Fluid Structure Interaction Analysis of Bend Pipe by Employing Co-Simulation Feature

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Abstract- Fluid Structure Interaction analysis of this study by ABAQUS Co-simulation is performed to obtain the transient temperature and pressure distributions of thermal flow and stress distributions in the wall of the solid pipe under water flow. The study was divided into two parts; the fluid flow interacted with rigid pipe and deformable pipe. From the structural co-simulation analysis, Von-Mises stresses at the solid pipe were computed in ABAQUS for the 0.4 seconds. The initial temperature was set at 25°C for all cases and the inlet flow velocity was considered as the variable condition; 2m/s, 2.5m/s and 3m/s respectively. The results of pressure and temperature distributions of flow domain for 0.4 seconds were computed from CFD co-simulation analysis.

Indexed Terms- Fluid flow; temperature distribution; pressure distribution; stress distribution

I. INTRODUCTION

Fluid-structure interaction in piping systems (FSI) consists of the transfer of momentum and forces between piping and the contained liquid during unsteady how. Over the past ten years, FSI has experienced renewed attention because of safety and reliability concerns in power generation stations, environmental issues in pipeline delivery systems. The phenomenon has recently received increased attention because of safety and reliability concerns in power generation stations, environmental issues in pipeline delivery systems, and questions related to stringent industrial piping design performance guidelines. Furthermore, numerical advances have allowed practitioners to revisit the manner in which the interaction between piping and contained liquid is modeled, resulting in improved techniques that are now readily available to predict FSI. This review deals with turbulent flow in hot water-filled, compliant piping systems. In this study, stress fluctuations exerted on the wall of the pipe and pressure and temperature distributions between fluid and fluid structure interaction methods influenced by hot water flow are determined.

II. MODEL DESCRIPTION

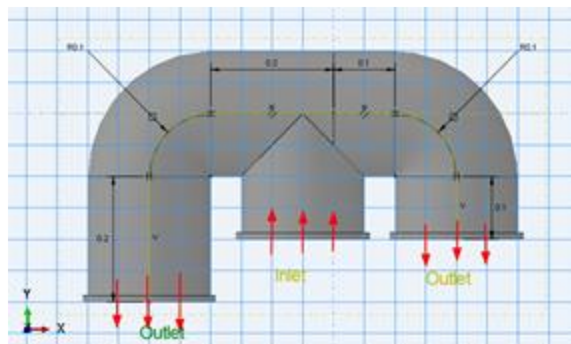


Figure 1. Schematic diagram of the pipe and dimensions

In this study, the bent pipe is subjected to internal hot water flow and consists of one inlet and two outlets flow conditions. It is assumed that the flow has constant properties (i.e. independent of temperature and pressure), incompressible, turbulent flow and the gravity effect is neglected. The temperature and velocity components obey the turbulent time-averaged continuity, momentum and energy equations. The dimensions and operating conditions considered in this study are summarized in Table 1and 2.

For the solid domain at room temperature;

Table1. Dimensions and operating conditions for solid

Solid domain	Aluminum	Units
Outside diameter	0.2	m
Inside diameter	0.18	m

Thickness	0.01	m
Modulus of elasticity	74	GPa
Poisson's ratio (υ)	0.33	Unit-less
Density (ρ)	2710	Kg/m^3
Yield strength	15-20	MPa
Ultimate strength	40-50	Mpa

Table 2. Dimensions and operating conditions for fluid

Fluid domain	Water	Units
Diameter	0.18	m
Density (ρ)	943.4	Kg/m3
Specific heat, C_p	4244	J/kg.k
Thermal conductivity, K	0.683	W/m.k
Dynamic viscosity (μ)	0.00232	Kg/m.s
Inlet temperature	120	°C

III. METHODOLOGY

The partial differential transport equations that all have the general form in the cylindrical coordinate as;

$$\rho\frac{\partial\phi}{\partial t}+\frac{\partial}{\partial x}(\rho U\phi)+\frac{1}{r}\frac{\partial}{\partial r}(r\rho V\phi)=\frac{\partial}{\partial x}(\Gamma_\phi\frac{\partial\phi}{\partial x})+\frac{1}{r}\frac{\partial}{\partial r}(r\Gamma_\phi\frac{\partial\phi}{\partial r})+S_\phi \quad (1)$$

Where ϕ is the general dependent variable such as U, V, t and $\Gamma\phi$ is the general form of diffusion coefficients, and $S\phi$ is the source term which include all terms except the convection and diffusion terms. The quantities, $\Gamma\phi$ and $S\phi$ are specific to a particular dependent variable of ϕ.

Turbulent flow fluctuations will increase the transfer of energy and momentum as well as the heat convection transfer rate. Turbulence is associated with random fluctuations and the fluid motion occurs on several length scales. In turbulence, the inertia forces are high in comparison to the viscous forces in the fluid. A common measure for this relation is the dimensionless Reynolds number. High Reynolds numbers will indicate higher levels of turbulence in comparison to organized laminar flow. The value of Reynolds number permits us to determine whether the flow is laminar or turbulent.

In a tube Reynolds number is defined as;

$$R_e=\frac{InertialForces}{ViscousForces}=\frac{\rho VD}{\mu} \quad (2)$$

Where,

D = Inside diameter (m)
ρ = Fluid density (Kg/m^3)
V = Average flow velocity (m/s)
μ = Dynamic viscosity (Kg/ m.s)
If, $R_e > 4000$ (turbulent flow) (3)
If $2300 < R_e < 4000$ (transitional flow) (4)
If $R_e < 2300$ (laminar flow) (5)

It is changed the inlet condition of the flow domain setting with the various flow velocities such as 2m/s, 2.5m/s and 3m/s to be the turbulent flow. The Reynolds number at which the flow becomes turbulent is called the critical Reynolds number. The value of the critical Reynolds number is different for different geometries and flow conditions. For internal flow in a circular pipe, the generally accepted value of the critical Reynolds number is Re,cr = 2300

For V = 2m/s;

$$R_e=\frac{943.4\times2\times0.18}{0.00232}=1.5\times10^5>4000 \quad (6)$$

For V = 2.5 m/s;

$$R_e=\frac{943.4\times2.5\times0.18}{0.00232}=1.8\times10^5>4000 \quad (7)$$

For V = 3m/s;

$$R_e=\frac{943.4\times3\times0.18}{0.00232}=2.2\times10^5>4000 \quad (8)$$

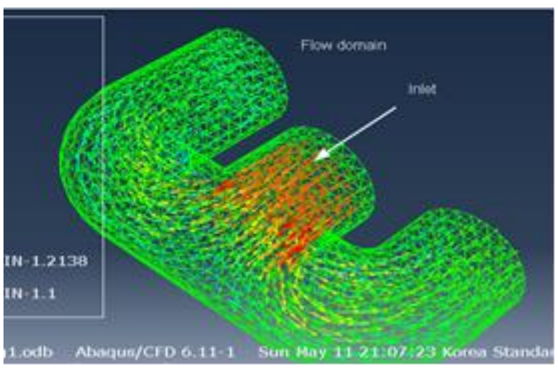
Therefore, the values of Reynolds number are between 104 and 106 of the turbulent region and the turbulent model is used in this analysis.

A. Analysis Procedure

In this research, Pre-processing simulation of FSI analysis by ABAQUS is organized into the following steps:

1. Material Properties
2. Mesh Generation
3. Boundary Conditions
4. Geometric Properties
5. Jobs

At the first step, two models for part I are pipe domain and flow domain were created in figure 2. Then, the solid model without including the flow domain was created. After that, the flow model without participation of solid structure was created. The fluid geometry was then defined in the program so that its diameter was equal to the inner diameter of bend pipe. After creating the part I, part II for both two models were created by making the copy from part I and modifying some steps for co-simulation. Basically the pipe has one inlet and two outlets having same diameter (0.2m) and it is an aluminum structure for hot water flow.



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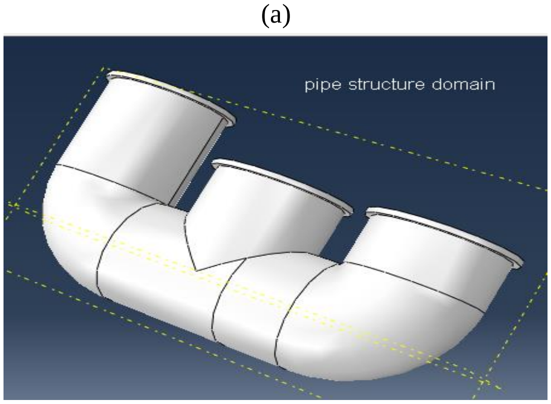


(b)

Figure2. The structure of (a) flow domain and (b) pipe domain

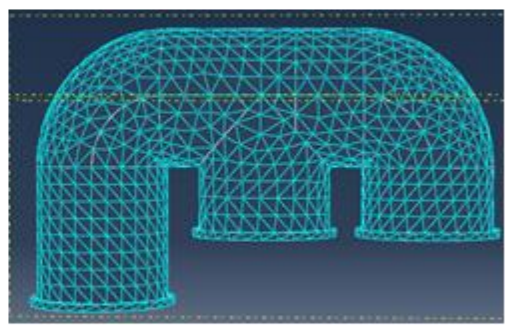
There are three important things to be careful when creating simulation of the fluid- structure interaction model.

- Both model should have same step time.
- Both model should have similar mesh size.
- Interaction name and surface must be identical.

1. Material Properties

   As the fluid is hot water, the density, thermal conductivity, specific heat and dynamic viscosity are considered in material properties. For the deformable solid domain, density, Modulus of elasticity and Poisson's Ratio are entered into the program.
2. Mesh Generation

   Both the fluid and solid models were meshed with linear tetrahedral solid elements, element sizes of 12321, 8-node elements and global sizes of 0.025 were generated. Figure 3 shows the mesh model of flow domain and pipe domain respectively.



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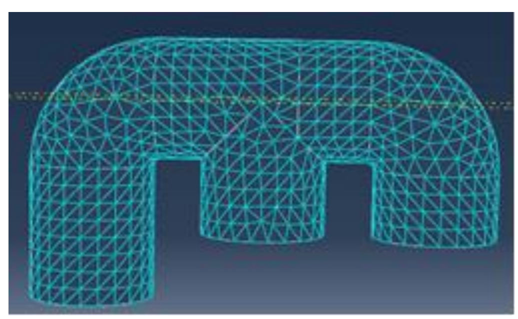

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Figure3. Meshing of (a) flow domain and (b) pipe domain

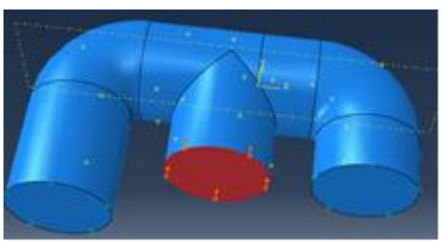
3. Boundary and Initial Conditions
   At the fluid inlet, as the flow is turbulent, a unidirectional flow with uniform inlet speed is assumed in the y direction and the inlet flow temperature is considered. At the fluid outlet, the pressure is set to zero and other conditions are not considered. In the fluid wall, the turbulent shear operating condition is considered and all the values of velocity are set to zero. The continuity equation of heat flux and temperature at the interface and energy balance at the wall is;

   At $r = r_i$,

$$U(T_{\sec} - T) = -k(\frac{\partial T}{\partial r}) + \rho_w C_{pw} b \frac{\partial T}{\partial t} \qquad (9)$$

Where Tsec is the secondary temperature and ρw, Cpw and b are the density, specific heat and thickness of the wall, respectively and U is the combined heat transfer coefficient of outer convection heat transfer coefficient and wall thermal conductivity. At the solid, both inlet and outlet ends have neither rotation nor translation.

At the solid fluid interface; $r = r_i$, $T_{solid} = T_{fluid}$



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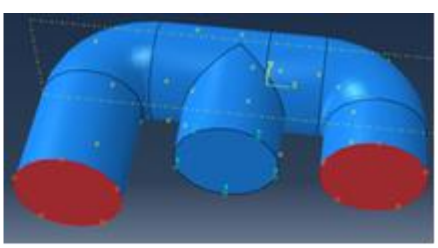

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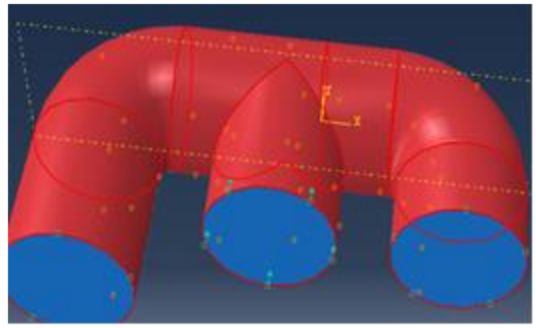
Figure 4. Flow condition (a) one inlet flow and (b) two outlet flow



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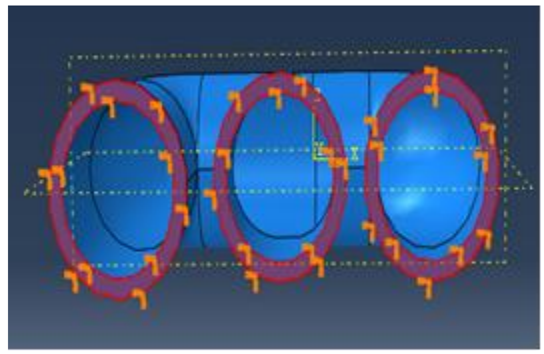
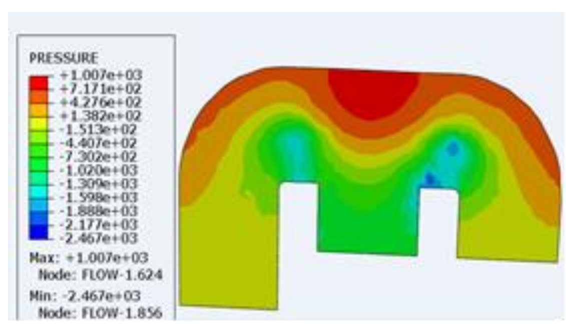


(b)

Figure5. Boundary conditions of (a) flow domain and (b) pipe domain

In order to reduce the running time, the time step of 0.4 seconds and initial time increment of 0.01 are considered for this simulation. Creating and submitting an analysis job, both FSI pipe and FSI fluid are submitted together at the same time.

IV. RESULTS AND DISCUSSIONS



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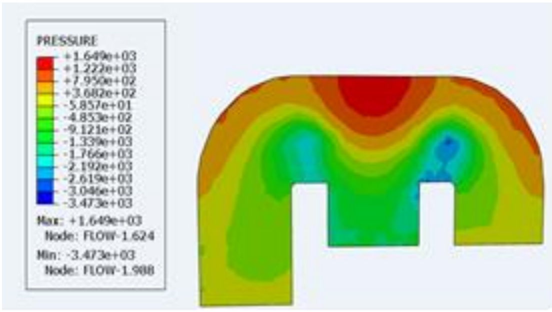

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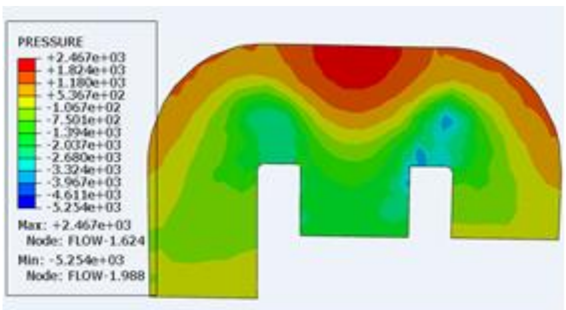


(c)

Figure 6. Pressure distributions of flow model at (a) v = 2 m/s; (b) v = 2.5 m/s; (c) v = 3 m/s

Pressure fluctuations in flow domain are higher at the top side of intersection of T-junction having the greater response with the maximum pressure in figures 6 and 7. In the entrance upstream section approaching the bend the pressure gradient is almost uniform. From the middle to the top area where streamline curvature is pronounced, there is a pressure difference is higher than the other sections and then the pressure is almost uniform again at the outlet downstream flow.

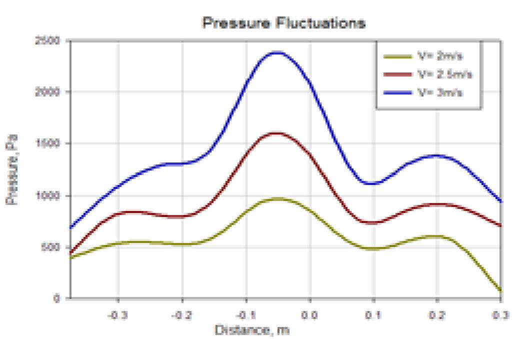
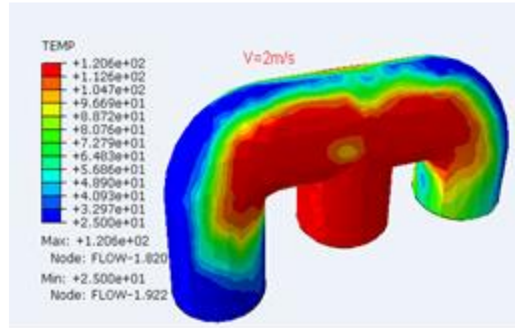


Figure 7. Pressure distributions along the cross sectional part of the flow domain



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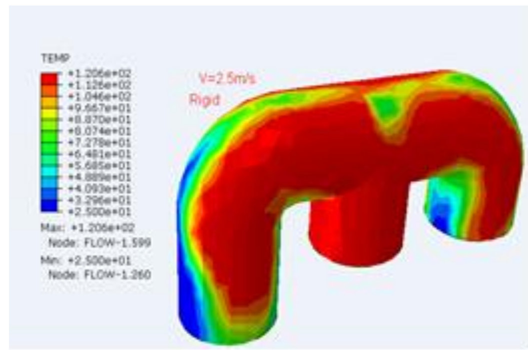

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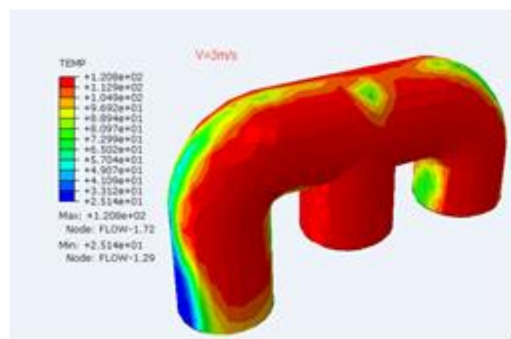

(c)

Figure 8. Temperature difference interaction between rigid and deformable body at (a) v = 2 m/s; (b) v = 2.5 m/s; (c) v = 3 m/s

The temperature drop is larger at interaction with deformable pipe than the rigid pipe. In both case, the maximum temperature drop occurs at the bend sections and there is a significant temperature difference between the bend area and intersection of the T-junction. We can review that the temperature drop at the intersection of T-junction and at the bend is almost doubles and the curve is got steeper. There is also a significant higher temperature at the middle and entrance upstream areas compare with the top area of the flow domain. The temperature distribution along the cross section of flow domain at different inlet velocities is shown in Figure 8. It can be observed that the faster the fluid flow, the smaller the temperature gradient. Comparing the three cases, temperature in the same location at the intersection area of the T-junction, the erosion pit is relatively high when v = 2 m/s. It can be explained that a greater amount of fluid is passing through the pipe for fast flow in the same time, providing more heat to exchange with the pipe wall.

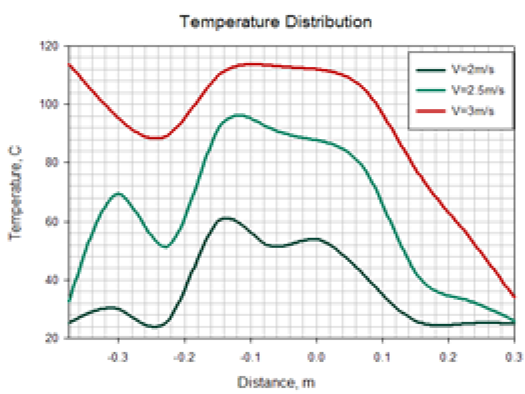

Figure 9. Temperature fluctuations of flow domain at different velocities

According to the simulation results, it can be reviewed that the highest value of stresses occurred at the intersecting area of the T-junction. This is due to the fact that abrupt changes in geometry of a component give rise to stress concentration. In contrast, the stress values at other areas, such as inlet and outlet, were very small compared with the maximum stress at the intersecting area. The stresses at the bends were also very low compared with the intersecting area at the junction of T. In addition, the Von Mises stress was lower than the yield strength of the material (20MPa). Therefore, it is concluded that the bend pipe may be collapsed since the Von Mises stress was lower than the ultimate strength (50MPa). Figures 10 and 11 are resulted the stress distribution of solid pipe at various flow velocities.

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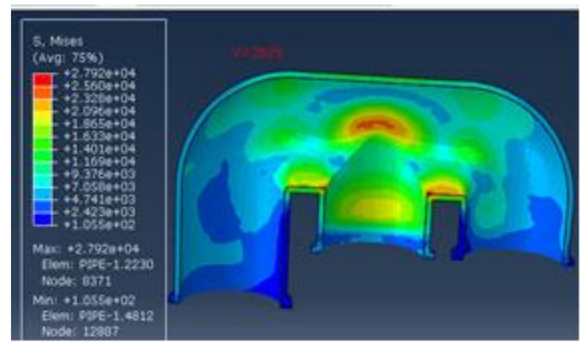

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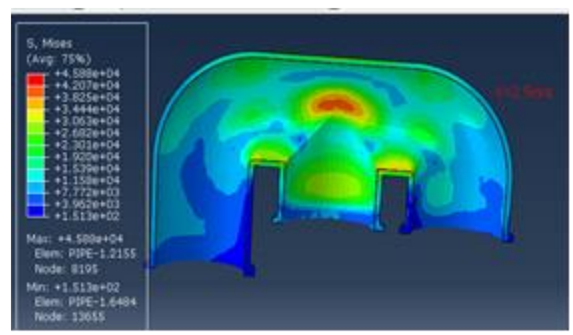

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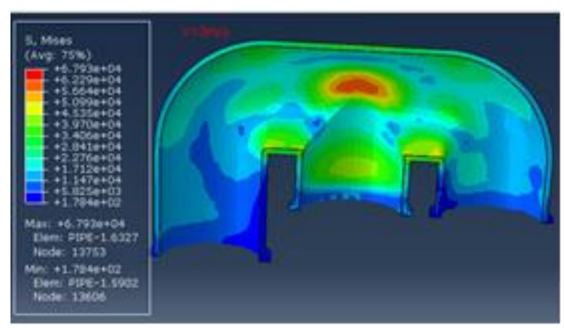

(c)

Figure10. Mises stress distribution of solid pipe in various flow velocities (a) v = 2 m/s; (b) v = 2.5 m/s; (c) v = 3 m/s

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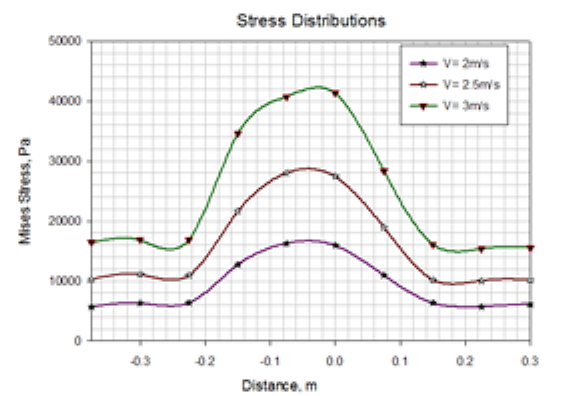

Figure 11. Mises stress distribution of solid pipe at various flow velocities

Pipe may be collapsed since the Von Mises stress was lower than the ultimate strength (50MPa). The simulation results for bend pipe are included in table 3 as follows.

Table 3. Summary of simulation results

Item	Value			Units
Velocity	2	2.5	3	m/s
Pressure (Max ;)	$1x10^3$	$1.6x10^3$	$4.6x10^3$	Pa
Pressure (Min ;)	$-2.5x10^3$	$-3.5x10^3$	$-4.1x10^3$	Pa
Temperature (max ;)	120	120	120	˚C
Temperature (min ;)	25	25	25	˚C
Mises stress (max ;)	$2.8x10^4$	$4.6x10^4$	$6.8x10^4$	Pa
Mises stress (min ;)	$1.1x10^2$	$1.5x10^2$	$1.8x10^2$	Pa

V. CONCLUSION

FSI analysis of this study by ABAQUS Co-simulation is performed to obtain the transient temperature and pressure distributions of thermal flow and stress distributions in the wall of the solid pipe under water flow. According to the simulation results, it can be concluded that the highest value of stresses occurred at the intersecting area of the T-junction. The stress values at other areas, such as inlet and outlet, were very small compared with the maximum stress at the intersecting area. It is concluded that the bend pipe may be collapsed since the Von Mises stress was lower than the ultimate strength (50MPa).

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