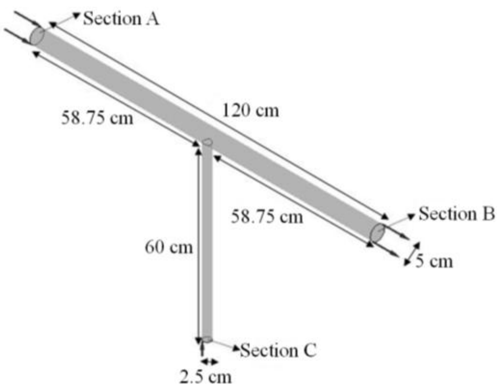

Figure 2. T-junction Domain

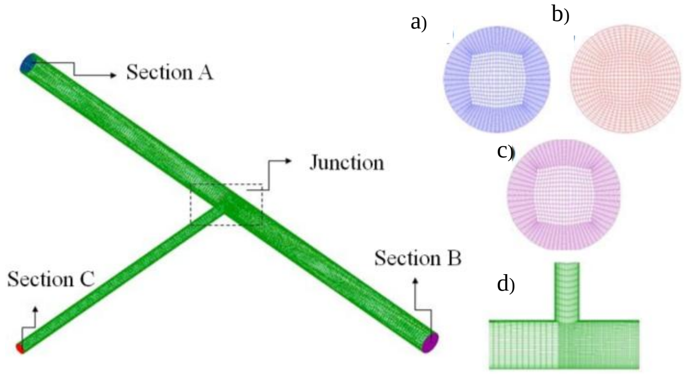

Figure 3. Mesh on the domain, with details in the Section (a) A, (b) B e (c) C and (d) T-Junction

2.2 Mathematical Modeling

The definition of the mathematical model to describe the flow is based on the mass conservation equations, momentum and energy. Adopting the following considerations:

a) Incompressible Newtonian fluid, with constant density and viscosity as a function of temperature;
b) Flow in steady state, non-isothermal and turbulent;
c) Pipe walls are static and without roughness;
d) Absence of chemical reaction;
e) There is no phase changes;
f) There is no external heat source;
g) Was used as a convergence criterion the root mean square (RSM) of 10^{-08};

With these considerations, the conservation equations are written as:

- ✓ **Equation of mass conservation:**

$$\nabla \cdot \left(\rho \vec{U}\right) = 0 \tag{1}$$

where ρ is the density and $\vec{U}$ is the velocity vector.

- ✓ **Equation of momentum conservation:**

$$\nabla \cdot \left(\rho \vec{U} \otimes \vec{U}\right) + \nabla \vec{p} - \nabla \cdot \left\{\mu_{ef}\left[\nabla \vec{U} + \left(\nabla \vec{U}\right)^T\right]\right\} = 0 \tag{2}$$

where $\vec{p}$ is the pressure vector and μ_{ef} is the effective viscosity defined by:

$$\mu_{ef} = \mu + \mu_t \tag{3}$$

where, μ is the dynamic viscosity of the fluid and μ_t is the turbulent viscosity given by:

$$\mu_t = C_\mu \rho \frac{k^2}{\varepsilon} \tag{4}$$

where C_μ is a constant (0,09), ρ is the density of fluid, κ is the turbulent kinetic energy and ε is the turbulent dissipation rate. The values of κ and ε were determined with the aind of the turbulence model κ-ε standard, shown below.

- ✓ **Equation of energy conservation:**

$$\nabla \cdot \left(\rho \vec{U} h - \lambda \nabla T\right) = 0 \tag{5}$$

where h is the heat transfer coefficient and λ the thermal conductivity.

2.2.1 Turbulence Model (κ-ε standard)

The transport equations for estimating the variables, κ, turbulent kinetic energy (dimensions L^2T^2) and, ε, urbulent dissipation rate (dimensions L^2T^2) are given by:

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial}{\partial x_j}\left(\rho U_j k\right) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial \kappa}{\partial x_j}\right] + P_k - \rho\varepsilon + P_{kb} \tag{6}$$

$$\frac{\partial(\rho \varepsilon)}{\partial t} + \frac{\partial}{\partial xj}\left(\rho U_j \varepsilon\right) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + \frac{\varepsilon}{k}\left(C_{\varepsilon 1}P_k - C_{\varepsilon 2}\rho\varepsilon + C_{\varepsilon 1}P_{\varepsilon b}\right) \tag{7}$$

where $C_{\varepsilon 1}$, $C_{\varepsilon 2}$ are empirical constants, respectively equal to 1,44 and 1,92; σ_{ε}, σ_k are constant equal to 1,0 and 1,3, respectively. P_{kb} and $P_{\varepsilon b}$ represent the influence of the forces of buoyancy.

In the equations (3.6) e (3.7), the term P_k corresponds to the production of turbulent viscous forces, given by:

$$P_k = \mu_t \left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i} \right) \frac{\partial U_i}{\partial x_j} - \frac{2}{3} \frac{\partial U_k}{\partial x_k} \left(3\mu_t \frac{\partial U_k}{\partial x_k} + \rho k \right) \quad (8)$$

2.2.2 Boundary Conditions

According to the sections shown in Figure 2 were set to the boundary conditions used in the numerical simulations.

In the input section A were assumed that:

$$u = u_A \quad (9)$$

$$T = T_A \quad (10)$$

In the input section C:

$$u = u_C \quad (11)$$

$$T = T_C \quad (12)$$

where the values of u_A, T_A, u_C and T_C are shown in Table 2 for the cases studied.

In the output section B were assumed that:

a) Static pressure equal to 101325 Pa.
b) In the walls were adopted the conditions of no slip, therefore, speeds components in the directions x, y and z null. (Equation 13).

$$u_x = u_y = u_z = 0 \quad (13)$$

Table 1. Values of speed and temperature at the inlet

Section A		Section C	
u_A (m/s)	T_A (K)	U_C (m/s)	T_C (K)
1	303	0,10	318
1	303	0.25	318
1	303	0.50	318
1	303	0.75	318
1	303	1.00	318
1	303	1.25	318

2.2.3 Physical and Chemical Properties

The properties of the oily water used in no isothermal simulations for the study the effect of operating parameters on the fluid-dynamic behavior of the mixing process performed at a T-junction are presented in Table 2.

Tabela 2. Propriedades Físico-Químicas do Fluido em estudo

	Property	**Values**
Water	Density (Kg/m^3)	997[(1)]
	Viscosity [Pa.s]	Equation 14 [(2)]
	Specific Heat (J/Kg.K)	4181,7[(1)]
	Thermal Conductivity (W/m.k)	0,6198[(1)]

[(1)]Manual of CFX 12.1; [(2)]Cunha (2010)

$$\mu_{água} = \frac{2,185}{\left(40,12 + 0,0051547.T_F\right)T_F - 1000} \tag{14}$$

where T_F is the temperature of the fluid in Kelvin.

3. RESULTS AND DISCUSSION

In order to analyze the pressure fields, speed and temperature with greater precision downstream of the T-junction, are shown in Figure 4 the study domain with an XY plane near the junction.

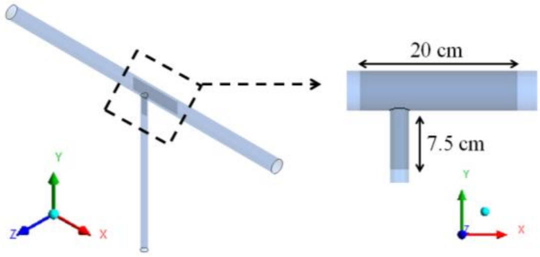

Figure 4. Representation of the XY Plane near the junction and their dimensions

In the Figure 5 is shown the speed field on the longitudinal plane XY illustred in the Figure 4. There are low values of velocity near the tube wall, particularly downstream of the junction where it is possible to observe a region with a tendency to the appearance of recirculation zones. These regions tend to increase proportionally as the speed of the inlet of the secondary branch (Section C) increases.This result is ratified from the representations of flow lines, starting from section A and C shown in Figure 6. The results indicate that the higher velocity gradient is present in the mixing zone of the Case 07, where it uses the speed of 1.25 m/s at the entrance of the secondary branch, providing higher velocity gradients.

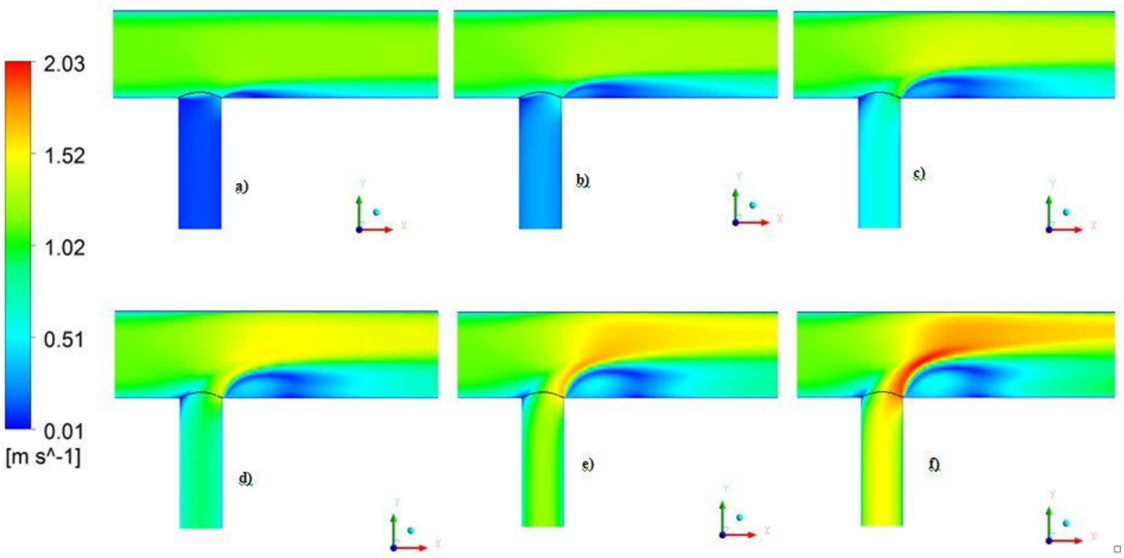

Figure 5. Velocity field in the longitudinal plane XY. (a) 0.10 m/s; (b) 0.25m/s; (c) 0.50m/s; (d) 0.75m/s; (e) 1m/s; (f) 1.25m/s

The Figure 7 show the pressure field on the plano XY (Figure 4). In the mixing system there is a decrease on the pressure gradient downstream the junction proportionally to the increased of inlet speed in main extension, generating potential stocks vacuums areas, being more prone to cracking and breaking of the pipe.

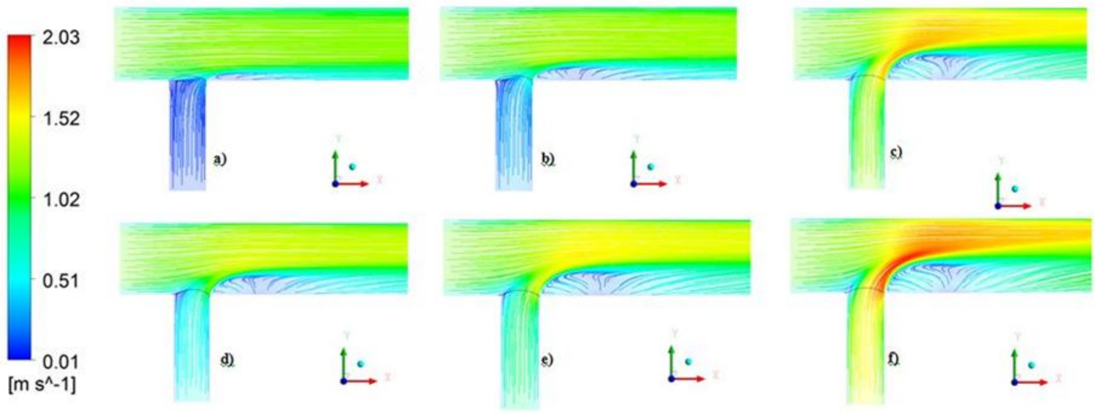

Figure 6. Representation of flow lines in the longitudinal plane XY: (a) 0.10 m/s; (b) 0.25m/s; (c) 0.50m/s; (d) 0.75m/s; (e) 1m/s; (f) 1.25m/s.

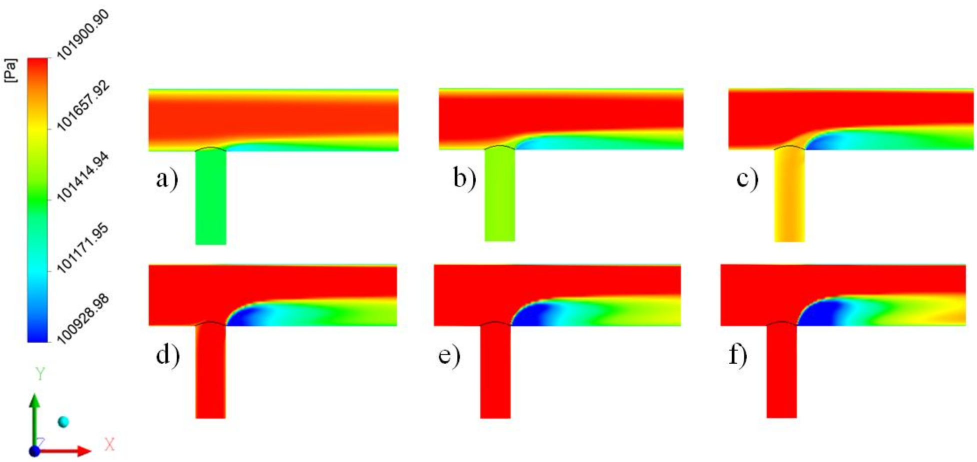

Figure 7. Pressure distribution on the longitudinal plane XY for the cases 02 to 07(a) 0.10 m/s; (b) 0.25m/s; (c) 0.50m/s; (d) 0.75m/s; (e) 1m/s; (f) 1.25m/s

The Figure 8 shows the temperature distribution on the plane XY(Figure 4) which can be seen the temperature fluctuations in the walls near the T-junction, caused by the behavior of the fluid downstream of the T-junction, which is affected by increased of the input speed in the secondary branch, making the region more propitious to suffer a thermal fatigue. It can also be seen that the higher velocities the temperature profile requires a greater length of the duct so that fluid can reach the temperature distribution as shown in Figure 9.

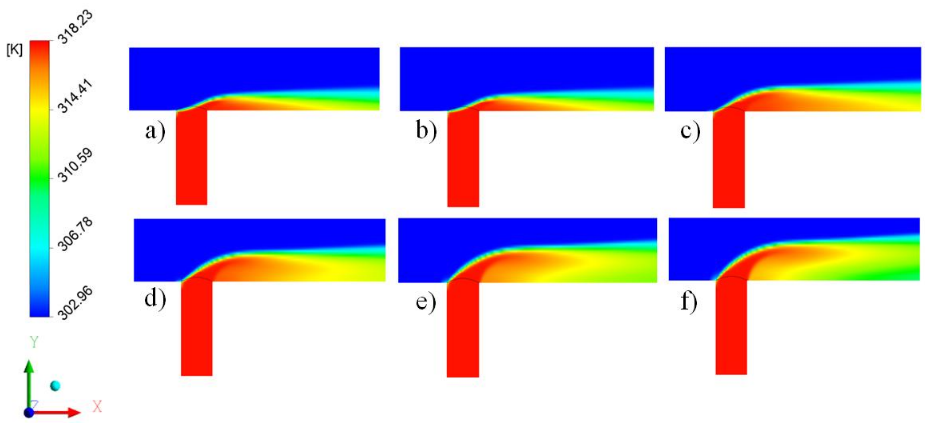

Figure 8. Temperature field on the longitudinal plane XY: (a) 0.10 m/s; (b) 0.25m/s; (c) 0.50m/s; (d) 0.75m/s; (e) 1m/s; (f) 1.25m/s

The temperature behavior shown in Figure 9 directly influence in the dynamic viscosity, as shown in Figure 10, which shows the dynamic viscosity field on the plane XY, and hence reduces the viscous resistance and directly influences on the behavior fluid, as shown in Figures 5 and 6.

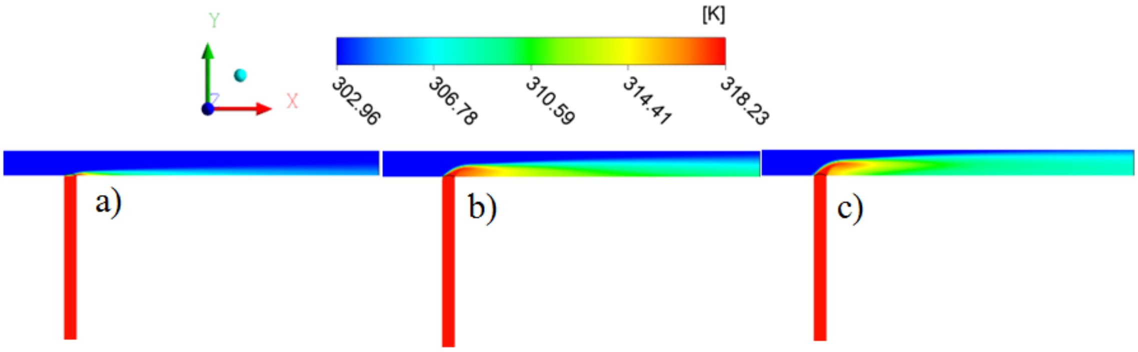

Figura 9. Temperature field on the longitudinal plane XY for the Cases 02 to 07: (a) 0.10 m/s; (b) 0.75m/s; (c) 1.25m/s.

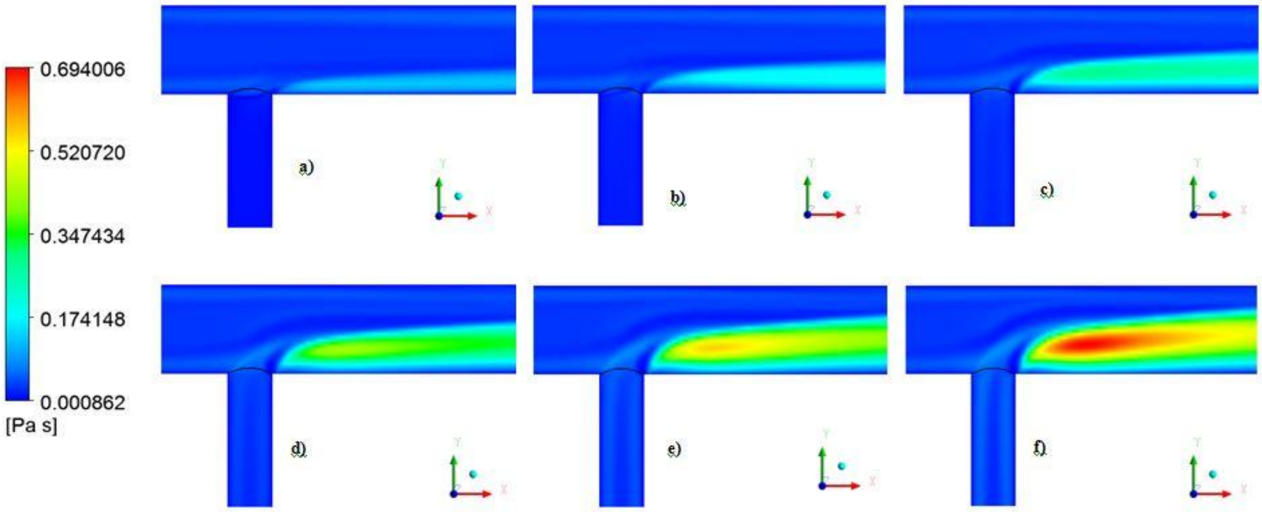

Figure 10. Dynamic viscosity field on the longitudinal plane XY: (a) 0.10 m/s; (b) 0.25m/s; (c) 0.50m/s; (d) 0.75m/s; (e) 1m/s; (f) 1.25m/s.

4. CONCLUSION

The results of numerical simulations of a mixing system in the presence of a T-junction provided the following conclusions:

- ✓ The mathematic model was able to represent the physical phenomena involved in the problem in question;
- ✓ The numerical results show good agreement with the data available in the literature;
- ✓ The velocity fields, pressure, temperature and flow lines indicate that a pipe with T-junction allows for good thermal mixture;
- ✓ The variation of inlet speed in the secondary branch has a significant influence on the velocity profiles and temperature of the flow;
- ✓ The regions nearest the T-junction are the most likely to suffer the effects of thermal fatigue.

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