# Analysis of Heat Flow and Transfer in the T Joint of a Steam Installation

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***Abstract:*** *In order to produce the steam necessary for the operation of the main cars of the ship and to supply all the consumers on board, the naval boilers need an operating regime, which ensures the transformation of the chemical energy of the fuel into caloric energy contained in steam in the best conditions. In this paper, we showed a high temperature fluid flow in a pipe through a T section and the effect of temperature on the pipe material. Pipe deformation caused by fluid temperature was analyzed. The temperature distribution effect of ANSYS Fluent was used as a thermal load in the pipe body. The pipe deflection was discovered together with the equivalent voltage and thermal stress.*

***Keywords:*** *Heat, flow, transfer, steam, structural, pipe, joint*

## 1. Introduction

The main parts of a steam production installation are the boiler itself or the boiler system (composed of the drum or water collectors and all the pipes in which the water vaporization occurs), the steam superheater, the preheater of the supply water, the air preheater and the hearth or combustion chamber.
The resulting steam will be used for the operation of various mechanisms and auxiliary devices or on-board systems such as:
• steam extinguishing system
• installation for heating fuel and oil in storage, settling, service and mixing tanks
• ship heating installation
• water heating to prepare the main engine.
In order to produce the steam necessary for the operation of the main cars of the ship and to supply all the consumers on board, the naval boilers need an operating regime, which ensures the transformation of the chemical energy of the fuel into caloric energy contained in steam in the best conditions [1].
The intimate operating regime of the boiler is when the water turns into steam, accumulating a maximum amount of heat from the burned fuel in the boiler hearth. The steam will be able to accumulate maximum heat, only if the combustion process takes place with a maximum heat release and if the heating is provided with a good circulation and water supply, and the heating surface allows a good heat transfer from gas to the water.

The above-mentioned boiler is an aquatubular naval boiler that works at a nominal pressure of 7 bar.

Boiler is used to produce the amount of steam needed to heat a ship's main engine.
The ship is equipped with a main engine type MAN 6L 52 / 55A with an effective power $P_e$ = 6100 HP = 4413 kW.
The available flow of the main engine is

$$Q_{dMP} = \frac{c_e \cdot P_e \cdot Q_l}{3600}, \text{[kW]} \quad (1)$$

Where:

$c_e$ = 0.265 [kg / kWh]- the actual specific consumption of the engine

$P_e$ = 4413 [kW] effective engine power

$Q_l$ = 37500 [kJ / kg] lower calorific value of the fuel used.
If the cooling water is heated by means of a preheater mounted in the technical water circuit, the following curves can be used (Figure 1) [2]:

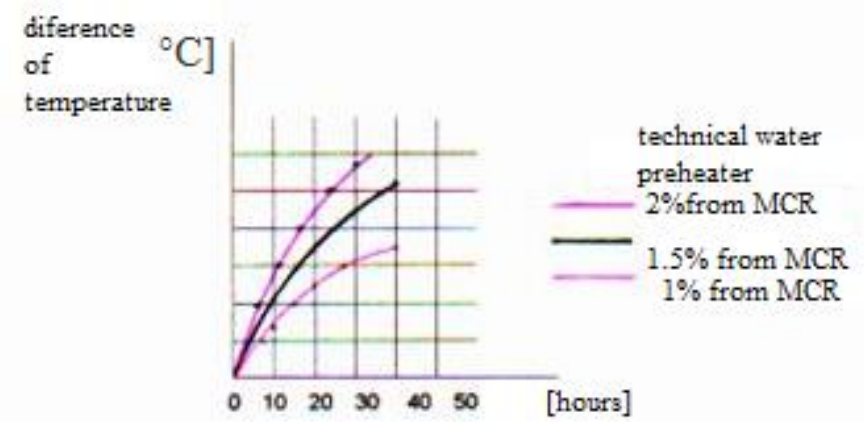


**Fig. 1.** Cooling curves in the preheater

The technical water flow of the preheater, if installed by bypass, will be around 10% of the flow of the main technical water pump. The pressure drop in the preheater will be about 0.2 [bar].
The curves are drawn in these hypotheses, at the beginning of the preheating, the temperature of the engine and of the engine room being equal [3].
Normally, before taking the first steps to start the engine, the minimum engine temperature must be 60°C, and the engine can start slowly without further restrictions. In exceptional cases, a minimum temperature of 20°C is allowed. In these circumstances, the engine can start slowly up to 90% rpm, without restrictions. In order to operate between 90% rpm and 100% MCR, a minimum temperature of 50°C must be ensured. The time interval for raising the engine temperature from 20°C to 50°C depends on the amount of water in the system and the engine load. It is recommended in the region of 90% rpm and 100% MCR; the load will be raised slowly - in 30 minutes.

## 2. Method and research

We will choose a preheater with a heating capacity of 2% of MCR, which will raise the engine temperature to 55°C in 30 hours.

$$Q_{pr} = P_e \cdot 0.02 \quad [kW] \tag{2}$$

So, $Q_{pr}$ = 88.26 kW.
However, this energy flow is equal to that given by the steam produced in the boiler necessary to heat the water

$$m = Q_{pr}/D_{i7bar} = 152.22 \ \ [kg/h] \tag{3}$$

Where:
$\Delta i_{5bar} = 2109 \ [kJ/kg]$- the difference in enthalpy of steam at the boiler working pressure of 5 bar.

### 2.1 The amount of steam needed to heat the fuel in the storage tanks

The cargo ship 7800 tdw can ship a bunker quantity of 1200 tons of fuel.
We consider that we must always have 10% of the amount of bunker, ready at all times, for consumption on board.

$m_{cb.\ tk.\ dep.}$= 120 [t].

The heating time of this mass of fuel will be: $\tau = 6\ hours$. It turns out that a mass flow of:

$$m_{cb.tk.dep.} = \frac{m_{cb.tk.dep.}}{\tau \cdot 3600} \quad \left[\frac{kg}{s}\right] \tag{4}$$

So, $m_{cb.tk.dep.}$= 5.55 [kg/s].
The energy flow required to heat the fuel will be:

$$Q_{cb.tk.dep.} = m_{cb.tk.dep.} \cdot c_{cb} \cdot \left(t_{cb} - t_{dep}\right) \ [kW] \tag{5}$$

So, $Q_{cb.tk.dep.}$ = 333.33 [kW],

Where:

$c_{cb} = 2\ [kJ/kg \cdot grd]$ is specific heat of the fuel;

$t_{cb} = 40°[C]$ is the temperature at which the fuel must be heated in the storage tank;

$t_{dep} = 10°[C]$ is fuel temperature in the storage tank.

The mass steam flow required to heat the fuel in the storage tank is:

$$\eta_{serp} = \frac{Q_{cb.tk.dep.}}{Q_{steam}} = \frac{Q_{cb.tk.dep.}}{m_{steam} \cdot \Delta i_{5bar}} \Rightarrow m_{steam} = \frac{Q_{cb.tk.dep.}}{\eta_{serp} \cdot \Delta i_{5bar}} \quad \left[\frac{kg}{h}\right] \tag{6}$$

So, the value is $\eta_{serp}$ = 605.16 [kg/h].

### 3. The amount of steam required to heat the fuel in the tailings tank

The hourly consumption of the 3 Diesel Generators is noted $C_{h3DG}$. The boiler with burner we assume has a consumption of: $C_{harz}$ = 88 [kg / h].

The total hourly consumption of all the aggregates on the ship is:

$$C_{htot} = C_{hMP} + C_{h3DG} + C_{harz} \ [kg/h] \tag{7}$$

So, the value is $C_{htot}$ = 0.4168 [kg/s] = 1500.4 [kg/h].

The mass flow rate of fuel to be heated in the tailings tank will be 2.5 times higher than the total hourly fuel consumption of the aggregates on the ship:

$$m_{cb.tk.dec.} = 2.5 \cdot C_{htot} \ [kg/h] \tag{8}$$

So, will be equal $m_{cb.tk.dec.}$ = 3751 [kg/h]
Where:

- fuel temperature in the settling tank, $t_{dec} = 30\ [°C]$;

- the temperature to be reached before the fuel enters the two preheaters of fuel separators, $t_{sep} = 70\ [°C]$.

The mass steam flow required to heat the fuel in the tailings tank is:

$$m_{steam.tk.dec.} = \frac{Q_{cb.tk.dep.}}{\eta_{serp} \cdot \Delta i_{5bar}} \quad \left[\frac{kg}{h}\right] \tag{9}$$

So, the value is $m_{steam\ tk.dec.}$= 211.87 [ kg/h].

**4. The amount of steam needed to heat the fuel in the mixing tank**

Whether

$t_{imp} = 120° \; [C]$ - fuel injection temperature;

$t_{tkam.} = 95° \; [C]$ - temperature in the mixing tank.

Mass flow rate of steam required to heat fuel before injection is calculated with formula (10):

$$m_{cb.tk.am.} = \frac{Q_{cb.tkam.}}{\eta_{serp} \cdot \Delta i_{5bar}} \quad \left[\frac{kg}{h}\right] \tag{10}$$

The values is $m_{cb\ tk.am.}$= 29.5 [ kg/h].

**5. The amount of steam needed to heat the main engine lubricating oil before entering the separator**

Actual specific oil consumption of the main engine is:

$$c_e = (2.5 \ldots 7) \cdot \; 10^{-4} \quad [kg/kWh] \tag{11}$$

So,
$c_e$ = 0.00033 [ kg/kWh].
Hourly oil consumption of the main engine is:

$$C_{hoil} = c_e \cdot P_e \qquad [kg/h] \tag{12}$$

So, $c_{hoil}$ = 1.4563 [kg/h].
Energy flow required to heat the oil before entering the separators is:

$$Q_{oil.inc.sep.} = \; m_{oil} \cdot c_{oil} \cdot \left(t_{sep} - t_{dep}\right) \qquad [kW] \tag{13}$$

Where:

$c_{oil} = 2.1 \;\; [kJ/kg \cdot grd]$ - specific heat of the lubricating oil;

$t_{sep} = 90° \; [C]$ - the temperature at which the oil is separated;

$t_{dep} = 20° \; [C]$ - the temperature at which the oil is stored.

So, $Q_{oil.inc.sep.}$ = 429.149 [kW].
Mass flow of oil to be circulated by separators is:

$$m_{oil} = 2 \cdot C_{oil} \qquad [kg/s] \tag{14}$$

So, $m_{oil}$ = 0.000809 [kg/s].
Mass flow of steam required to heat the oil in the separator preheaters is:

$$m_{steam\ oil} = \frac{Q_{oil\ inc\ sep.}}{\eta_{serp} \cdot \Delta i_{5bar}} \qquad [kg/h] \tag{15}$$

So, $m_{steam\ oil}$ = 0.2159 [kg/h].

**6. The amount of steam needed to heat the air in the room heating installation**

The mass flow of air circulated for heating the cabins is given by the volume flow of the fan, which is:

$$m_{air} = \rho_{air} \cdot V_{air} \qquad [kg/s] \tag{16}$$

Where:

$V_{air}$ = 25000 [$m^3$/h]; $c_{air} = 1\ [kJ/kg \cdot grd]$ - specific heat of the air; $t_{inc} = 24°\ [C]$ - cabin heating temperature; $t_{m\ amb} = 5°\ [C]$ - ambient temperature.

Therefore, the mass flow of air circulated will be $m_{air}$ = 8.5139 [kg/s].

Mass flow of steam required for heating the air in the air conditioning system is:

$$m_{steam\ inc\ air} = \frac{Q_{air\ inc}}{\eta_{serp} \cdot \Delta i_{5bar}} \quad [kg/h] \tag{17}$$

So, the value is $m_{steam\ inc.air}$ = 293.68 [kg/h].

## 7. Determining the boiler flow and its power

The total flow of the boiler with aquatubular type burner is given by the relation:

$$m_{CA} = \sum_{i-1}^{8} m_i \quad [kg/h] \tag{18}$$

So, $m_{CA}$ = 1455.3 [kg/h].

The available boiler flow is:

$$Q_{DCA} = \frac{C_h \cdot Q_i}{3600} \quad [\text{kW}] \tag{19}$$

So, $Q_{DCA}$ = 916.66 [kW].

Boiler power is:

$$Q_{CA} = Q_{DCA} \cdot \eta_{CA} \tag{20}$$

So, $Q_{CA}$ = 843.33 [kW]. Otherwise, the power of the boiler is given by the relation:

$$Q_{Cazn} = m_{steam\ tot} \cdot \Delta i \quad [kW] \tag{21}$$

So, $Q_{Cazn}$ = 843.81 [kW].

Fuel consumption will be determined from the relation:

$$\eta_{CA} = \frac{Q_{Cazn}}{Q_{dispCA} \cdot \frac{C_h \cdot Q_i}{3600}} \Rightarrow C_h = \frac{3600 \cdot Q_{Cazn}}{\eta_{CA} \cdot Q_i} \quad [kg/h] \tag{22}$$

Therefore, the value is 88.05 [kg/h] and the value adopted in the previous point is correct.

## 8. Analysis of heat flow and transfer in the T joint

### 8.1. The interaction of fluid structure

The geometry of the part is created in the Ansys program and the domains are defined and the surface of the inner domain is defined. (Figure 2).

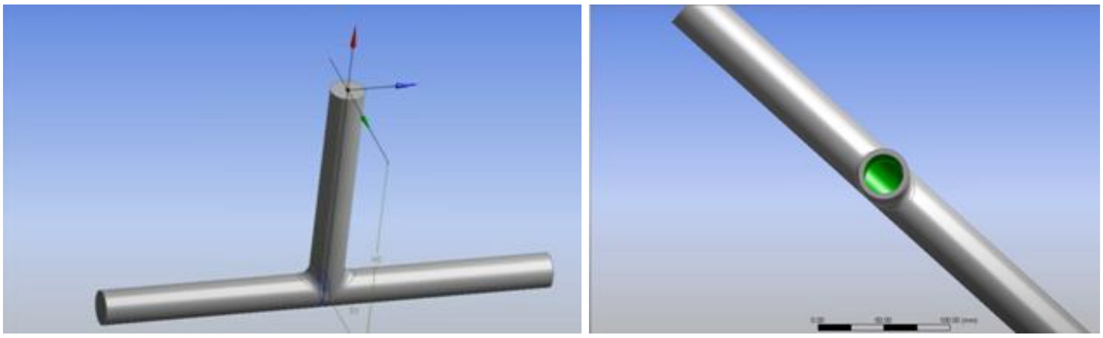

**Fig. 2.** The geometry and the inner domain

We change the flow direction to be able to add the inner surface to the solid so that it forms a single body. The fluid domain is created inside the pipe as seen in the figures below (Figure 3, 4).

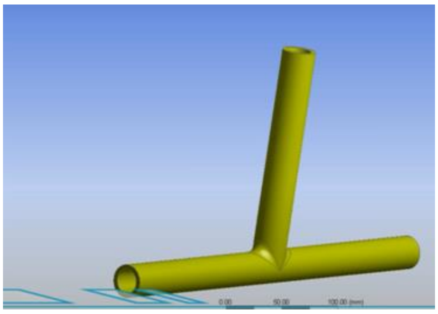

**Fig. 3.** The flow direction and the addition of the inner surface to the solid

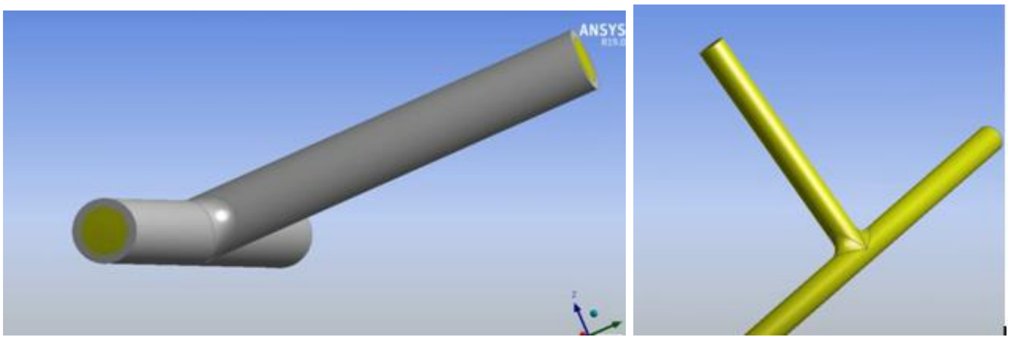

**Fig. 4.** The fluid domain

The discretization of the reference piece follows. Following the discretization, 16429 nodes and 83346 elements are obtained (Figure 5).

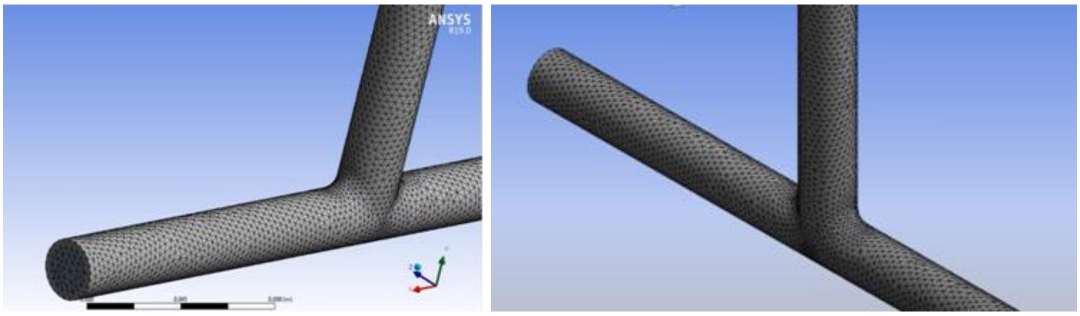

**Fig. 5.** The discretization

Check the quality of the discretization using the "Skewness" display style (Figure 6).

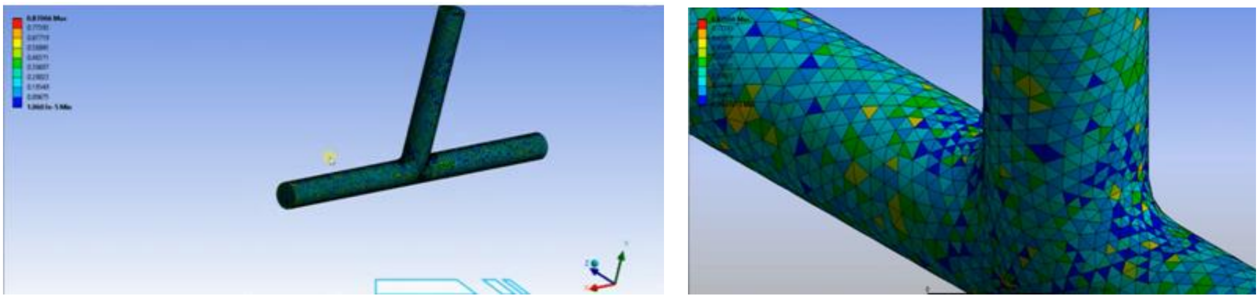

**Fig. 6.** The discretization using the "Skewness" style

We name the surfaces as can be seen in the following Figures 7, 8, 9.

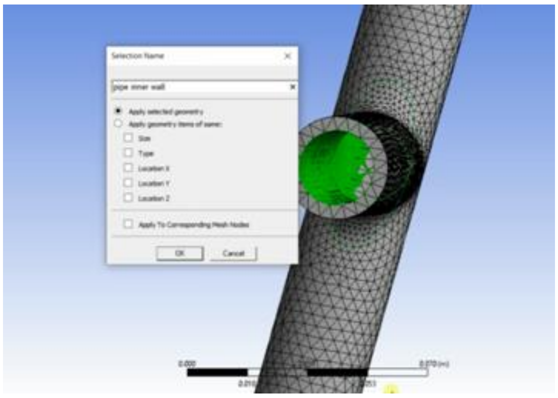


**Fig. 7.** The pipe inner wall

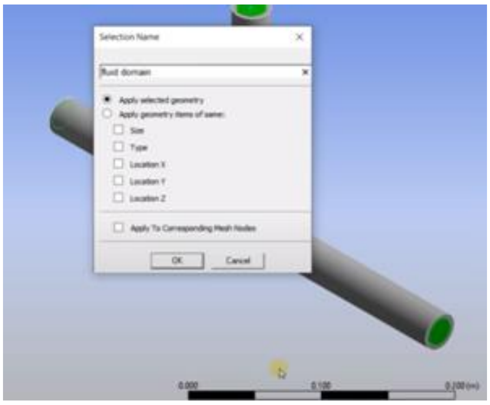


**Fig. 8.** The fluid domain

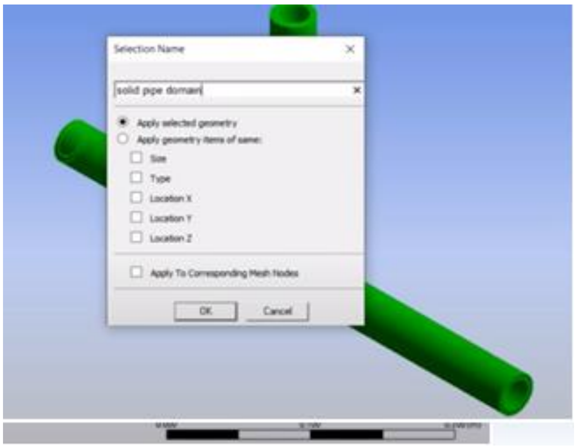


**Fig. 9.** The solid domain

The characteristics of the model and the material are defined. The material is assigned to the areas for which we have defined it. We set the limit conditions for entry and exit (Figure 10).

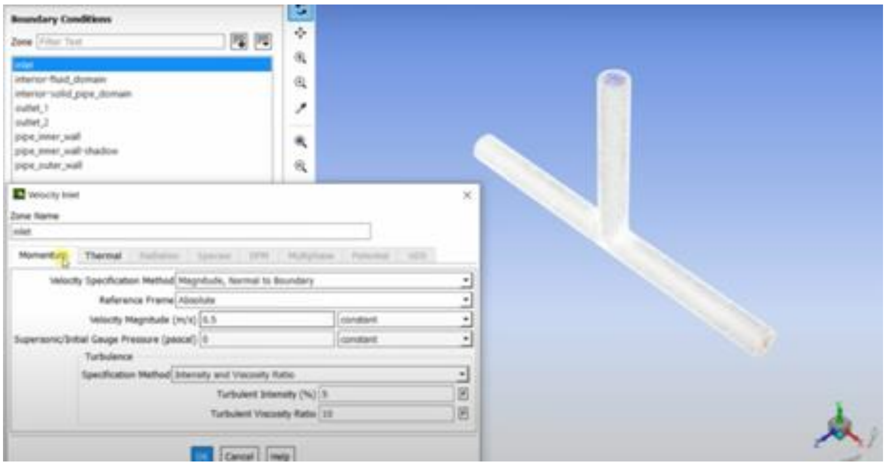

**Fig. 10.** The boundary conditions

### 8.2. Experimental data

Set the temperature of the pipe ($300^0$ C) and the hybrid solution is initialized with a number of 800 iterations. Create a plan in the middle section of the pipe. When representing the temperature, we notice that the temperature decreases towards the outside of the pipe (Figure 11).

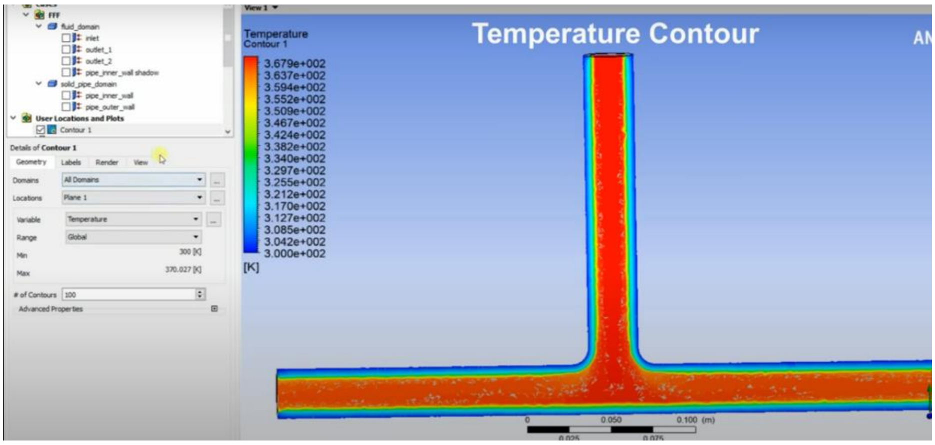


**Fig. 11.** The variation of temperature

The fluid speed decreases in the flow direction, from the inlet to the outlets (Figure 12).

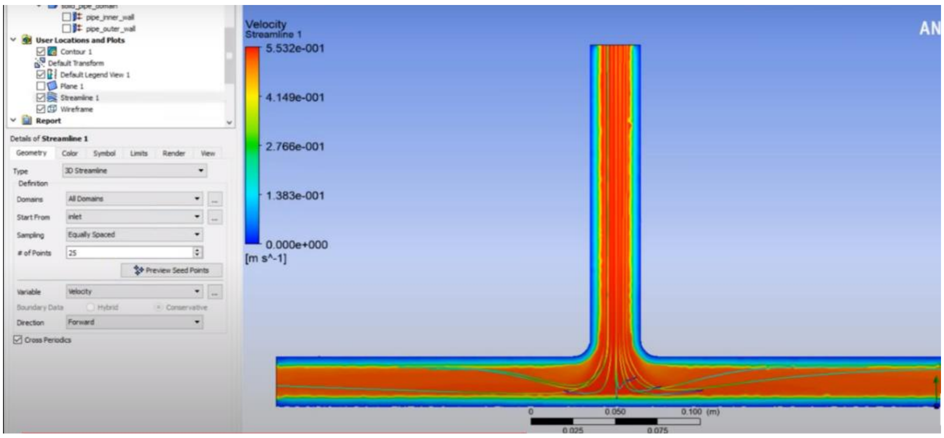


**Fig. 12.** The variation of fluid speed

The speed animation I showed in the figure below (Figure 13).

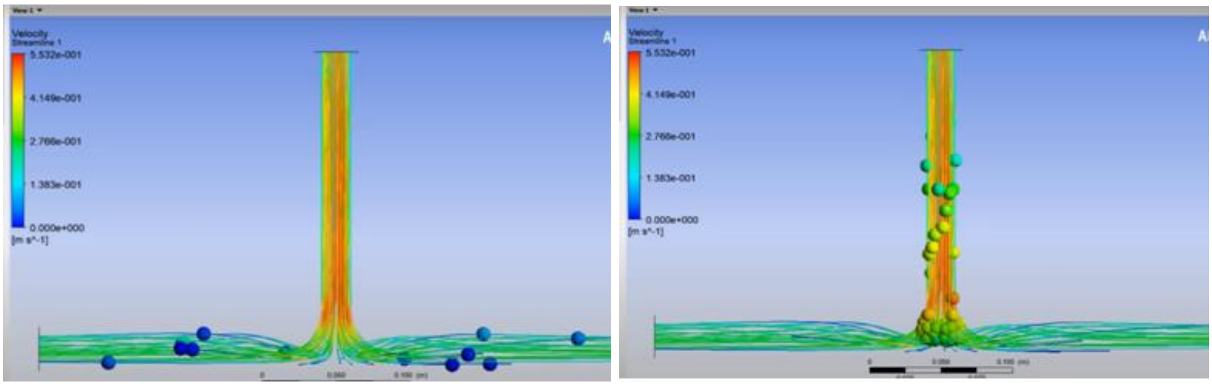

**Fig. 13.** The speed animation

We add the static structural analysis system in the schematic window of the project, near the "Fluid Flow (Fluent)" analysis system; we connect the geometry and the solution between the two systems (Figure 14).

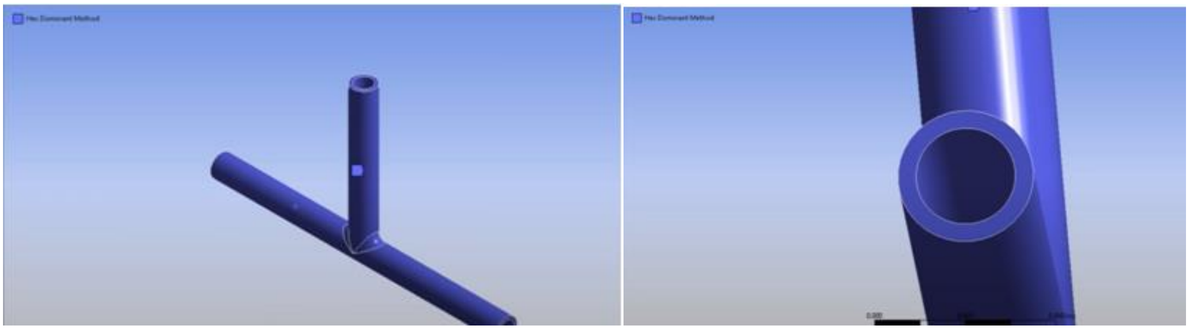

**Fig. 14.** The static structural analysis system

The piece is discretized and 59826 nodes and 15721 elements are obtained (Figure 15).

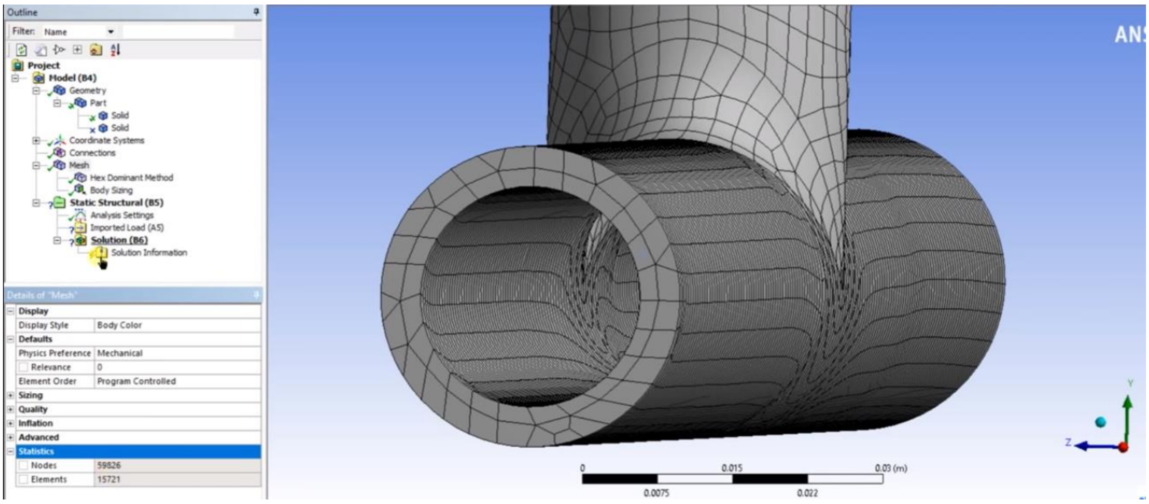


**Fig. 15.** The discretization of system

The standard gravitational acceleration is introduced in the direction of the fluid velocity, in order to be able to calculate the deformation (Figure 16) [4].

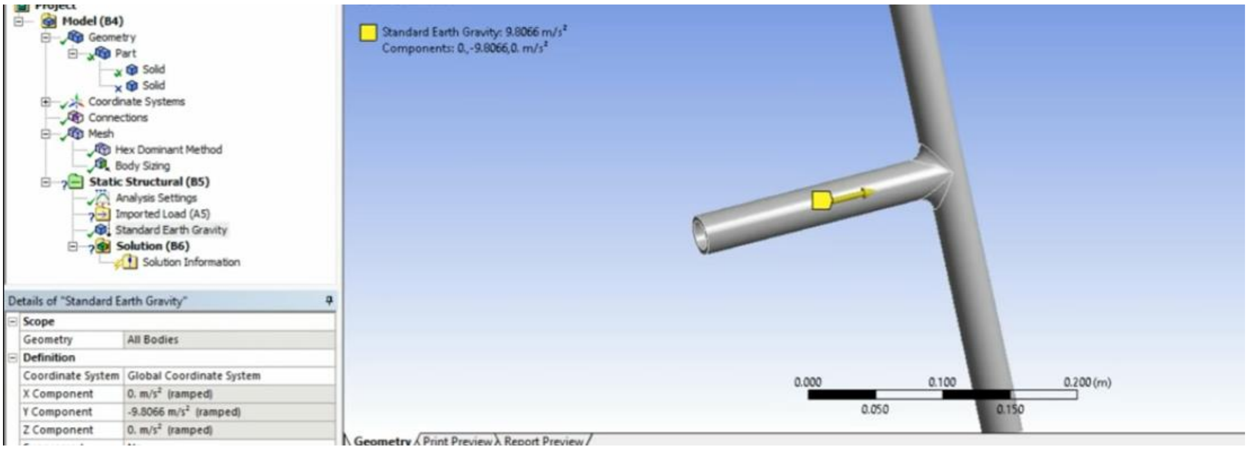


**Fig. 16.** The addition of standard gravitational acceleration

The distribution temperature is imported (Figure 17).

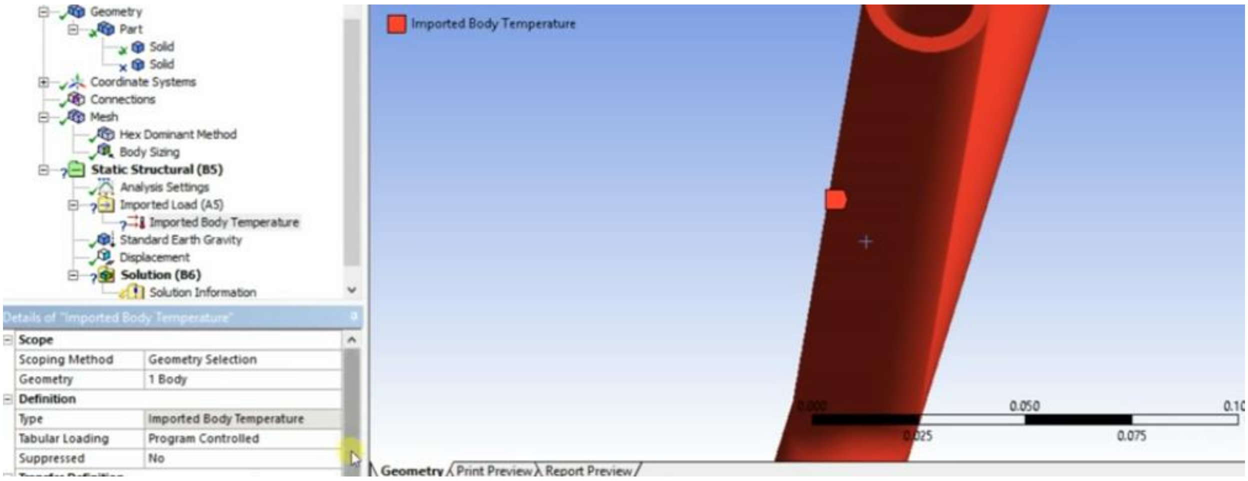


**Fig. 17.** The imported distribution of temperature

The points where the temperature is maximum are shown, it is found inside the pipe (Figure 18).

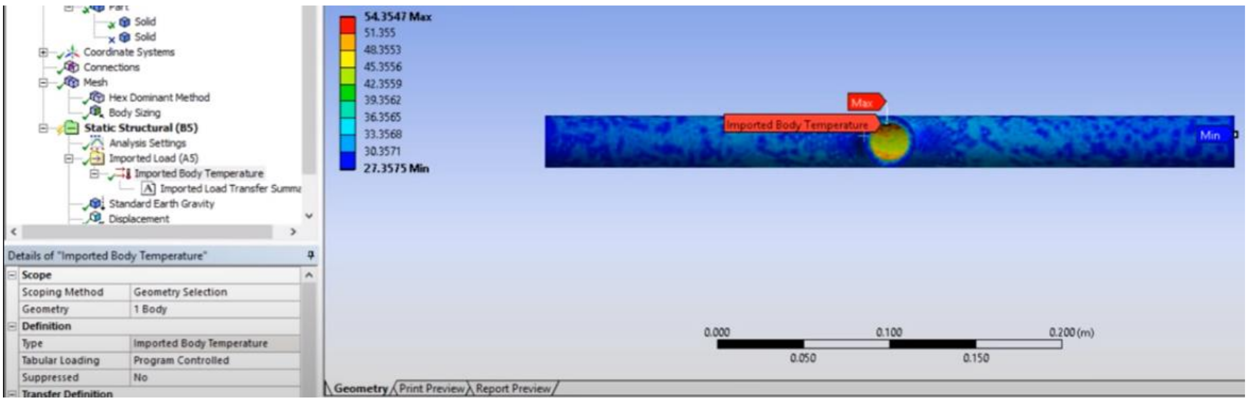


**Fig. 18.** The maximum temperature inside of pipe

The maximum total deformation is found in the pipe joint (Figure 19).

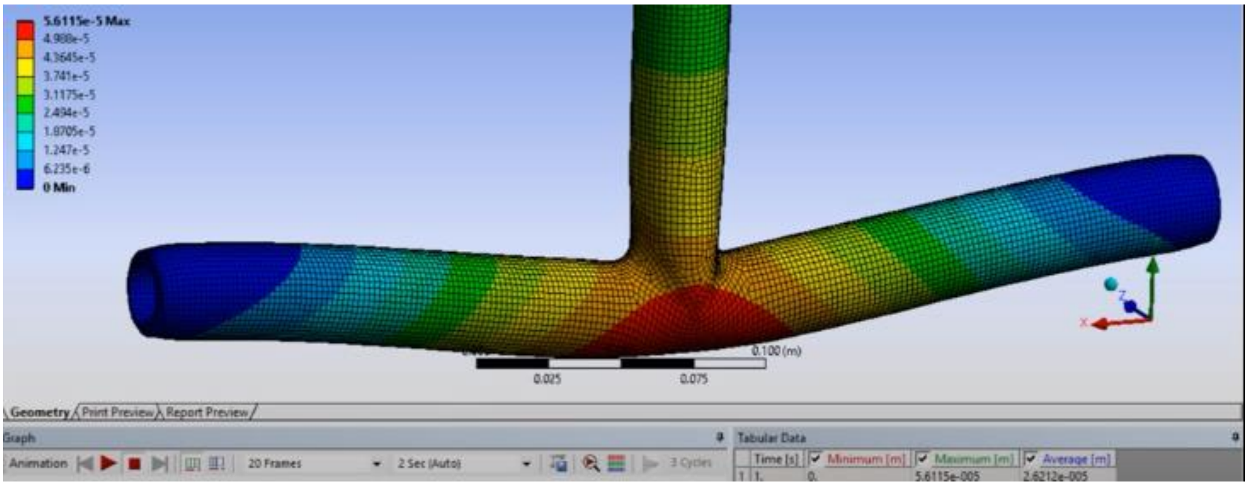


**Fig. 19.** The maximum total deformation

The directional deformation, on the y axis, has a maximum value of 0.002824 [mm].

The maximum equivalent stress is found in the joint area (Figure 20) and has a maximum value of 530.36 MPa.

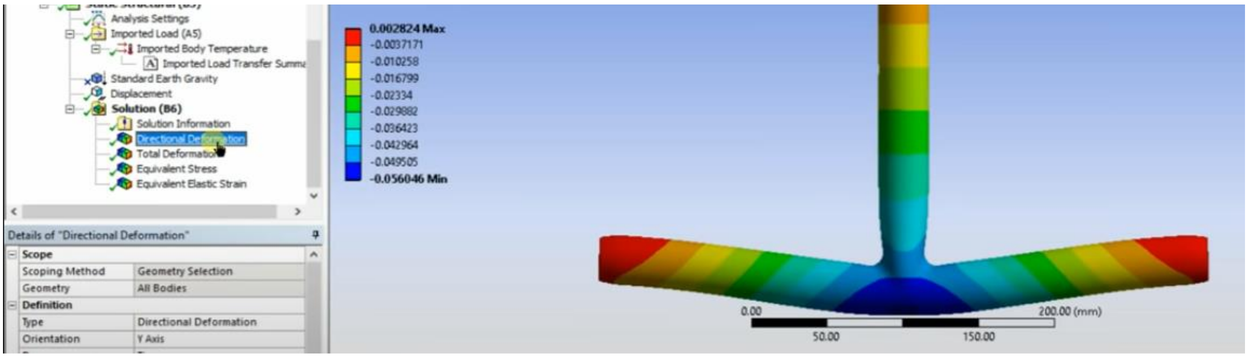


**Fig. 20.** The maximum equivalent stress

The equivalent elastic tension (Figure 21) has a maximum value of 0.0027516 and is found inside the pipe.

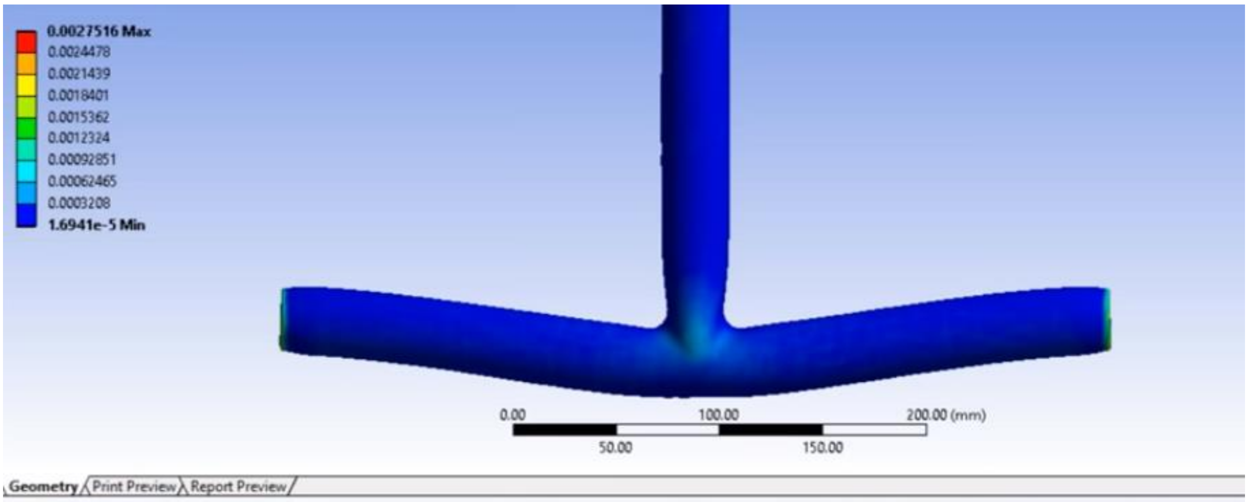


**Fig. 21.** The equivalent elastic tension

### 8.3. Final results

The final results are:
- Total deformation (Figure 22);
- Deformation on the "Y" direction measured in mm (Figure 23);
- Equivalent stress measured in MPa (Figure 24);
- Equivalent elastic tension measured in mm (Figure 25).

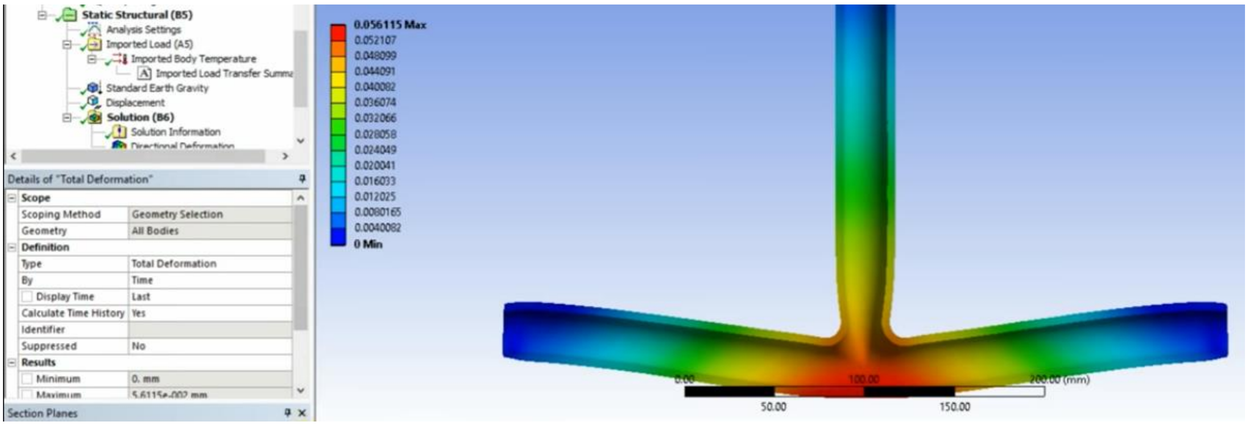


**Fig. 22.** Total deformation

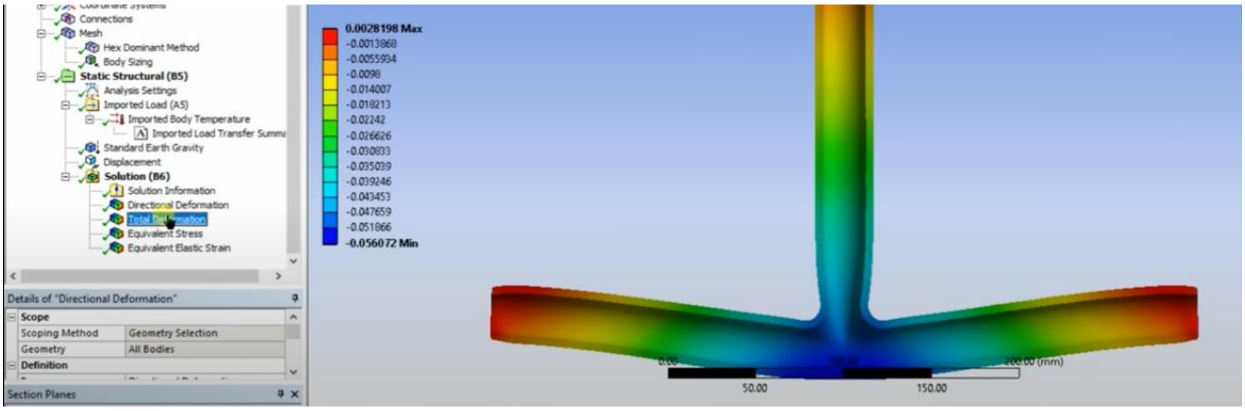


**Fig. 23.** The deformation on the "Y" direction

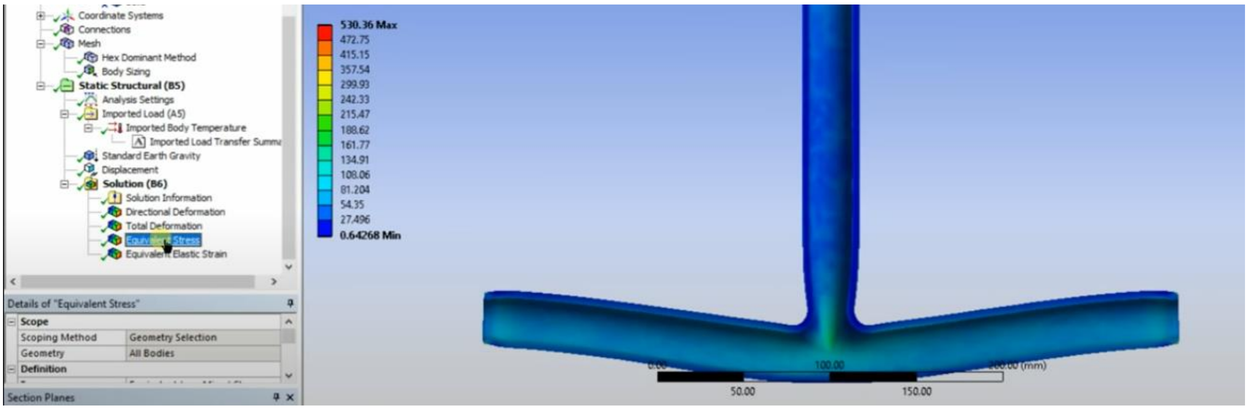


**Fig. 24.** The equivalent stress

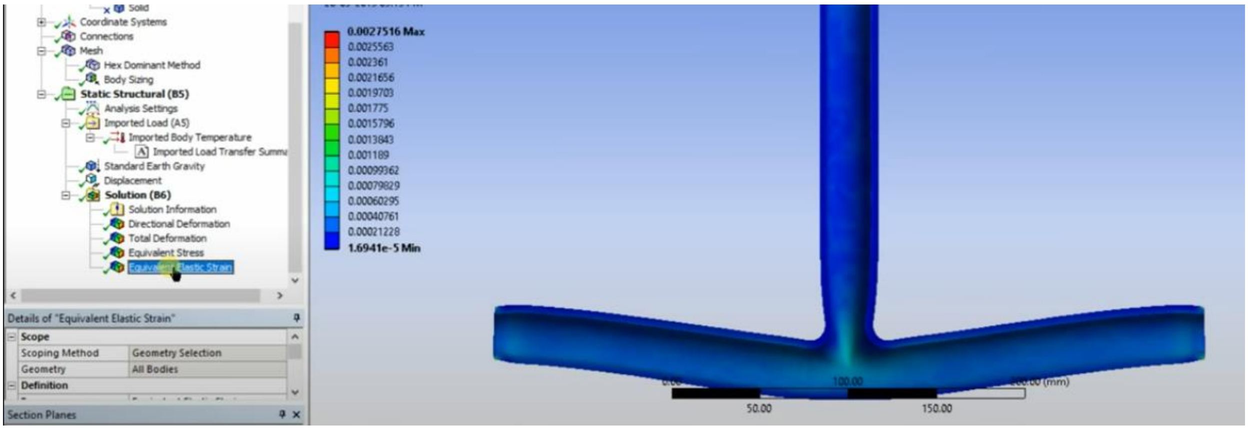

**Fig. 25.** The equivalent elastic tension

## 9. Conclusions

We analyzed a high temperature fluid flow in a pipe through a T section and the effect of temperature on the pipe material. Pipe deformation caused by fluid temperature was analyzed. The temperature distribution effect of ANSYS Fluent was used as a thermal load in the pipe body. The pipe deflection was discovered together with the equivalent voltage and thermal stress.

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