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Investigation of the Effect of Hot Fluid on Deformation in T-Shaped Pipes by FSI Method Using Different Material

Haydar KEPEKCİ*[1], Erman ASLAN[2]

Abstract

In this study, the high-temperature liquid water flow through the cross-section of a T pipe and the effect of the temperature of the liquid on the pipe material has been investigated. Pipe deformation caused by fluid temperature has been analyzed by the Fluid-structure interaction method. The effect of temperature distribution inside the pipe has been considered as thermal load in the structural analysis of the pipe body. The finite volume method has been used in the study with numerical methods. While $\boldsymbol{k-\varepsilon}$ is preferred as the turbulence model, the mesh file created to be used in the analysis contains 200,000 grid cells. For all calculations, the Reynolds number has been set to 3900 and kept constant. The geometry of the T pipe, the fluid passing through the pipe and used the boundary have been constant for the numerical analysis made in the study. The pipe material has been determined as the only parameter that changed. As different pipe materials magnesium, aluminum, copper, steel, concrete, cast iron, and titanium have been used. As a result of the study, thermal strain, total deformation, and directional deformation values have been determined. As a result, it has been determined that the greatest deformation under thermal load is in magnesium pipes, and the smallest deformation is in titanium pipes. It has been observed that the total amount of deformation of the pipe made of magnesium is three times higher than that of the titanium pipe.

Keywords: Fluid-structure interaction, computational fluid dynamics, flow and heat transfer, T-shaped pipes.

1. INTRODUCTION

With the spread of industrialization, the usage area of hydraulic and pneumatic systems has also expanded. These systems are used in petrochemical plants to energy production areas, from thermal heating systems to car engines. Energy transmission in hydraulic and pneumatic systems is done through pipes. The pipe surface is required to be smooth so that the uniformity of the flow in the pipe is not disturbed, there is no noise caused by vibration and it does not cause undesired turbulence during the flow. The unpredictability of turbulence during any flow means not knowing the characteristics of the flow. This means that the wrong components are selected in the system design, thus

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disrupting the energy transmission. In all pneumatic and hydraulic systems used, the amount and speed of the in-pipe flow are of great importance. In order to calculate these parameters correctly, it is necessary to know the deformity of the pipe surface. However, the idea is that the pipes are not deformed. Because pipes with increased deformation become unusable and need to be replaced. There are two main reasons for the deformation of pipes. These are the mechanical loads caused by the pressure of the fluid passing through it and the thermal loads caused by the temperature difference between the fluid and the pipe surface. Detection of deformations occurring during flow and heat transfer is important in terms of ensuring continuity in production and power transfer [1].

Fluid-Structure Interaction (FSI) is a scientific subject that examines the relationship between a moving fluid and a solid surface that has deformations in its structure. During flow fluctuations, such as increasing the flow rate or switching a pump on and off, the effect of the fluid on the solid surface may increase. FSI serves to calculate this incremental effect and to examine its consequences [2]. Accurate calculations cannot be made without knowing the roughness and amount of deformation of the solid surface that any flow contacts. For this reason, the FSI method should be considered to calculate the amount of power and energy transmitted by continuous flows. The interaction of the fluid with the solid surface is one of the topics that has attracted attention both academically and in the sector recently. There are many studies on this subject in the literature.

Xu et al. created a pipe system model operating under various boundary conditions and examined the effect of fluid motion on the solid surface using the fluid-structure interaction model. They integrated straight, curved, and T-shaped pipe models into a more complex system and worked on the overall solution of the multi-branch pipe system. They carried out their studies both numerically and experimentally. As a result, they found that the data they obtained were compatible with each other [3]. Hös et al. have derived mathematical equations for a straight pipe connected to the discharge valve of the pressure tank, taking into account the fluid velocity. They found that the results of the simulations they made using the new model they obtained and the FSI model were compatible with each other [4].

Dongwei et al. investigated the response of fluids in hydraulic systems affected by external loading. While doing this study, they proposed alternative models to the fluid-structure interaction method that can predict pressure values along the pipeline. FSI analyses were performed using the CFD program to validate the proposed models. As a result, they found that the models they proposed were successful in pressure estimation [5]. Evrim and Lauiren investigated the thermal fatigue failure of the turbulent mixture inside the T-type pipes used in nuclear power plants. They used the Large Eddy Simulation method as the turbulence method in their work using OpenFoam. As a result of their analysis, they determined that there are significant temperature fluctuations near the mixing zone of the hot and cold fluid inside the T-pipe. They obtained similar results in their experiments to validate the simulations [6]. Yao et al. used CFD-DEM-FEM and FSI methods to analyze pipe vibration when the solid-liquid two-phase flow is carried in oil pipes. As a result of their research, they found that when the velocity of the two-phase flow and the sand ratio increase, the accumulation of particles is more important where the pipe diameter changes. They said that their study will guide the design process of the pipes to be used during high-concentration solid-liquid two-phase flow [7].

Tijsseling has derived a one-dimensional mathematical model to study the acoustic behavior of thick-walled liquid-filled pipes. The basis of this model is the fluid-structure interaction (FSI) [8]. Li and He conducted investigations using the FSI model to detect the mechanical failure of buried gas pipelines. They found relations to calculate pipeline deformations and pipeline reliability [9]. Zhang and Lu performed analyses using the ANSYS program to calculate the thermal stress and thermal fatigue of a T-pipe under turbulent flow mixing. They used the FSI model in their work. They also conducted experiments to confirm the results they obtained from their analysis. As a result, they found that thermal fatigue occurred mostly at the T-junction [10]. Espinosa and Garcia studied vibrations arising from fluid-structure interaction at the junctions of the T-junction during flow. As a result of their work with the CFD method, they determined that the vibrations occurred due to the unstable structure of the flow [11].

Jaing et al. carried out studies to examine the vibrations caused by the fluid-structure interaction in the centrifugal pump. During the calculations of their work with the CFD method, they neglected the vibrations at the blade transition frequencies. During their studies, they said that the pipe-valve system increased the flow instability of the fittings [12]. Zhou et al. carried out experiments to investigate the effects of thermal fatigue in the regions of T-section pipes close to the weld joint during turbulent flow. While the hot fluid used during the experiments had a temperature of 280 degrees and the cold fluid had a temperature of 20 degrees, the pressure inside the pipe was chosen as 75 bar. As a result of their experiments, they determined that the temperature difference change has a significant effect on the stability of the thermal stratification [13].

In this study, the effect of the hot fluid passing through the T-shaped pipe, which is frequently used in hydraulic systems, on the pipe deformation has been investigated by the FSI method using the CFD program. Numerical and visual data obtained as a result of numerical analyzes by selecting seven different materials have been compared with each other and the material most resistant to thermal load has been determined.

2. NUMERICAL METHODS

This study, which examines the deformation created by the hot fluid on the pipes through which it passes, has been carried out numerically using computational fluid dynamics software. The reason why CFD method studies replace experimental studies in both academic and sectoral studies is to save cost and time. Because while experimental studies correspond to large sums, calculations made using computer software can be made much cheaper. This causes them to be preferred [14]. The first thing to consider when performing a study using CFD software is to correctly determine the boundary conditions. The geometry to be worked on is created. The geometry of the T pipe drawn to be used in the analysis is shown in Figure 1 as measured and the boundary conditions used in the analysis are shown in Figure 2.

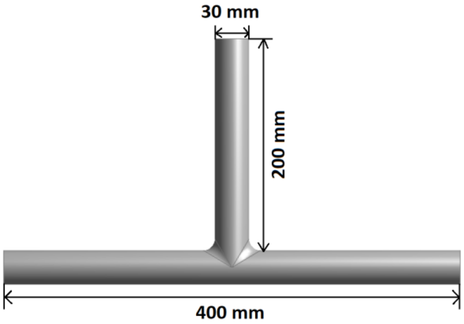


Figure 1 Dimensioning of the T-shaped pipe

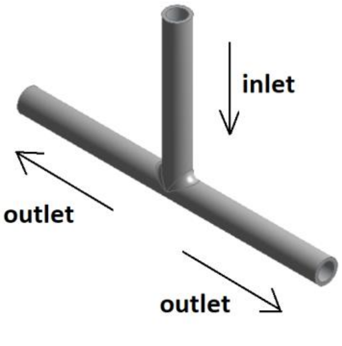


Figure 2 Boundary conditions of the T-shaped pipe

After the geometry is created, it is divided into small regions called grids with a process called mesh. The higher the mesh number, the higher the accuracy of the analysis. However, as the number of meshes increases, the solution times of numerical analyzes also increase. For this reason, the number of meshes should not be kept too high [15]. Then, analyses are made using the created mesh file. The mesh file used in this study consists of 200,000 grid cells. The mesh structure consists of hexahedral cells. The piece of pipe being worked on is designed with minimum dimensions. A large-diameter geometry has been not preferred as the analysis would take longer as the pipe size grew. Since the purpose of this study is to compare T pipe materials, geometry size and analysis time do not matter in analyzes without changing boundary conditions. Mesh independence has not been done in this study. Instead, a value close to the number of grids in the mesh files used for analysis in similar studies has been determined. Thus, time is saved by not repeating the same process. In the mesh file creation process, the y+ value has been taken into account in order to keep the mesh quality high. The expression y+ means the mesh fineness in the area close to the wall and indicates the sensitivity of the mesh file to be used in the analysis. As the sensitivity of the y+ value increases, the accuracy of the data obtained from the CFD calculations also increases. In this study, the y+ value has been determined as 0.8. The view of the created mesh geometry is given in Figure 3.

Figure 3 General view of the mesh structure

In this study, it is necessary to determine the turbulence method for the solution. Among the turbulence models, the best option to solve this problem has been determined as k–ε as a result of the research made in the literature [15]. The k-epsilon model is one of the most widely used turbulence models, but that doesn't well perform in cases of large adverse pressure gradients [16]. It is a two-equation model, which includes two extra transport equations to represent the turbulent properties of the flow. This allows a two-equation model to account for historical effects like convection and diffusion of turbulent energy. The first transported variable is turbulent kinetic energy, k.

The second transported variable, in this case, is the turbulent dissipation, epsilon. It is the variable that determines the scale of the turbulence, whereas the first variable, k, determine the energy in the turbulence [16]. Turbulence kinetic energy and dissipation equations are given in Eq. 1 and Eq. 2.

For turbulent kinetic Energy, k;

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho k u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_k}\frac{\partial k}{\partial x_j}\right]+2\mu_t E_{ij}E_{ij}-\rho\varepsilon \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

For dissipation, ε;

$$\frac{\partial(\rho\varepsilon)}{\partial t}+\frac{\partial(\rho\varepsilon u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_\varepsilon}\frac{\partial\varepsilon}{\partial x_j}\right]+C_{1\varepsilon}\frac{\varepsilon}{k}2\mu_t E_{ij}E_{ij}-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}\ldots \quad \ldots\ldots\ldots \quad (2)$$

In Eq. 1 and Eq. 2 u_i is represents the velocity component in the corresponding direction, E_{ij} is represents a component of the rate of deformation, and μ_t is represents eddy viscosity [16]. At the inlet section velocity inlet boundary condition is applied as 0.5m/s, and constant temperature is given as 370K. The drichlet boundary condition is applied at the wall, and constaant temperature is 300K. Pressure outlet is given at outlet sections (P_{gauge} =0). The FSI method has been preferred to examine the effect of the material change of the T pipe on the solid surface. In recent studies, it has been determined that there is an interaction between the fluid and solid surface due to contact, and this situation causes deformation. The amount of deformation is estimated using CFD programs. Related programs use Eq. 3 and Eq. 4 to detect deformation on a solid surface;

$$[M_s]\{\ddot{U}\} + [K_s]\{U\} = [F_s] + [R]\{P\} \qquad (3)$$

$$\begin{bmatrix} M_s & 0 \\ \rho R^T & M_f \end{bmatrix}.\{\ddot{U}/\ddot{P}\} + \begin{bmatrix} K_s & R \\ 0 & K_f \end{bmatrix}.\{U/P\} = F_s/F_f \;\ldots\ldots\ldots\ldots\ldots \qquad (4)$$

M_s represents the structural mass matrix, M_f liquid mass matrix, F_s structural force matrix, F_f fluid force matrix, R represents the effective surface area matrix where the fluid and solid surface are in contact, ρ represents fluid density, R static pressure given in Eq. 3 and 4 [17]. In this study, the deformation of the hot fluid passing through the T pipe according to the material type has been investigated by choosing seven different materials. The selected materials are magnesium, aluminum, copper, stainless steel, concrete, gray cast iron, and titanium. The physical properties of these materials are given in Table 1.

Table 1 Physical properties of materials used in the analysis

Material	**Density** $[kg/m^3]$	**Coefficient of Thermal Expansion** $[K^{-1}]$	**Specific Heat** $[J/kg.K]$
Magnesium	1800	2.6E-05	1024
Aluminum	2770	2.3E-05	875
Copper	8300	1.8E-05	385
Stainless Steel	7750	1.7E-05	480
Concrete	2300	1.4E-05	780
Gray Cast Iron	7200	1.1E-05	447
Titanium	4620	9.4E-06	522

In analyses of solid models, there are different parameters used in deformation calculations. These parameters are Young's modulus, Poisson's ratio, and density. Young's modulus is a term that expresses a material's elastic properties. It is usually represented by the symbol "E" and determines how much a material can return to its original shape after being stretched or bent. Young's modulus is equal to the ratio of stress to strain. Young's modulus is particularly important for material behavior under tensile and compressive forces and determines the material's deformation capacity. Each material has a unique Young's modulus value, and it can be used to compare the elastic properties of different materials [18].

Poisson's ratio is a material property that expresses the transverse deformation ratio that occurs with longitudinal stress. It is used to determine how deformation occurs in other directions when a material is stressed in one direction. Poisson's ratio is also known as the Poisson coefficient and has a negative value. This means that when a material is stressed in one direction, it tends to compress in the other direction. Poisson's ratio is important for understanding a material's elastic behavior and is used in structural engineering, material science, and many other industries [18].

Density is a physical property defined as the mass of a substance per unit volume. This property is used to determine how dense a substance is and how much matter it contains in a unit volüme [19]. Table 2 provides the values for Young's modulus, Poisson's ratio, and density for the materials used in this study.

Table 2 The other physical properties of materials used in the analysis

Material	**Young's modulus [GPa]**	**Poisson Oranı**	**Mass density** $[kg/m^3]$
Magnesium	45	0.29	1738
Aluminum	70	0.33	2700
Copper	120	0.34	8960
Stainless Steel	200	0.30	7930
Concrete	30	0.15	2300
Gray Cast Iron	170	0.26	6800
Titanium	110	0.34	4500

The fluid used in the study was water, and its properties at a temperature of 370 K are given in Table 3.

Table 3 Properties of water at 370 K

Density	940.8 [kg/m³]
Viscosity	0.000366 Pa.s]
Thermal conductivity	0.625 [W/(m.K)]
Heat capacity	4182 [J/(kg K)]
Coefficient of thermal expansion	0.00021 [K^{-1}]
Surface tension	0.0589 [N/m]

The physical properties of the selected materials are completely different from each other. As a result of the study, it has been desired to determine which physical properties of the materials have been more effective on the deformation caused by thermal effects. "AMD Ryzen 9-5900HX CPU@4.6 GHz, 8 cores" gaming notebook has been used in the analysis. Calculations have been solved in a steady-state manner independent of time and numerical analysis is stop when converge is done.

3. RESULTS

The temperature and velocity distributions of the flow in the pipe with the results of the analysis whose solution has been completed are given in Figures 4 and 5, respectively.

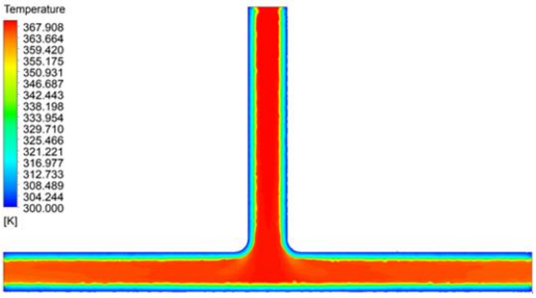


Figure 4 Temperature distribution in the T-shaped pipe

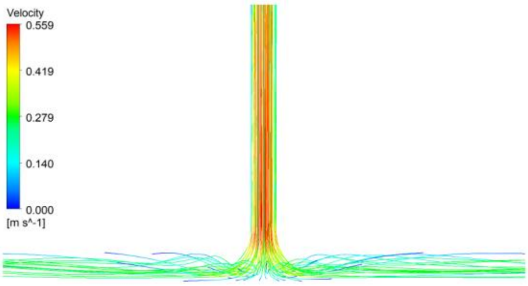
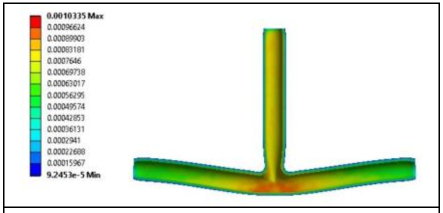


Figure 5 Velocity distribution in the T-shaped pipe

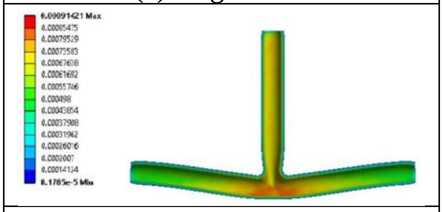
Since only the pipe material has been determined as the variable parameter in the analysis, it has been observed that the flow velocity and temperature distribution within the pipe have been the nearly same in every calculation. In Figure 4, it is seen that the fluid temperature cools down when it approaches the pipe surface.

The reason for this is thought to be heat transfer by conduction arising from contact with the cold surface. In Figure 5, it is seen that the fluid velocity at the outlet of the T pipe is lower than the velocity at the inlet. This situation is thought to be caused by the pressure drop caused by the pipe geometry. Visuals of the thermal strain results obtained from the analyzes using seven different materials for the T pipe are given in Figures 6.

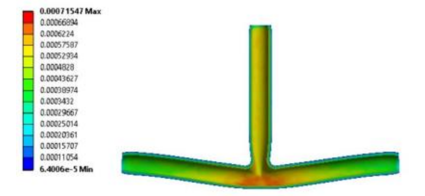
When Figures 6 is examined, it is seen that the highest thermal strain amount is in magnesium pipe with 0.0010335 mm, and the lowest thermal strain amount is in titanium pipe with 0.00037363 mm. It has been understood that there is a thermal strain difference of about three times between these materials. Among the materials used in the analysis, it has been determined that the most heat-resistant material after the magnesium pipe is aluminum and its thermal strain is 0.00091421 mm, close to the strain amount of the magnesium pipe. This value is 0.00071547 mm for copper, 0.00067667 for steel, and 0.00055648 mm for concrete.



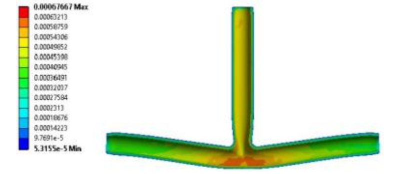
(a) magnesium



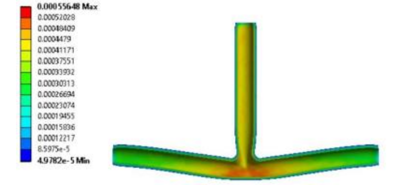
(b) aluminum



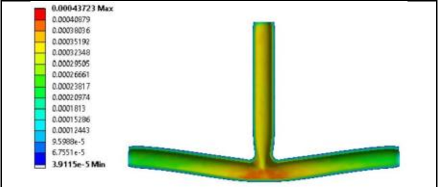
(c) copper



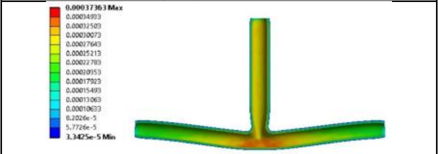
(d) stainless steel



(e) concrete



(f) gray cast iron

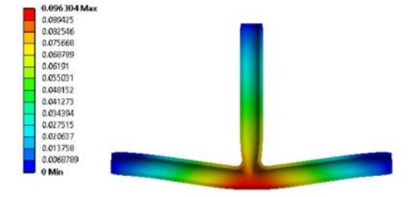


(g) titanium

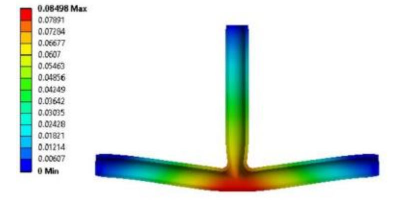
Figure 6. Thermal strain in the pipe made of (a)magnesium, (b) aluminum, (c) copper, (d) stainless steel, (e) concrete, (f) gray cast iron, (g) titanium

It has been determined that the most heat-resistant pipe material after titanium is gray cast iron. The elongation amount of this material due to thermal effects is 0.00043727 mm from the results obtained from the analysis. Thermal strain is not the only reason why materials deform. Materials can be deformed due to different reasons during flow. From the analyzes made, the total deformation amounts of the materials used for the T pipe design have been also calculated. The visuals of the total deformation results obtained from the analyzes using seven different materials for the T pipe are given in Figures 7.

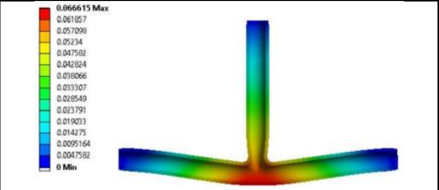
When Figures 7 is examined, it is seen that the highest total deformation amount is in the magnesium pipe with 0.096304 mm, and the lowest total deformation amount is in the titanium pipe with 0.034882 mm. Looking at the results of the analyzes made using these materials, it has been understood that the total deformation amount differences have been approximately three times. It has been determined that aluminum is the most unstable material after magnesium in case of hot fluid passing through the materials used in the analysis. The highest total amount of deformation of the aluminum pipe has been calculated as 0.08498 mm. This value is very close to the total deformation amount of the magnesium pipe. In this case, it can be said that there is not much difference between them. This value is 0.06615 mm for copper, 0.062661 for stainless steel, and 0.050873 mm for concrete. It has been determined that the most resistant pipe material to thermal deformation after titanium is gray cast iron. It is among the results obtained from the analyses that the amount of deformation of this material due to thermal effects is 0.040424 mm. The total deformation and thermal strain amounts of the materials obtained from the analysis are given in Table 4.



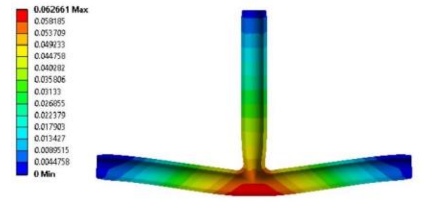
(a) magnesium



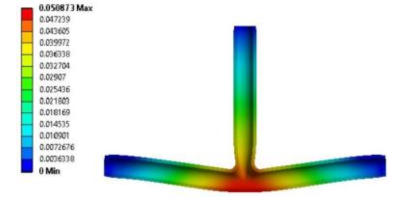
(b) aluminum



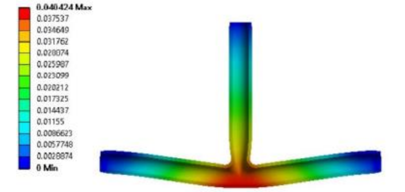
(c) copper



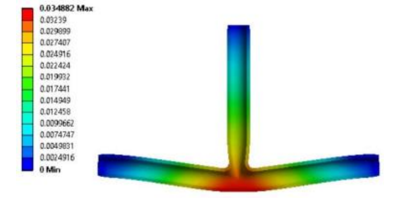
(d) stainless steel



(e) concrete



(f) gray cast iron



(g) titanium

Figure 7 Total deformation in the pipe made of (a)magnesium, (b) aluminum, (c) copper, (d) stainless steel, (e) concrete, (f) gray cast iron, (g) titanium

Table 4 Thermal strain and deformation values of different materials obtained from the results of the analyzes

Material	**Thermal Strain** $[mm]$	**Total Deformation** $[mm]$
Magnesium	0.0010335	0.096304
Aluminum	0.00091421	0.08498
Copper	0.00071547	0.066615
Stainless Steel	0.00067667	0.062661
Concrete	0.00055648	0.050873
Gray Cast Iron	0.00043723	0.040424
Titanium	0.00037363	0.034882

When Table 4 is examined, it is seen that there is a directly proportional relationship between thermal strain and total deformation. Materials with high thermal strain values also have high total deformation values.

4. CONCLUSIONS AND DISCUSSION

In this study, the deformation of the T pipe, through which the hot fluid passes, due to thermal effects have been investigated. In this examination, which has been carried out with numerical methods, seven different pipe materials have been selected and CFD analyzes have been carried out using the FSI method. Numerical data and images obtained as a result of the analyzes have been compared with each other and some inferences have been made. The temperature distributions inside the pipe have been examined and it has been determined that the flow cooled down where it approached the pipe walls. This situation, which is caused by the heat transfer between the hot fluid and the cold surface, has been seen in all analyses.

In addition, when the velocity distribution inside the pipe is examined, it is seen that the velocity at the inlet is greater than the velocity at the outlet. This is due to the pipe geometry and the axis difference between the inlet and outlet directions of the fluid. Since the temperature and velocity distribution have been obtained in the same way in all analyses, it has been understood that the pipe material change did not affect these results. According to the data obtained from the FSI solutions, it has been determined that the magnesium pipes with the highest thermal strain are not suitable for systems with the hot fluid transmission. The tube with the lowest thermal strain has been determined to be made of titanium. However, since titanium is a very expensive material and it is known that it is generally used in the aviation industry, it can be said that gray cast iron material, which gives close values to it in FSI analyses, is more suitable for hydraulic systems with hot fluids. In addition, it has been clearly seen from the analysis that the region with the highest deformation risk in the T pipe is the junction point. For this reason, the junction point of the T pipes through which hot fluid passes should be supported with materials with low thermal strain value. Otherwise, the micro-cracks in the pipes will grow over time and cause the pipes to lose their function. This is of great importance for the continuation of the systems and the deterioration of the flow characteristics.

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Authors' Contribution
The authors contributed equally to the study.

The Declaration of Conflict of Interest/ Common Interest
No conflict of interest or common interest has been declared by the authors.

The Declaration of Ethics Committee Approval
This study does not require ethics committee permission or any special permission.

The Declaration of Research and Publication Ethics
The authors of the paper declare that they comply with the scientific, ethical and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.

REFERENCES

[1] D. Andrade, F. Rachid, A. Tjsseling, “A new model for fluid transients in piping systems taking into account the fluid-structure interaction”, Journal of Fluids and Structures, vol. 114, pp. 103720, 2022.

[2] M. Li, J. Pan, M. Ni, N. Zhang, “Heat transfer and thermal stress analysis in fluid-structure coupled field”, Applied Thermal Engineering, vol. 88, pp. 473-479, 2015.

[3] Y. Xu, D. Johnston, Z. Jiao, A. Plummer, “Frequency modeling and solution of fluid-structure interaction in complex pipelines”, Journal of Sound and Vibration, vol. 333 (2014), pp. 2800-2822, 2014.

[4] C. Hös, A. Champneys, K. Paul, M. McNeely, “Dynamic behaviour of direct spring loaded pressure relief valves: III valves in liquid service”, Journal of Loss Prevention in the Process Industries, vol. 43, pp. 1-9, 2016.

[5] S. Dongwei, D. Jianbo, Z. Yong, “Investigation of pressure in pipe subjected to axial-symmetric pulse loading”, International Journal of Impact Engineering, vol. 25, pp. 523-536, 2001.

[6] C. Evrim, E. Laurien, “Large-Eddy Simulation of turbulent thermal flow mixing in a vertical T-Junction configuration”, International Journal of Thermal Sciences, vol.150, pp. 106231, 2020.

[7] L. Yao, Z. Xiao, J. Liu, Q. Zhang, “A new multi-field coupled dynamic analysis method for fracturing pipes”, Journal of Petroleum Science and Engineering, vol. 196, pp. 108023, 2021.

[8] A. Tijsseling, “Water hammer with fluid-structure interaction in thick-walled pipes”, Computers and Structures, vol. 85, pp. 844-851, 2007.

[9] Q. C. Li, S. He, “Research on effect factors of mechanical response of cross-fault buried gas pipeline based on fluid-structure interaction”, Journal Pressure Vessel Technology, vol. 143, no. 6, pp. 061402, 2021.

[10] Y. Zhang, T. Lu, “Study of the quantitative assessment method for high-cycle thermal fatigue of a T-pipe under turbulent fluid mixing based on the coupled CFD-FEM method and the rainflow counting method”, Nuclear Engineering and Design, vol. 309, pp. 175-196, 2016.

[11] F. Espinosa, J. Garcia, “Vibration failure in admission pipe of a steam turbine due to flow instability”, Engineering Failure Analysis, vol. 27, pp. 30-40, 2013.

[12] Y. Jiang, S. Yoshimura, R. Imai, H. Katsura, T. Yoshida, C. Kato, “Quantitative evaluation of flow-induced structural vibration and noise in turbomachinery by full-scale weakly coupled simulation”, Journal of Fluids and Structures, vol. 23, no. 4, pp. 531-544, 2007.

[13] M. Zhou, R. Kulenovic, E. Laurien, “Experimental investigation on the thermal mixing characteristics at a 90^o T-Junction with varied temperature differences”, Applied Thermal Engineering, vol. 128, pp. 1359-1371, 2018.

[14] H. Kepekci, B. Zafer, H. Guven, B. Korbahti, “Aeroacoustics Investigation of a Wind Turbine for Different Blade Tip Shapes Using Computational Fluid Dynamics Software”, Fresenius Environmental Bulletin, vol. 30, no. 11, pp. 12037-12047, 2021.

[15] H. Kepekci, E. Aslan, “CFD Analysis of Convection Heat Transfer in Corrugated Channels for Different Inclination Angle”, Sakarya University Journal of Science, vol. 26, no. 2, pp. 333-341, 2022.

[16] Kaya F., and Karagöz İ. (2007) Girdaplı Modellerin Türbülans Modellerinin Uygunluğunun İncelenmesi. Uludağ Üniversitesi Mühendislik-Mimarlık Fakültesi Dergisi, 12(1), 85-97.

[17] D. Dhande, D. Pande D, “Multiphase flow analysis of hydrodynamic journal bearing using CFD coupled Fluid-Structure Interaction considering cavitation”, Journal of King Saud University-Engineering Sciences, vol. 30, pp. 345-354, 2018.

[18] Yang L., Yang L., Lowe R. (2021) A viscoelasticity model for polymers: Time, temperature, and hydrostatic pressure dependent Young's modulus and Poisson's ratio across transition temperatures and pressures. Mechanics of Materials, vol. 157, pp. 103839.

[19] Barney C., Helgeson M., and Valentine M. (2022) Network structure influence bulk modulus of nearly incompressible filled silicone elastomers, Extreme Mechanics Letters, vol. 52, pp. 101616.