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Numerical Study of Oil Flow in Tee Junction with Leaks

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Abstract

This article describes oil flow dynamics behavior in a tee junction with one or two leak orifices. The main branch is 6 m long and has 10 cm in diameter, while the secondary branch has the same diameter and 3 m long. The interest of this work is to evaluate the influence of the leak in the flow dynamics parameters. The behavior of the fluid was analyzed using velocity vectors, streamlines and pressure fields.

Key words: Numerical simulation; Oil; Tee junction

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INTRODUCTION

The pipelines used to transport oil and others chemical products must be made with good materials that support high tensions and are resistant to corrosion. Despite the development in this area, cracks and leakages are detected in large range of industries in all the world.

In the literature various researches about the behavior of the fluid through the tee junction has been found. Some of these works are related to effects of the fluctuation of temperature in the pipe.

Frank *et al.* (2010) report a numerical work of water flow in tee junction using the software CFX 11.0, in order to test turbulence models. For the isothermal and converging flow, the models SST and BSL RSM of water produced results consistent with the experimental ones. For non-isothermal single phase flow of water, this fluid was injected in an inlet section with temperature of 15 °C and at another inlet with 30 °C. The results produced with the SST-SAS model showed the best results.

Naik-Nimbalkar *et al.* (2010) have studied the effects of thermal mixing in tee junction. The authors say that the temperature fluctuations cause cyclic thermal stress and a sequential fatigue crack on the structure of the duct.

Kamaya and Nakamura (2011) studied the three-dimensional flow in a tee junction, where the water enters in the main duct (horizontal) with a temperature of 321 K and velocity of 1.46 m/s, and in the branch (vertical) the fluid enter with 306 K and 1 m/s. The authors used the software CFX-10 (ANSYS, Inc.) to generate the mesh on the domain and perform the transient simulation . The authors report that fatigue have been found in tee junction where fluids that entered with different temperature are mixed. Due to fluctuations of temperature caused by flow mixture, the pipe wall suffer cyclic thermal stresses.

The results show that the stresses are big in the edge of the tee junction and the biggest stress was verified in the main pipe after T-junction.

Ming and Zhao (2012) simulated with aid of the software FLUENT the water flow in a T-junction. The boundary conditions used were: water flow in the inlet (horizontal main duct) with a temperature of 293.15 K and velocity 0.27 m/s, while in the ramification (vertical) were used 326.05 K and 1.26 m/s. Evaluating how the mesh size can interfere in the results, four cases were simulated with the same conditions. The mesh with 1265424 elements was chosen, because the rise of this mesh do not interfere in the velocity and temperature profiles. Were tested the models of turbulence RANS

(*Reynolds Averaged Navier-Stokes*) and LES (*Large Eddy Simulation*) and was concluded that the LES model shown clearer the vortices formed inside the duct.

Stigler *et al.* (2012) analyzed the experimental velocity profiles provided by PIV system (Particle Velocity Measurement) in a T-junction. The physical domain was reproduced in the software GAMBIT 2.2.30 and the simulations were made using the software Fluent 12.1. The authors assumed a value of pressure at the ends of the T-junction, justifying that despite this assumption is not true, it have still been used because it is very simple and handy. The *k-e* turbulence model was used. The authors concluded that the PIV measurements and numerical result are very close, which enables the confidence in the numerical solution.

The articles cited previously, in general, report the mixing of fluids in different temperatures and the effects on the pressure and velocity fields. Others articles refer to separation of different fluids along the pipe with the assistance of tee junction[4,7,9,10,15].

Several authors[1,2,3,12,14] studied techniques based on pressure transient analysis under different flow conditions, such as type fluid in the tubing, the magnitude and location of leakage, discharge outlets, duct dimensions, pressure operation and flow regime (laminar or turbulent).

Based on the topic reported, this work aim to study the effect of leak on the flow transient behavior in a T-junction using the ANSYS CFX software.

1. METHODOLOGY

1.1 Study Domain

To study the hydrodynamics of the oil flow in a horizontal tee junction, was adopted a physical domain. The study domain consists of a horizontal main pipe with 6 meters and a branch pipe with 3 meters. The pipe has 0.1 m in diameter. There are two leak orifices, how is shown in the Figure 1. The representation of the computational domain was done with the aid of ICEM-CFD 12.1 through points, curves and surfaces (Figure 1).

The representative mesh of the pipe was generated using the block strategy, in which a single block is initially created involving the area of study and then the block is subdivided into several others. This strategy allows greater control of mesh refinement in regions desirable. The mesh was refined on the geometry and contains approximately 695676 control volumes as shown in Figure 2.

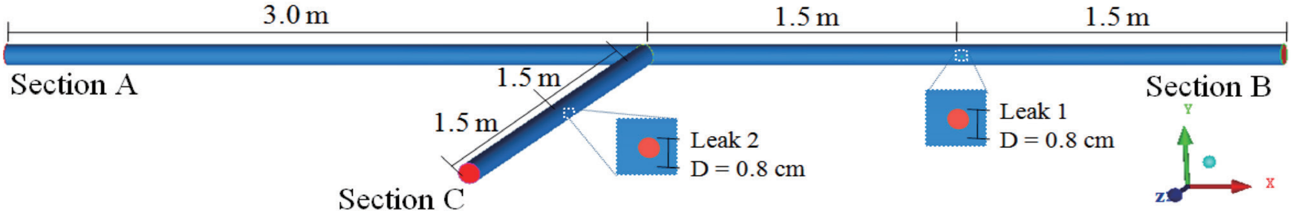
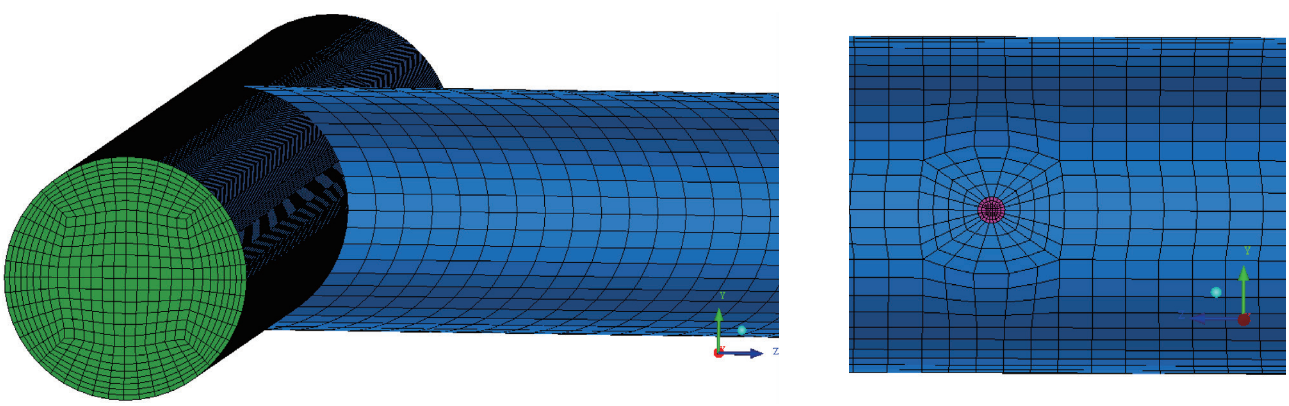


Figure 1
Physical Domain of the T-Junction Used in This Work



(a) (b)

Figure 2
Computational Domain of the (a) T-Junction and (b) Detail of the Leak Orifices

1.2 Mathematical Modeling

The governing equations to describe the single-phase fluid flow in a T-junction are the conservation of mass and momentum, represented by Equations (1), (2), (3) and (4) where they were used the following assumptions:

- The fluid is Newtonian and incompressible;
- The physico-chemical properties are constants;
- Isothermal process;
- There is no occurrence of chemical reactions;

• It was not considered the gravitational effect;

• Laminar flow.

The transport equations that describe the flow were withdrawn in the manual of CFX 12.1.

a) Permanent model there is the equation of mass conservation:

• Mass conservation equation

$$\nabla \cdot (\rho \boldsymbol{U}) = 0 \tag{1}$$

Where *r* and ***U*** are, respectively, the density and the velocity vector.

• Momentum conservation equation

$$\nabla \cdot (\rho \boldsymbol{U} \otimes \boldsymbol{U}) + \nabla p + \nabla \cdot \tau = 0 \tag{2}$$

Where *p* is the pressure and *t* is the stress tensor.

b) Transient model:

• Mass conservation equation

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{U}) = 0 \tag{3}$$

Where *t* is the time.

• Momentum conservation equation

$$\frac{\partial (\rho \boldsymbol{U})}{\partial t} + \nabla \cdot (\rho \boldsymbol{U} \otimes \boldsymbol{U}) + \nabla p + \nabla \cdot \tau = 0 \tag{4}$$

1.3 Boundary Conditions

The boundary conditions of all case are described in the Table 1.

The Case 1 was simulated in a steady state condition and without leakage. This case was used how initial conditions to the Cases 2, 3 and 4, which were simulated in transient conditions. This methodology was adopted because there is a need for defined flow behavior before that a leak occurs, better characterizing the physical phenomenon.

1.4 Physico-Chemical Properties

The properties of the oil used in the present work are shown in Table 2.

Table 1
Studied Cases

	Section A	Section B	Section C	Leak orifice 1	Leak orifice 2
Case 1	0.5 m/s	101325 Pa	101325 Pa	No slip wall	No slip wall
Case 2	0.5 m/s	101325 Pa	101325 Pa	101325 Pa	No slip wall
Case 3	0.5 m/s	101325 Pa	101325 Pa	No slip wall	101325 Pa
Case 4	0.5 m/s	101325 Pa	101325 Pa	101325 Pa	101325 Pa

Table 2
Oil Physico-Chemical Properties Used in This Work

Properties	Oil	Source
Density (kg/m³)	868.7	Araújo *et al*. (2013)
Molar mass (kg/kmol)	105.47	Araújo *et al*. (2013)
Dinamic viscosity (Pa.s)	0.17	Araújo *et al*. (2013)

2. RESULTS AND DISCUSSION

2.1 The Steady State Flow

The first case was simulated to be obtained initial condition to the next cases. The flow of oil occurs in the steady state and the behavior of the fluid inside the tee junction is shown in a pressure field (Figure 3.a), vectors of velocity (Figure 3.b) and streamlines (Figure 3.c). There is no leakage in this case.

Note that the region near the junction between the main and secondary branches undergoes a mechanical stress larger than the rest of the wall pipe due to the inertial and pressures forces in the fluid which provokes recirculation zone, becoming more prone to the appearance of cracks and fissures.

2.2 The Transient Flow

In the Case 2, a leak was opened in the main branch of the tee junction, Leak 1. Figure 4 shows the pressure field in three different times and it is possible note the variation in pressure near the leak. Figure 5 shows the vectors of velocity, showing the increase of velocity in the leak with time. Figure 6 illustrates streamlines that exhibit the path taken by the oil.

In the Case 3, a leak was opened in the secondary branch of the T-junction, Leak 2. The same analyze for the Case 2 was done for the Case 3 and results are illustrated in the Figures 7, 8 and 9.

In the Case 4, the two leaks were opened simultaneously and consequences are shown in the Figures 10, 11 and 12.

By analyses of the Figures 4 and 7 we can see that the local pressure drop in the leak 2 is higher than in the leak 1, however when two leaks occur the pressure behavior is different.

Due the flow conditions used in this work, the pressure changes with the time along the pipe, but in the sections B and C, the value is constant and equal to 101325 Pa because this value was taken like boundary condition. So, to analyze the pressure variations caused by leak (s), was measured the mean pressure at the section A at different times.

When a leak occurs there is a sudden change in duct pressure that, after a period of time, acquires stability. It can be proved analyzing the Figure 13, where initially there is no leak and at the initial instant (t = 0 s) the leakage is activated. After this time, we can verify that by the measure of the mean pressure at the section A, there is a change in pressure.

By comparing the Cases 2 and 3, note that the leak in the main branch causes a higher pressure drop than the leak in the secondary branch, remembering that both leaks have the same dimension and equal distance from the section A, section of measurement of pressure.

In the Case 4, where the two leaks are opened in the same time, the pressure drop caused for that is bigger that all other simulations.

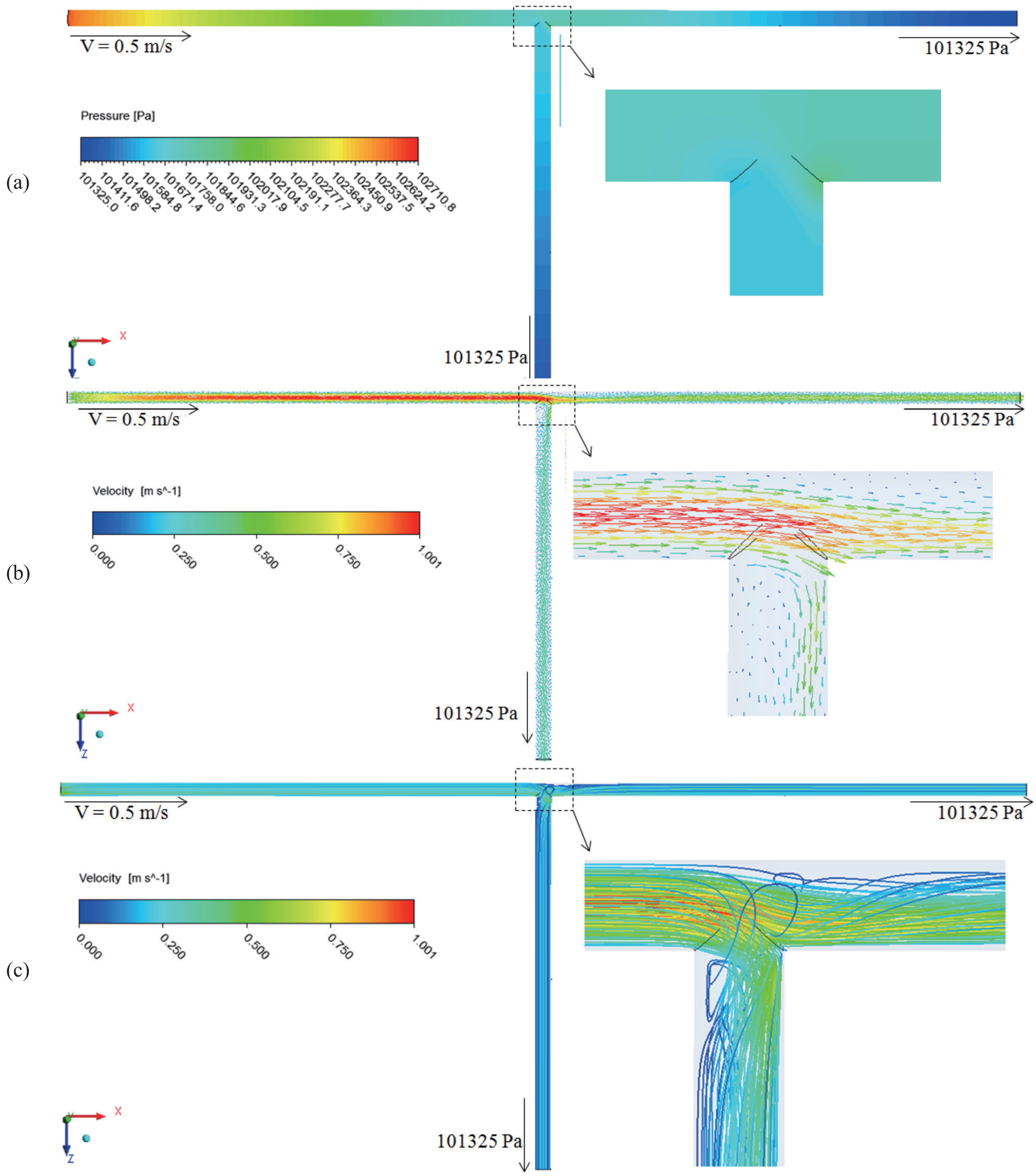


Figure 3
Behavior of Oil in a Steady State Flow (a) Pressure Field, (b) Velocity Vectors and (c) Streamlines (Case 1)

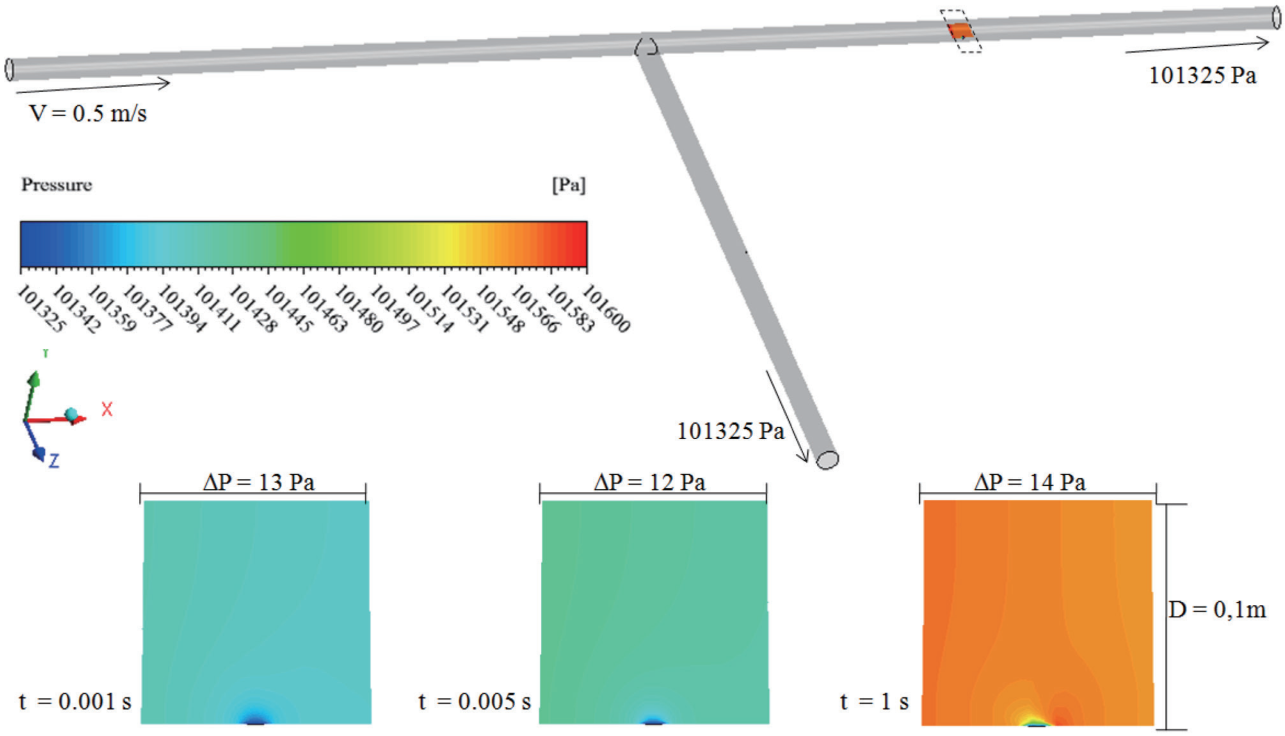


Figure 4
Oil Pressure Field at the Times of 0.001 s, 0.005 s and 1 s (Case2)

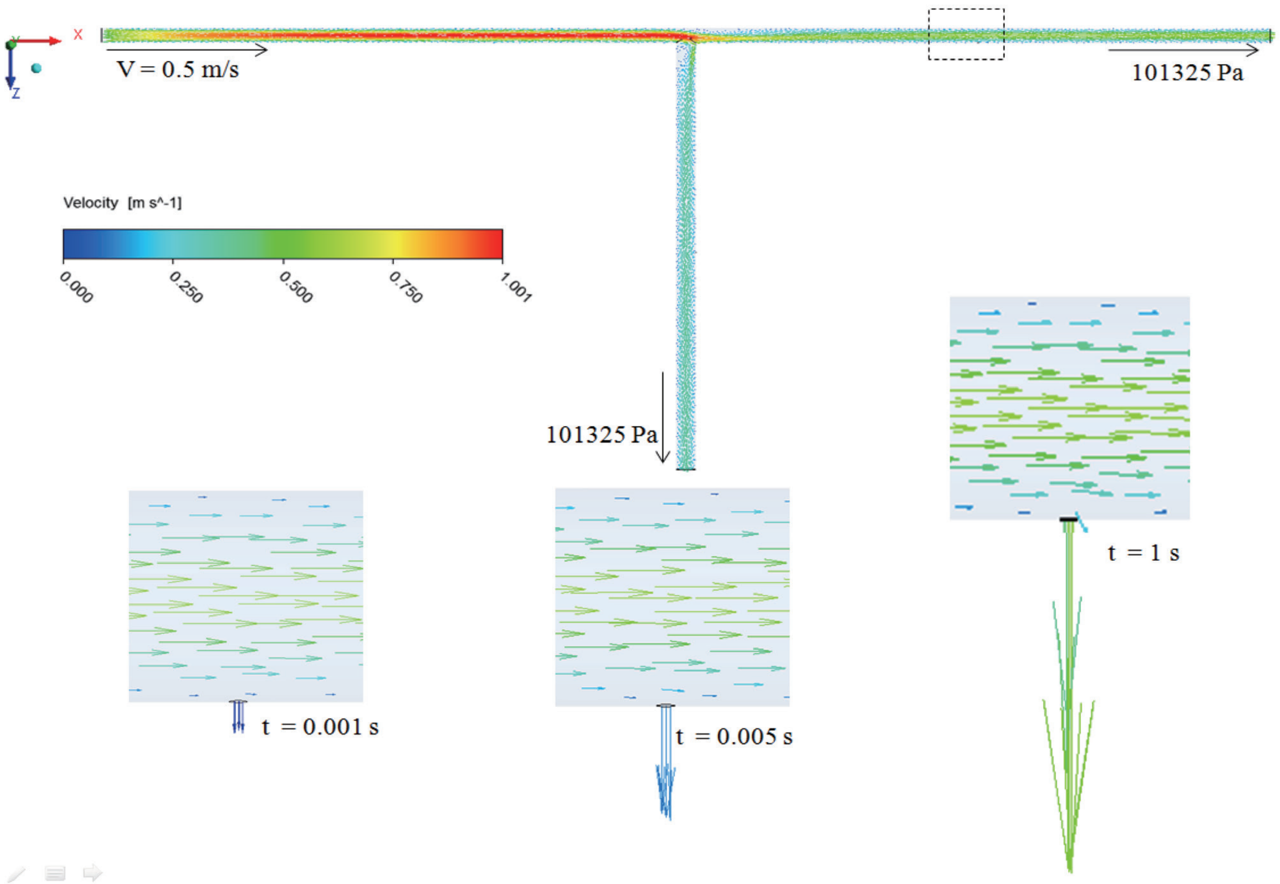


Figure 5
Velocity Vectors of the Oil at the Time of 0.001 s, 0.005 s and 1 s (Case 2)

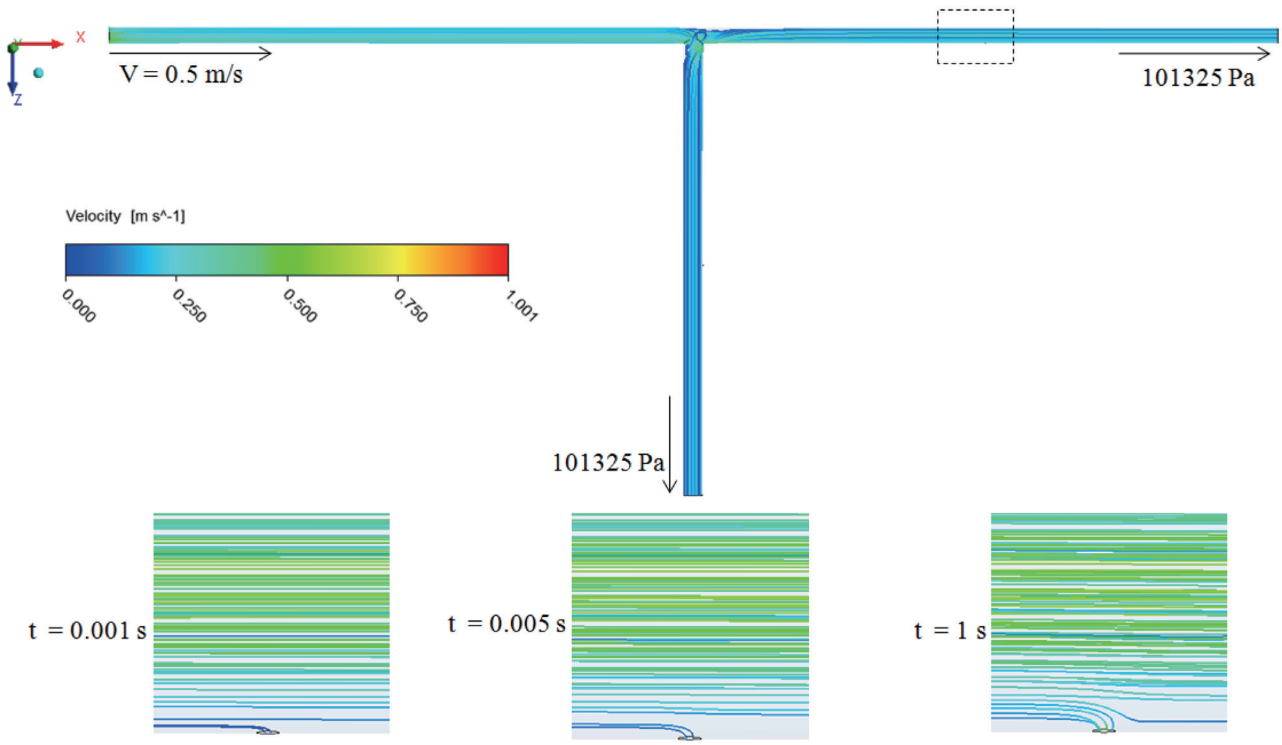


Figure 6
Streamlines of the Oil at the Time of 0.001 s, 0.005 s and 1 s (Case 2)

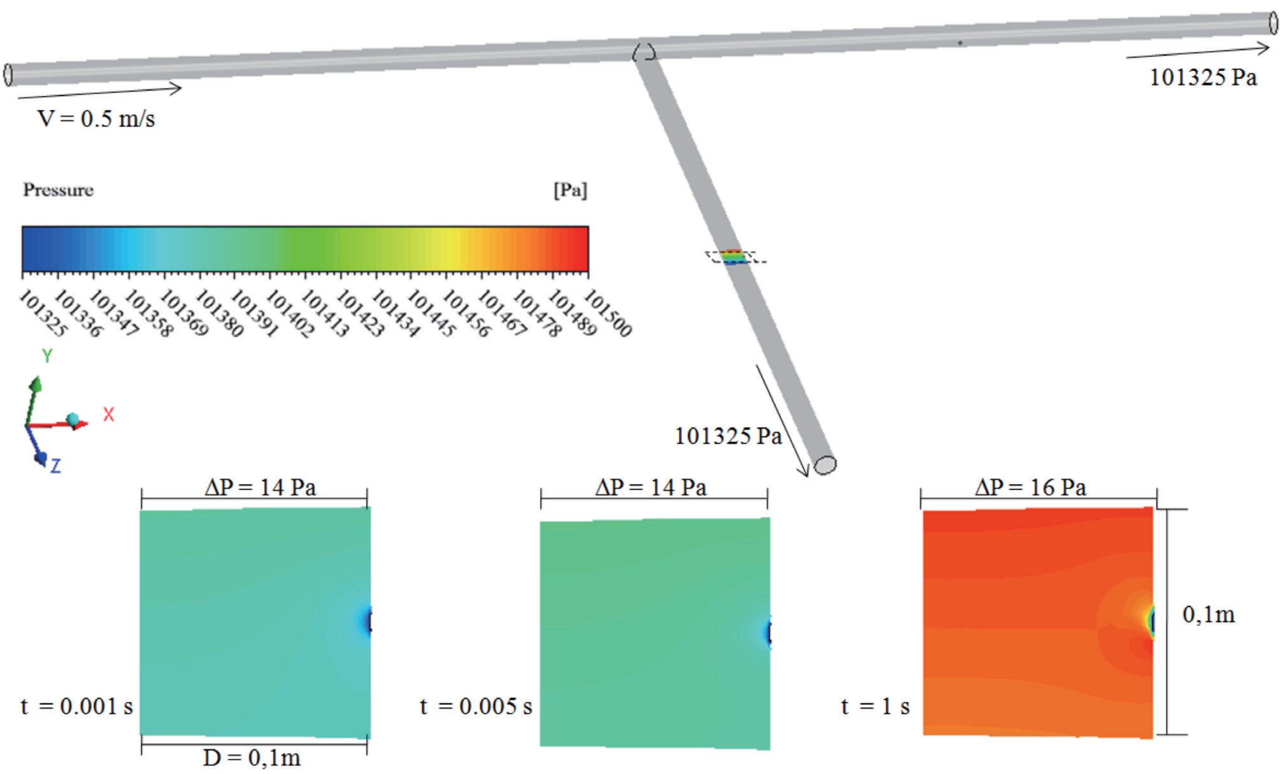


Figure 7
Oil Pressure Field at the Times of 0.001 s, 0.005 s and 1 s (Case 3)

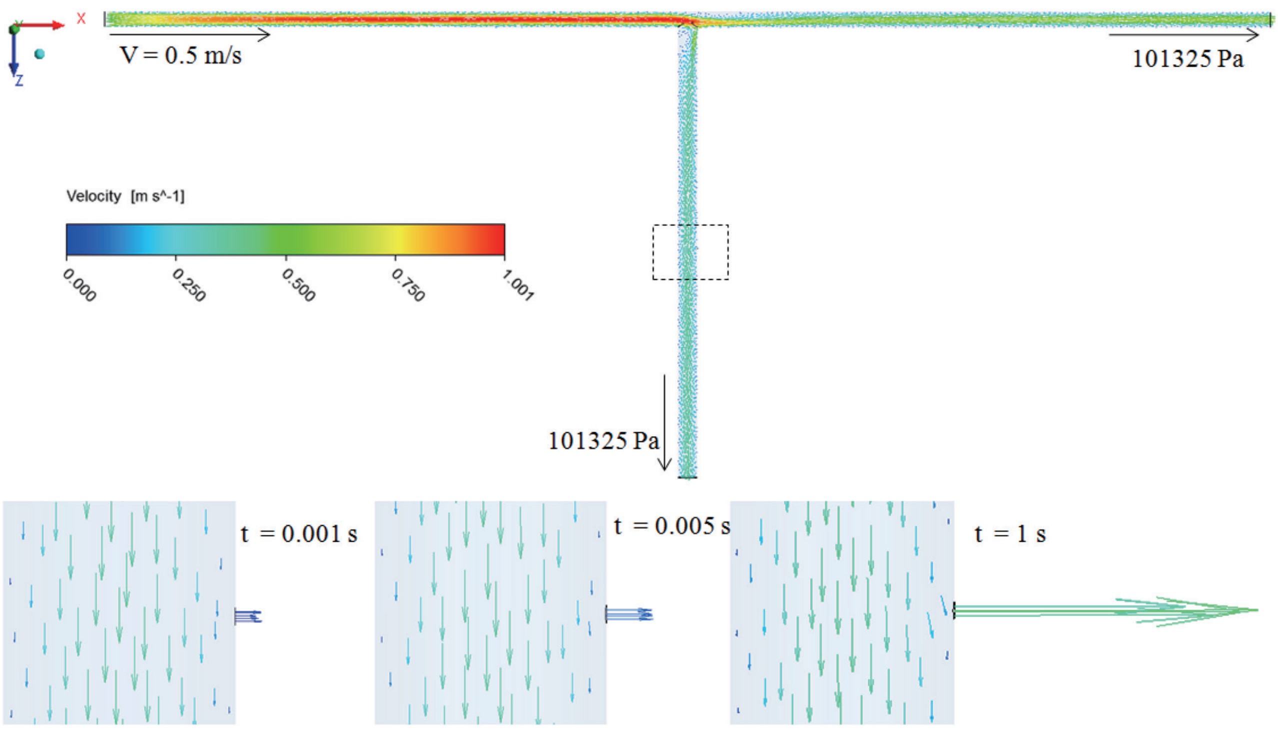


Figure 8
Velocity Vectors of the Oil at the Times of 0.001 s, 0.005 s and 1 s (Case 3)

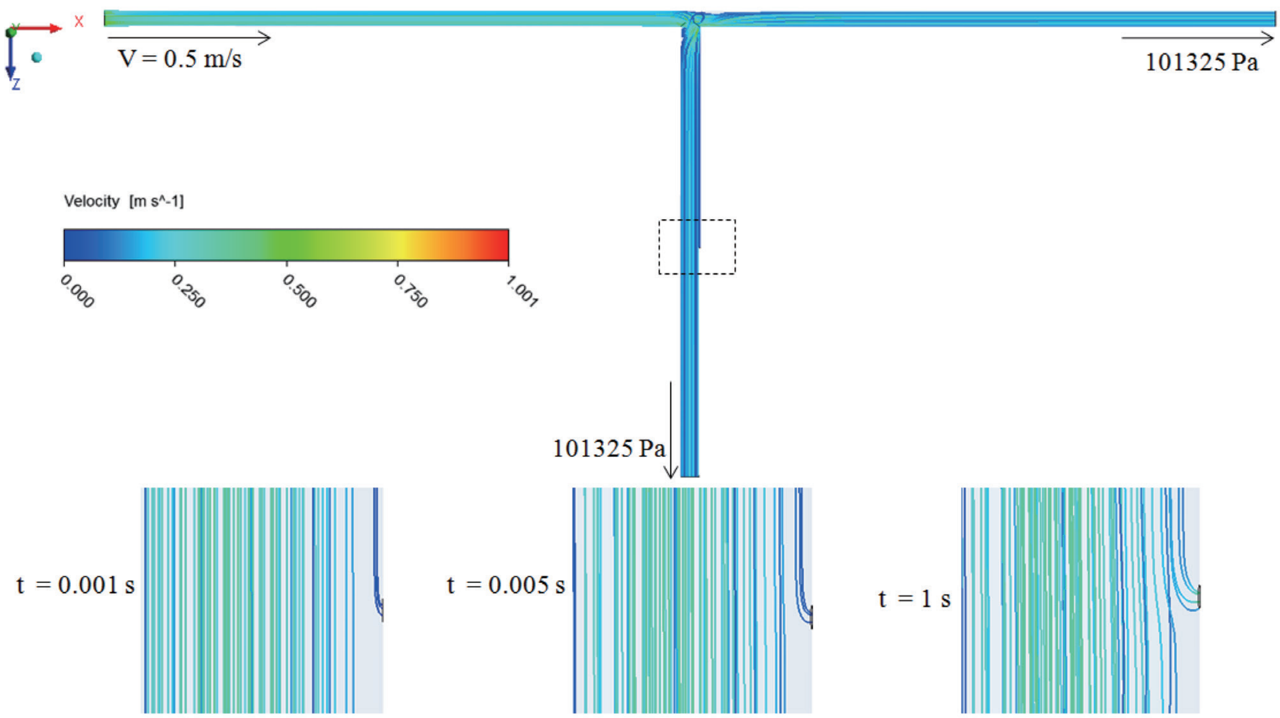


Figure 9
Streamlines of the Oil at the Times of 0.001 s, 0.005 s and 1 s (Case 3)

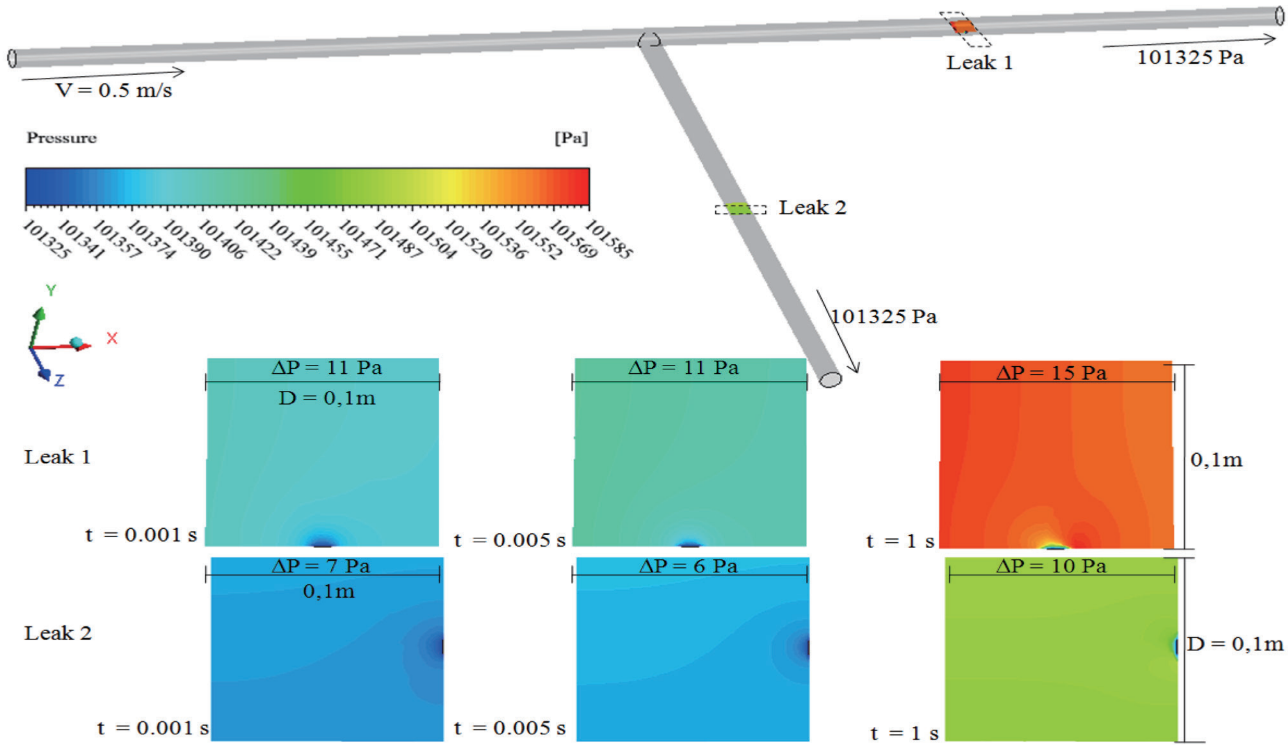


Figure 10
Oil Pressure Field at the Times of 0.001 s, 0.005 s and 1 s (Case 4)

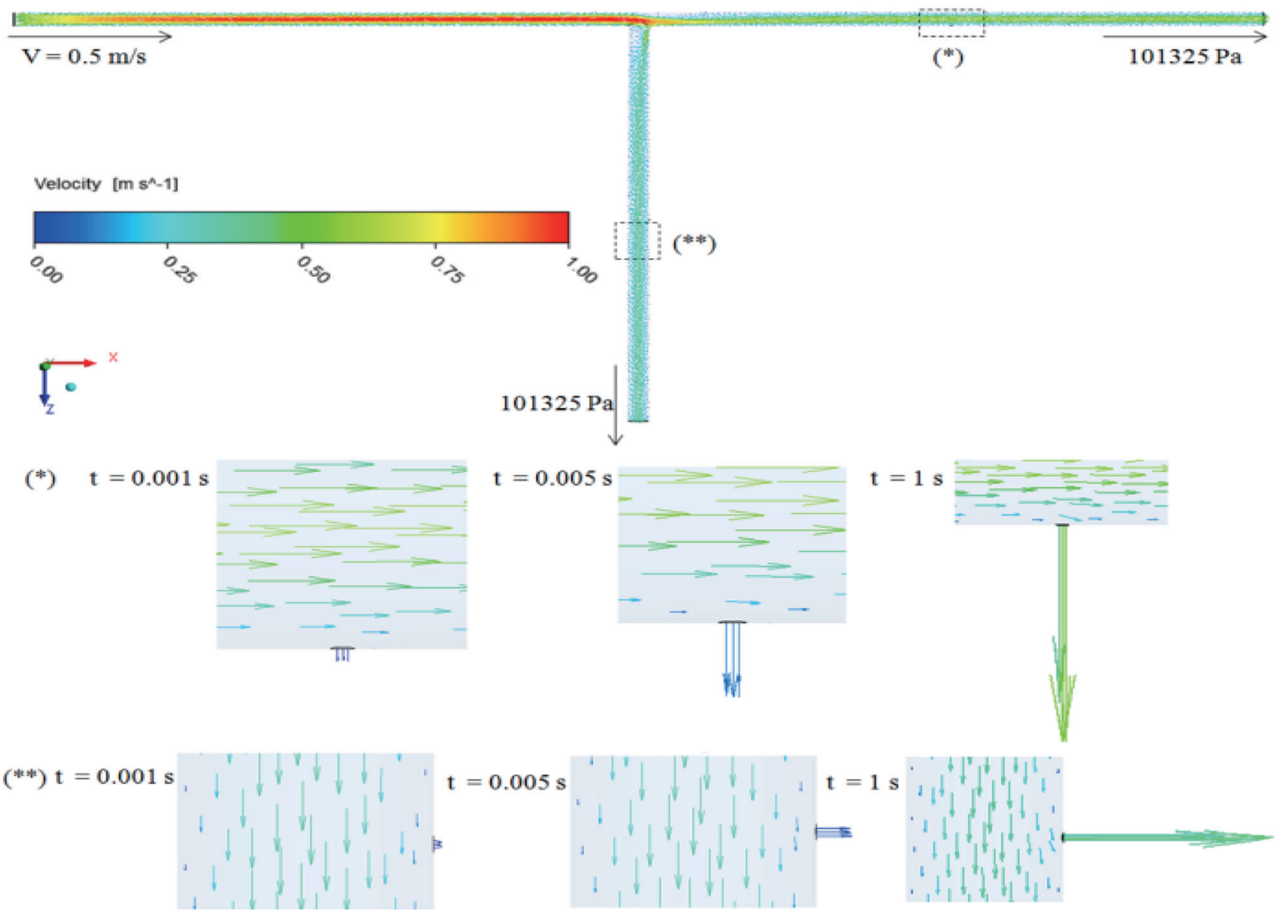


Figure 11
Velocity Vectors of the Oil at the Times of 0.001 s, 0.005 s and 1 s (Case 4)

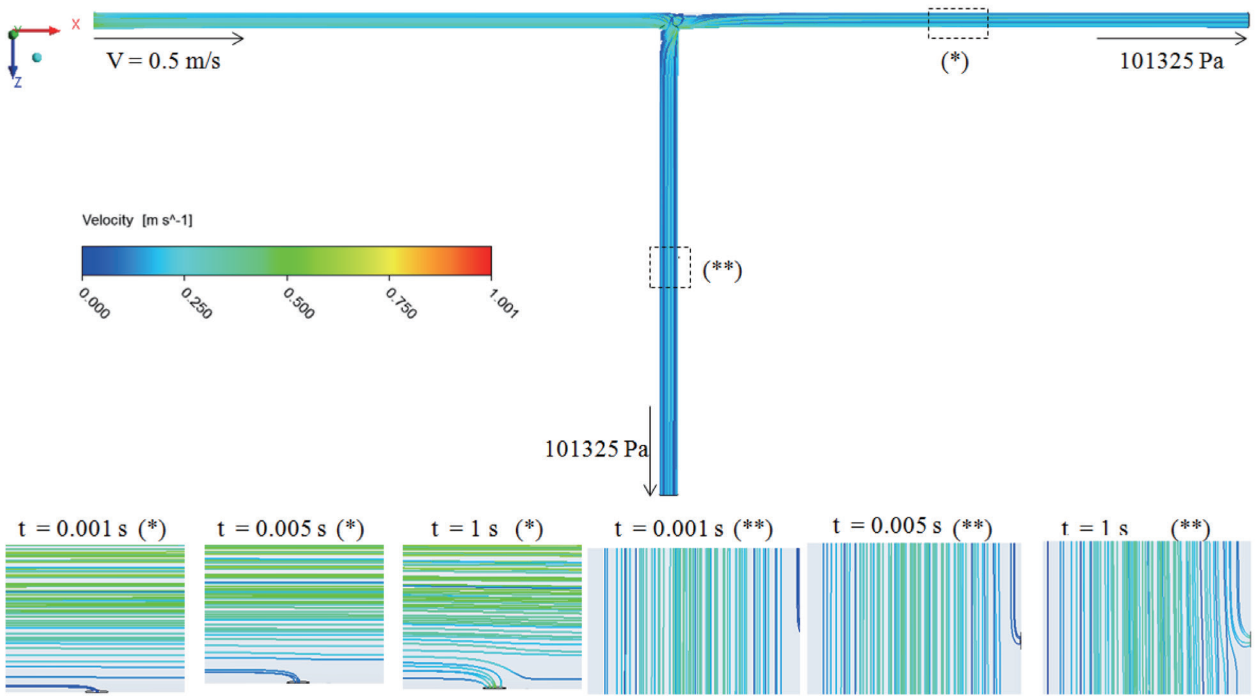


Figure 12
Streamlines of the Oil at the Times of 0.001 s, 0.005 s and 1 s (Case 4)

The measured pressure at the inlet section for pipes without leakage is 102642 Pa. At the moment that the leak happens, the pressure drops are 134 Pa, 105 Pa and 177 Pa for the Cases 2, 3 and 4, respectively. A few moments later, when the pressure is established, the differences between the pressure measured at the inlet section for the instant of time t = 0 s and t = 1 s are, for the Cases 2, 3 and 4, respectively, 3 Pa, 2 Pa and 4 Pa.

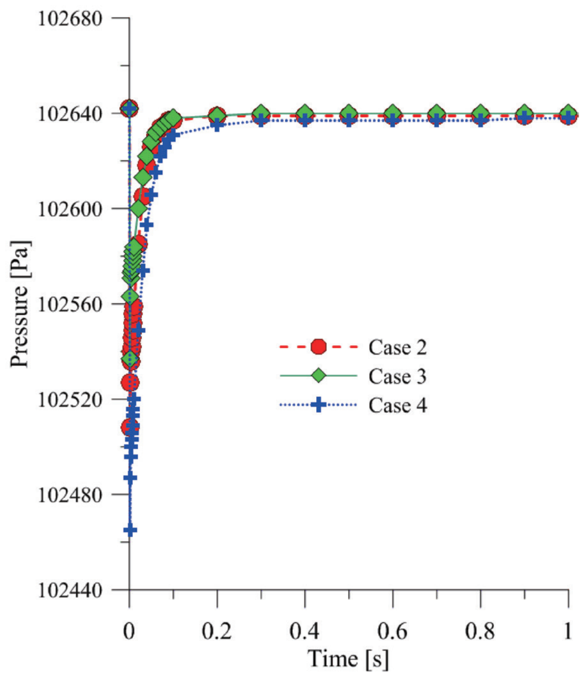


Figure 13
Mean Pressure at the Section A for Transient Flow

Figure 14 shows the mass flow rate in the Leak 1 for the Case 2, in the Leak 2 for the Case 3 and the sum of the mass flow rate in the Leaks 1 and 2 for the Case 4.

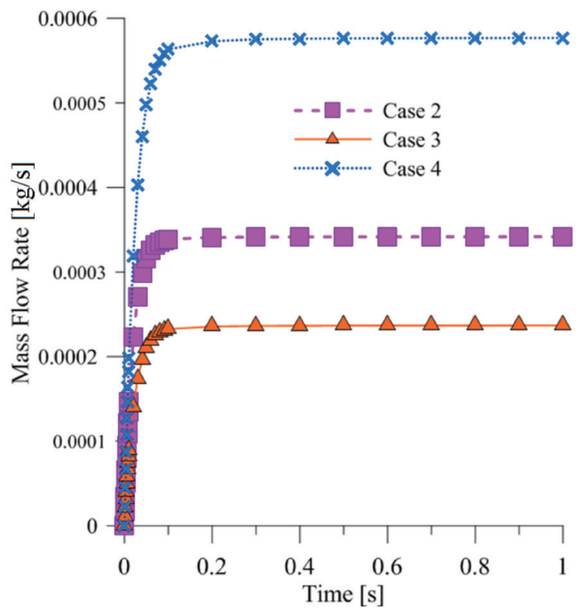


Figure 14
Mass Flow Rate at the Leak as a Function of the Time

The Figure 15 shows the mass flow rate through the outlet sections for all cases. For the Case 4, the loss of oil is approximately 57.4 L/day. According to Price Table of National Agency of Petroleum, Natural Gas and Biofuels – ANP (Brazil) for the year 2013, this mass flow is equivalent to a financial loss of US$ 41.3 per day.

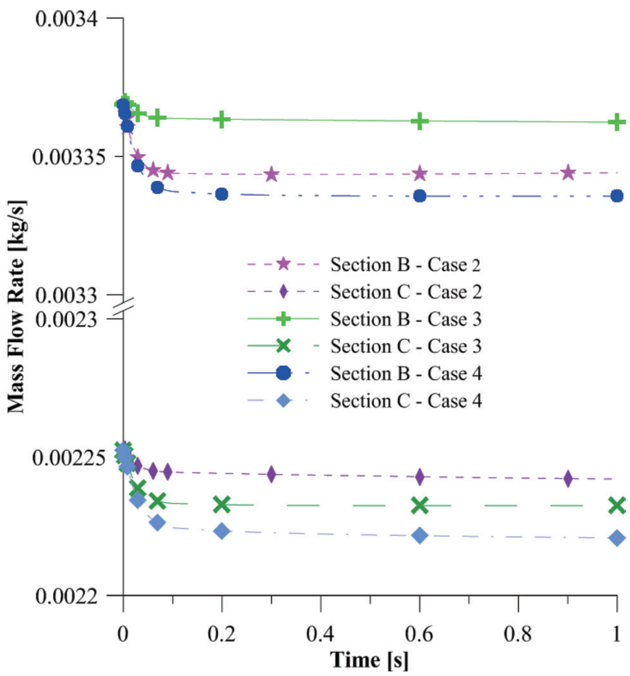


Figure 15
Mass Flow Rate at the Sections B and C as a Function of the Time

The fluid, when pass through the tee junction, tends to follow through the main branch because of the principle of inertia, while a smaller portion of the fluid follows the secondary branch. This justifies the fact that in the Leak 1, Case 2, the flow is established with a mass flow rate bigger than the Leak 2, Case 3.

In the oil industry T-junction are used to sum or divide streams. In this work the division of oil stream was used. The mass flow entering the pipe is 0.005 kg/s. In the Case 1, the mass flow passing through the main branch is 0.003 kg/s, characterizing 60% of the inlet mass flow, while in the secondary branch the value is 0.002 kg/s, which is equivalent to 40% of the inlet mass flow.

CONCLUSIONS

Based on the results of numerical simulation of single-phase flow (oil) in a T-junction with and without leak, it can be concluded that:

(1) The proposed mathematical model was able to predict flow in leak in a horizontal tee junction, evaluating the effect of the position and number of leaks on the flow behavior;

(2) The leak in the main pipe cause a bigger disturb in the pressure at the section A than the leak in the branch of the pipe;

(3) The pressure at the section A measured in a moment before the leak is compared with a pressure at the same region after 1 s of leak, enough time to stabilize the pressure. There was a slight variation of the pressure values due the amount of fluid flowing through it.

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