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STUDY OF A FLAMMABLE FLUID PASSING THROUGH A MIXING T-JUNCTION BY USING THE ANSYS FLUID STRUCTURE INTERACTION CAPABILITIES

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Abstract: *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. In engineering literature, there have been various researches about the behavior of the fluid through the tee junction. Some of these works relate to effects of the fluctuation of temperature in the pipe. The purpose of this article is to study the Fluid-Structure Interaction of a heated flammable fluid (a C10H22-Decane component of gasoline in gaseous phase) passing through a T-Junction where the cold fluid (20^{0}C) is mixing with the warm fluid (90^{0}C). The software used is ANSYS 16. The problem of mixing different temperatures of a certain fluid into a T-Junction and the study of the effects of fluid pressure and fluid temperatures on the stress distribution of the structure is by no means an easy problem to solve. The ANSYS capabilities of treating such Fluid Structure Interaction Problems with different interconnected modules is instead making this problem a trivial problem to solve. The T-Joint under scrutiny is performing well regarding structural safety as demonstrated inside this paper.*

Keywords: *Flammable Fluid; T-Junction; CFD, Fluid Structure Interaction*

Introduction

The pipelines used to transport oil and others chemical products are made with good materials that support high tensions and are resistant to corrosion. [16]

There are many researches about the behavior of the fluid through the tee junction and some of these works relate to effects the fluctuation of temperature has in the pipe.

Frank et al. (2010) used the software CFX 11.0 to report a numerical work of water flow in tee junction, this helped to test turbulence models. The models SST and BSL RSM, for the isothermal and converging flow of water, produced results congruous with the experimental ones.

The results from the SST-SAS model turn the best results for non-isothermal single-phase flow of water (where fluid is injected into an inlet section with a temperature of 15 °C and at another inlet with 30 °C).

Naik-Nimbalkar et al. (2010) have researched the effects of thermal mixing in tee junction. The authors concluded that the fluctuations in temperature 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 T-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 software used by the authors to generate the mesh on the domain and perform the transient simulation was CFX-10 (ANSYS, Inc.). They discovered that in the T-junction where fluids that entered with different temperatures were mixed there were signs of fatigue. Because of the fluctuations in temperature caused by flow mixture, the pipe wall suffers cyclic thermal stresses.

This resulted in big stresses on the edge of the tee junction, and the biggest stress was identified in the main pipe after the T-junction.

Ming and Zhao (2012) have used the FLUENT software to simulate the water flow in a T-junction. The boundary conditions were: water flow in the main horizontal duct (inlet) with a temperature of 293.15 K and velocity 0.27 m/s, while in the vertical duct (ramification) were 326.05 K and 1.26 m/s. For the evaluation of how the mesh size can interfere with the results, the same conditions were simulated in four cases. Because the rise of this mesh does not interfere in the velocity and temperature profiles, the chosen mesh was the one with 1.265.424. The following models of turbulence were tested: RANS (Reynolds-Averaged Navier-Stokes) and LES (Large Eddy Simulation) and the conclusion drawn was that the LES model shown clearer the vortices formed inside the duct.

Stigler et al. (2012) utilized the PIV system (Particle Velocity Measurement) in a T-junction for analyzing the experimental velocity profiles. The physical domain was rendered in the software GAMBIT 2.2.30 and the simulations were made using Fluent 12.1.

The value of pressure assumed by the authors for the ends of the T-junction has been used because it was simple and convenient even if it was not true. They used the k-e turbulence model. The authors have arrived at the conclusion that the

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PIV measurements and numerical result were very close, this enables the confidence in the numerical solution.

The articles mentioned previously report the mixing of fluids in different temperatures and the effects on the velocity and pressure fields, in general. Other articles refer to the separation of different fluids along the pipe with the assistance of tee junction.

The purpose of this article is to study the Fluid-Structure Interaction of a heated flammable fluid (a C10H22-Decane component of gasoline in gaseous phase) passing through a T-Junction where the cold fluid (20^0C) is mixing with the warm fluid (90^0C). The software to be used is ANSYS 16.

Methodology

Study domain

A T-Junction model is subjected to the mixing of two fluids of differing temperatures as seen in the following figure:

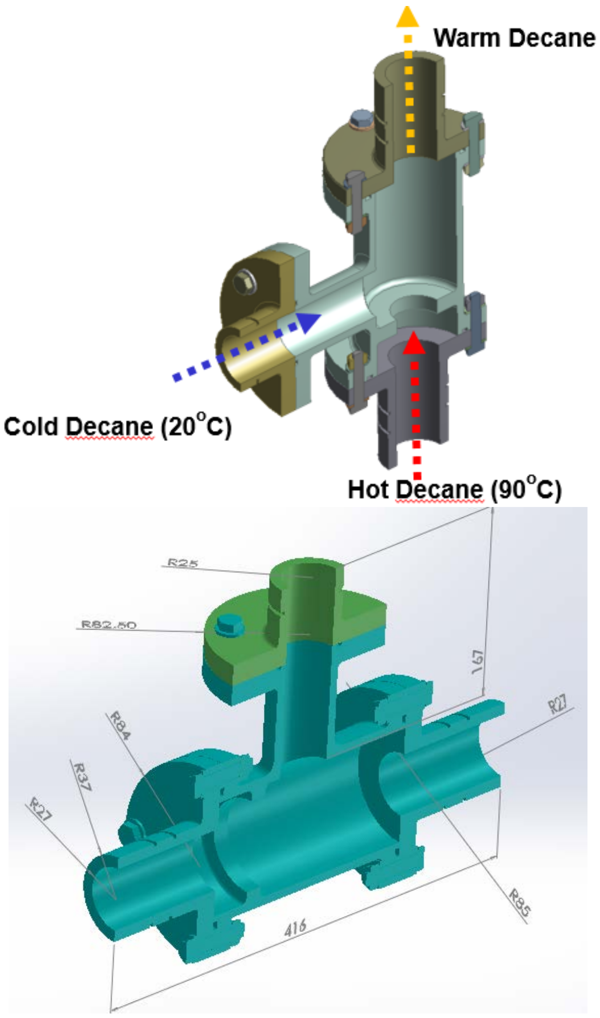

Fig.1 The T-mixing T-Junction

Some of the dimensions of the T0Junction are provided as well, for instance, the diameters of the main pipe branch is 52 mm whereas the cold injection branch is 50 mm in diameter. The pipe material is steel, with tensile yield strength 250 MPa and the ultimate strength 460 MPa. Thermal Conductivity has a value of 60.5 [W m^-1 C^-1], and Specific Heat Capacity has a value of 434 [J kg^-1 C^-1].

The fluid passing through this T-Junction is the normal-decane ("*n*-decane"), with the formula $CH_3(CH_2)_8CH_3$ in gaseous phase, with the following properties:

- Molar mass 142.285 kg / kmol
- Dynamic viscosity 0.0008481 kg/(m/s)
- Thermal conductivity 0.1294 W/mK

The flammable gas in entering the T-Junction with 90^0C and is mixing the cold gas with 20^0C.

The model is developed only half of it taking advantage of the symmetry properties of the geometry.

To perform 1-Way Fluid Structure Interaction, three stages of modeling will be considered:

1. The fluid flowing study by using the ANSYS CFX module standing for CFD (Computer Fluid Dynamics) will calculate velocities, temperatures and pressures for the fluid.
2. The Steady state thermal study by using the thermal module to determine the temperatures of the mixing fluids; it will calculate the structure temperatures in relation with the environment.
3. The Structural module will import pressures from CFX and temperatures from the thermal module in order to calculate the final equivalent von Mises stresses inside the T-Junction. It will calculate the structure stresses.

The models and the boundary conditions

Since the simulation is performed in a CFD-Thermal-Structural approach, then for any and each of these modules we need to have different boundary conditions imposed by the model.

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The CFD model and the boundary conditions

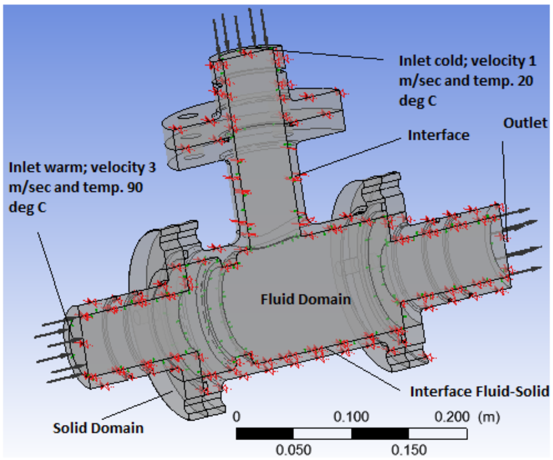

Fig.2 The CFD model with boundary conditions

The inlet for the warm branch is has the fluid at 3 m/sec velocity and 90^0 C, and the cold branch is 1 m/sec and 20^0 C. In between the Fluid and Solid domains an interface was established as seen in the figure above. The Outlet is releasing the fluid at the pressure of 5 bars.

The Thermal model and the boundary conditions

The thermal model is following the thermal conditions of heat transfer between the warm fluid and the environment via the structure. The environment effect is modeled with a convection having the temperature of 15 deg C and the convection coefficient as 20 W/m^2. The fluid temperatures calculated were imported from the CFX module.

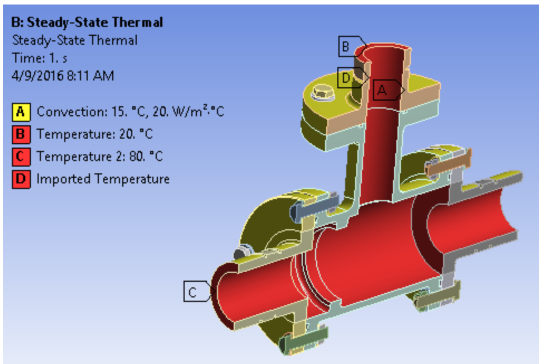

Fig 3 The Thermal model with boundary conditions

The Structural model and the boundary conditions

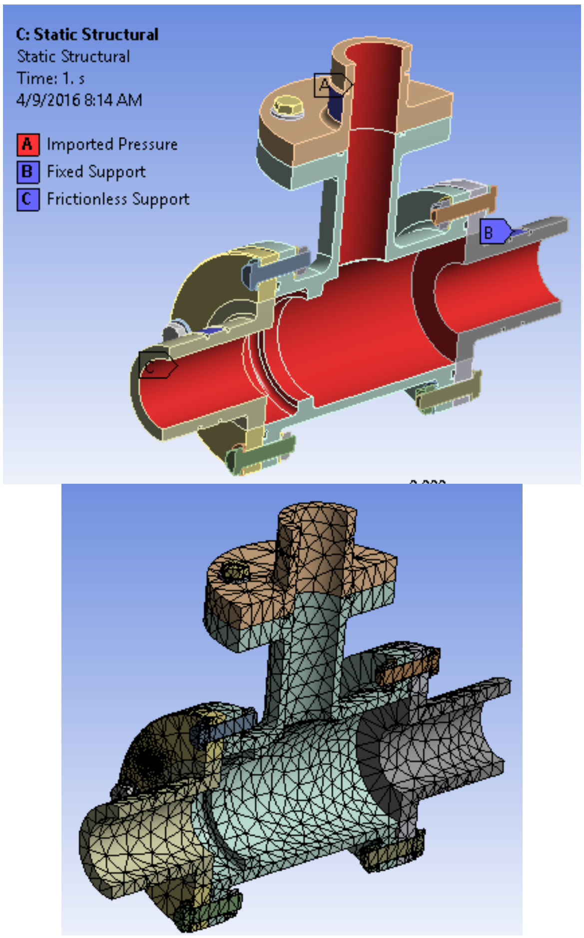

Fig 4 The Structural model with boundary conditions and the finite elements meshing

The boundary conditions are Fixed Support for the Outlet branch and Frictionless Support for the Inlet branches of the T-Junction. The pressures were imported from the CFX module and the Structure temperatures from the Thermal module. The mesh of finite elements of the structure is comprising 80409 nodes for 45290 finite elements.

Results and discussion

The results of the simulation will be presented for each of the involved modules into the model.

The CFD model results

- **Pressure of the fluid**

The pressure of the fluid is impacting the final stress distribution of the T-Junction structure so that it is a must to calculate it. The results are

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presented only for the symmetry plane of the model.

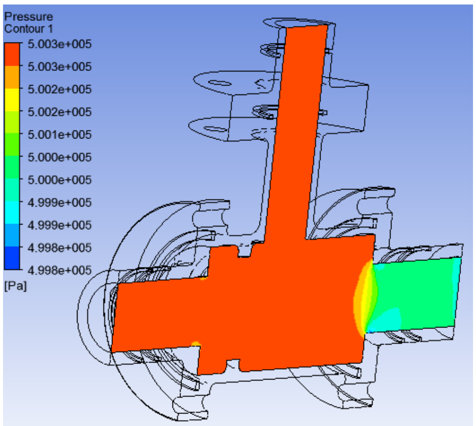

Fig 5 The fluid pressure

The fluid pressure is not varying heavily but is stabilized around the value of 5 bar which is the Outlet imposed pressure.

- **Velocity of the fluid**

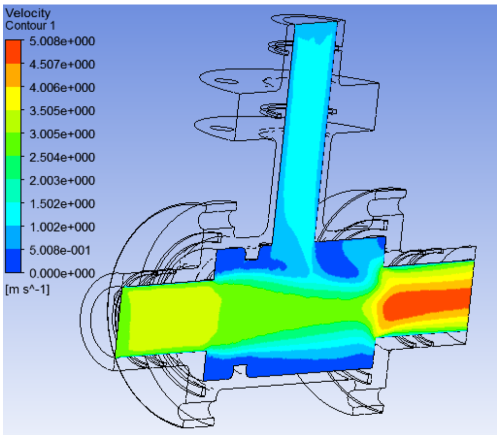

Fig 6 The fluid velocity

As seen in the figure above the fluid is accelerating in the outlet branch at a peak value of 5 m/sec since the flows of the Inlet branches are combining and mixing.

- **Temperature of the fluid**

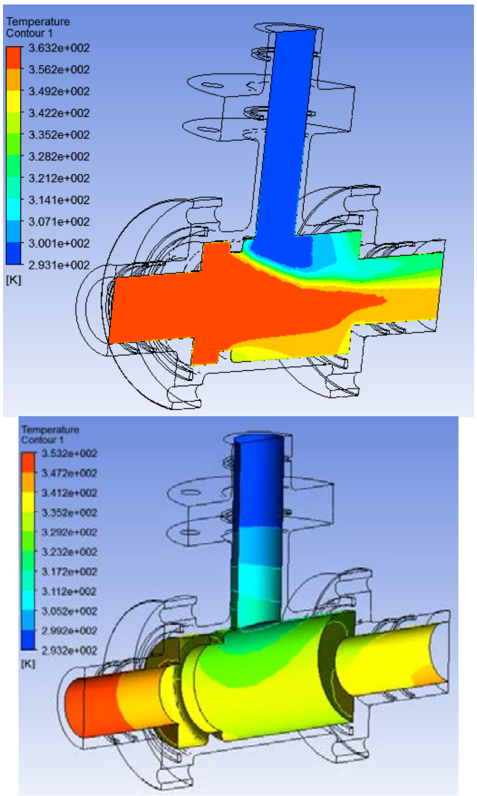

Fig 7 The fluid and the fluid-solid interface temperatures

The fluid temperature is decreasing toward the Outlet branch since the two fluids with different temperatures are mixing inside the T-Junction. On the interface between the fluid and the solid domains, the temperatures distribution is showing how the fluid heat is imparted to the structure. These values are to be used further by the Thermal module.

The Thermal model results

The thermal model will calculate the way in which the given above temperature fields at the solid-fluid interface is shared with the environment.

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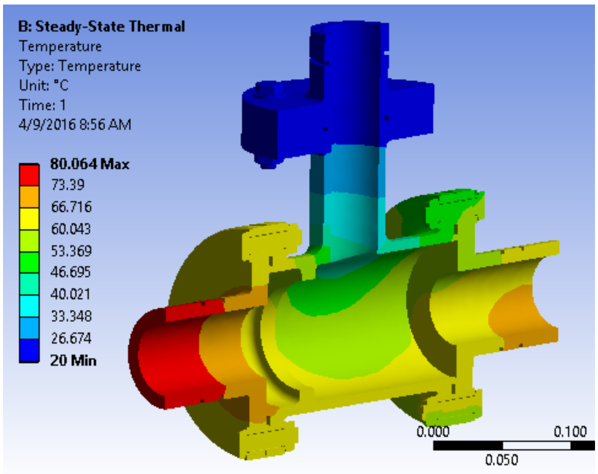

Fig 8 The temperature fields in the structure

The temperature fields are to be used further on by the structural module for the stress calculation. The warm zones will expand more than the colder zones and therefore a thermal gradient stress will develop inside the structure.

The Structural model results

- **The Total Deformation**

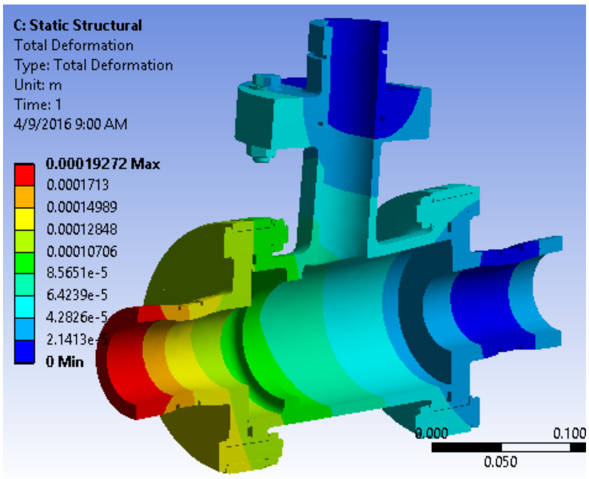

Fig 9 The total deformation of the T-Junction

The total deformation is showing how the structure will deform due to the fluid pressures and the temperature fields calculated above and with constraints imposed by the supports defined inside the structural model. The biggest displacement will be at warm inlet branch with a value of 0.19 mm.

- **The equivalent stress**

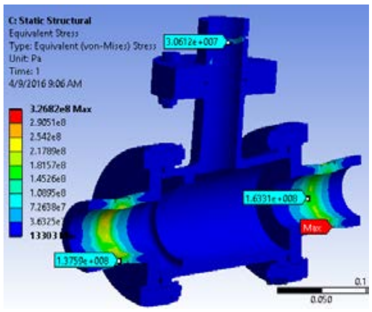

Fig 10 The equivalent stress

The resulting equivalent stress has an average of 137 MPa well below the tensile yield strength of 250 MPa. Some tiny spots inside the structure will approach 326 MPa but due to the plastic behavior of the steel these spots will be distributed inside the mass of the steel. The T-Joint will perform inside the safe envelope of operation.

CONCLUSIONS

The problem of mixing different temperatures of a certain fluid into a T-Junction and the study of the effects of fluid pressure and fluid temperatures on the stress distribution of the structure is by no means an easy problem to solve. The ANSYS capabilities of treating such Fluid Structure Interaction Problems with different interconnected modules is instead making this problem a trivial problem to solve. The T-Joint under scrutiny is performing well regarding structural safety as demonstrated in this paper.

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