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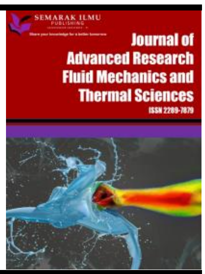


# Characteristics of Flow-Induced Vibration of Conveying Pipes for Water and Coolant Flow

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**ABSTRACT**

One of the effects of vibrations resulting from the flow of fluids is the failure that occurs to the structure of the systems, which in turn affects the efficiency of the parts that make up those systems. for the purpose of studying the possibility of improving the performance of the systems, a liquid other than water and coolant (super antifriz\petrol ofisi) was chosen because of its advantages that can be taken advantage of, including the high viscosity of water and its tolerance to high temperatures resulting from combustion or air temperature, as well as low temperatures to ensure the operation of the system, that is, it maintains stability system temperature to obtain the best possible condition In addition to the purity of the liquid from salts and the presence of a percentage of oil in the composition of the coolant, an insulating layer is formed inside the pipes to prevent rust and corrosion in the pipes, thus ensuring the flow of fluids and prolonging the life of the pipes. The aim is to study and analyze the effect of induced vibrations and internal pressure on fluid transport pipes, and to compare them in the cases of using water and coolant under the same conditions. An empirical analysis considering the natural frequencies produced by the effect of fluid pressure under various stabilization conditions. It was observed from the results that the higher the pressure, the greater the percentage of the deflection of the copper tubes compared to the Aluminium tubes when using both liquids (water and coolant) at the same boundary condition noted the percentage of the deflection difference when using copper pipe (from 0% to 20.3%) was less than using Aluminium (from 2% to 59%) when the pressure was increased. That mean the Aluminium pipe better than copper pipe.

## 1. Introduction

Attention to vibrations caused by flow in a pipe has become one of the most serious considerations in the design of structure and piping equipment. When all pipes are vibrating under all flow conditions, attention is paid to vibrations that cause significant damage to the pipe [1]. Structural failure due to vibration caused by flow is a common problem for [2-5] heat exchangers affecting their suitability and performance. Vibrations from the flow can also damage the tubes in the evaporators [6]. Flow Induced Vibration (FIV) can be applied in the design of oil pipelines [7],

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pump discharge lines [8] rocket engine [9] fuel lines [9-10] reactor system components [11] and sun concentrator systems [12,13].

Engineers and analysts rely primarily on Energy Institute (EI) guidelines for vibration-induced failure avoidance in piping work to determine the potential for piping system failure due to vibration-induced flow. While emotional intelligence guidelines provide a quantitative measure of the probability of failure and offer potential remedial actions, some basic criteria such as fatigue age cannot be obtained Richard *et al.,* [14] Used numerical simulations to determine the fatigue life of a flow line transporting natural gas at three different flow speeds; 65m/s, 130m/s and 170m/s. also studied experimentally the wall pressure fluctuations associated with single-phase flow in a geometrically complex manifold. References [15-16] studied the dynamic behavior of a copper tube that transports fluids in different ways, where the use of three types of supports, which are simply support - simply support, fixed support - fixed support and fixed free support. The effect of support types on the vibration frequency and capacitance of the pipe transporting the fluid at different flow temperatures was studied. These vibration characteristics have been tested at temperatures of 50, 65 and 80°C. Yun-dong *et al.,* [17] Presented a method of investigating the forced vibrations of pipe conveying fluid using green function. The proposed method provides exact solutions in closed form. Green's functions for pipes with Different homogenous and elastic boundary conditions are also presented in this study. The natural frequencies of the fluid- conveying pipes can be obtained using the method of Green's function. The results demonstrate that Green's function is an efficient means of analyzing the forced vibration of pipes that convey fluid. Tao *et al.,* [18] examined the effect of the guide vane fixed at the elbow on the noise and vibration caused by flow in the range of Reynolds numbers from 1.70 to 6.81-105. Dhia *et al.,* [19] studied the effect of vibration caused by the flow of water in a spiral tube. Fluid-induced vibration due to fluid temperature and mass flow rate has been studied experimentally. A copper tube with an inner diameter of 10 mm and a length of 15 meters was used to make the spiral tube. Water flow rates from 4 to 7 LPM and fluid temperatures from 45 to 65 °C were used in the experiments. The results of the experiment showed that the frequency and natural frequency of vibration of the spiral tube are affected by the fluid temperature and the mass flow rate. The frequency of the vibrations increased to a maximum of 2.989 Hz as the temperature was raised to 65 °C. This has been explained due to the higher kinetic energy of the high temperature flows. Chen An *et al.,* [20] studied the dynamic behavior of tubes transporting gas-liquid flow in two phases analytically and numerically on the basis of generalized integrated transfer technique (GITT). While Mohamed [21] studied transverse dynamic response of simply supported pipe with variable tubular cross sectional area carrying fluid with a constant flow rate is investigated. Euler Bernoulli's beam theory is used to model the pipe. Hamilton's principle will be used to produce the governing equation of motion for the system. Jinlong *et al.,* [22] studied The Three-dimensional (3-D) dynamical behaviors of a fluid-conveying pipe subjected to vortex-induced vibration are investigated with different internal flow velocity v. The values of the internal flow velocity are considered in both subcritical and supercritical regimes. Asie *et al.,* [23] tend to investigate the dynamic behavior of fluid transport tubes under the influence of the impact force generated by the ball collision, and the soil reaction force on the tube is directly calculated using the nonlinear hysteretic soil model, while the tube-soil interactions at the shoulders can significantly affect the vibrations Vortex-induced (VIV) of freely extending tubes on the seafloor as studied by GAO Xi *et al.,* [24]. In general, it can cause internal vibrations within pipelines caused by the passage of fluids through the pipeline system. This pipeline system can be damaged by sudden amplified vibrations that were not taken into account when designing the system, and the vibrations caused by the flow resonate with the natural frequency of the pipes. Therefore, it is important to predict and quantify pipeline system vibrations during its lifetime. This led to the existence of several studies [25-28].

Ansam and Haitham [30] conducted research on a circular pipe with a length of 1.6 m with two different diameters, d=15 mm and d=35 mm, at a height of 4 m in a tank. two conditions were applied to the pipe environment, the first being in the air. the other one is immersed in water; the forced excitation vibration is studied. harmonic forced vibration with two different excitation frequencies (10 Hz and 15 Hz) in all five locations. the distance between two stations (0.2 m). it is concluded that the effect. the vibration caused by the flow due to the tube transmission fluid increases maximum deflection when increasing fluid velocity. water surrounds the tubes reduce the effect of excitation vibrations by about (33-46%). the effect difference between excitation frequencies was about (4-7%).

In this paper, an experimental system was modeled and built to study and analyze the effect of induced vibrations on two types of pipes using two different fluids (water and coolant), where the Reynolds number was fixed for both fluids. and the study of sudden forced vibration imposed at three locations on the tubes. The distance between two sites (250 mm).

## 2. Experimental Program

### *2.1 Apparatus and Procedures*

Modeling and construction of an experimental platform to study the effects of flow factors on FIV in the fully developed flow area of the liquid transport pipe and find the natural frequency of each tube using both fluids

### *2.2 Experimental Setup*

The experimental rig was designed and constructed in the laboratory of the Mechanics Department at Al-Nahrain University/College of Engineering. A schematic diagram of the experimental model is shown in Figure 1 and Table 1.


**Fig. 1.** Set-up for vibration test

**Table 1**
Item description for rig

| Item no. | Description |
|---|---|
| 1 | Ball valve |
| 2 | Flow meter |
| 3 | Test pipe (Aluminium or copper) |
| 4 | Accelometer |
| 5 | Bearing support |
| 6 | Pressure gauge |
| 7 | Excitement hammer |
| 8 | Oscilloscope |
| 9 | Amplifier waves |
| 10 | Personal computer |
| 11 | Base (120*40*1) cm |
| 12 | I – Beam (22*20*1) cm |

The rig is built to meet the various boundary conditions of the test samples with the ability to be rebuilt to meet experimental requirements. The rig consists of two components, the foundation and the outriggers are shown in Figure 2.

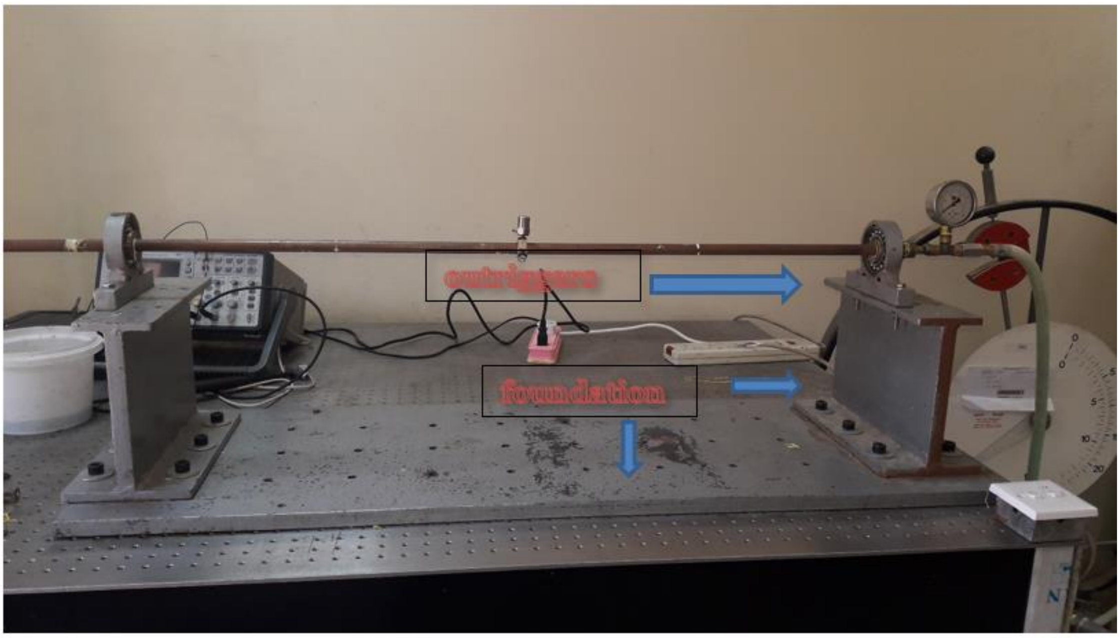


**Fig. 2.** Position of Outriggers and foundation in rig

It was built on the basis of specifications (120*40*1) cm, rectangular sheet metal with supporting columns of specifications (22*20*1) cm as shown in Figure 1.

To achieve the different requirements of the installed and stable conditions, the two substrates are designed. Two main parts of it are

i. The iron base (the first section - the crossbar) is fixed with three nails on each side is shown in Figure 3.

**Fig. 3.** Show the connect between the base and I beam

ii. The case with a rotating ball bearing that can be moved freely in the vertical axis to achieve zero torque of the support type (pin) is shown in Figure 4.

**Fig. 4.** Show the details of bearing

To achieve different boundary conditions, a single ball bearing was used to achieve zero (displacement and moment) support for the clamping end of the pin, as shown in the Figure 5. Moreover, one ball bearing (with a distance of 3 cm); used to achieve the zero (offset and slope) that represents the condition of the threaded ends.

**Fig. 5.** Bearing support

*2.3 Assumptions*

i. The flow is laminar.
ii. Fully developed flow.
iii. The tube is subject to Bernoulli's theory
iv. A horizontal tube was used in the study.
v. A slight deformation occurred in the tube frame X/D=0.05 ReD [31]

where X is the minimum length required to fulfill a fully developed flow as shown in Figure 6.

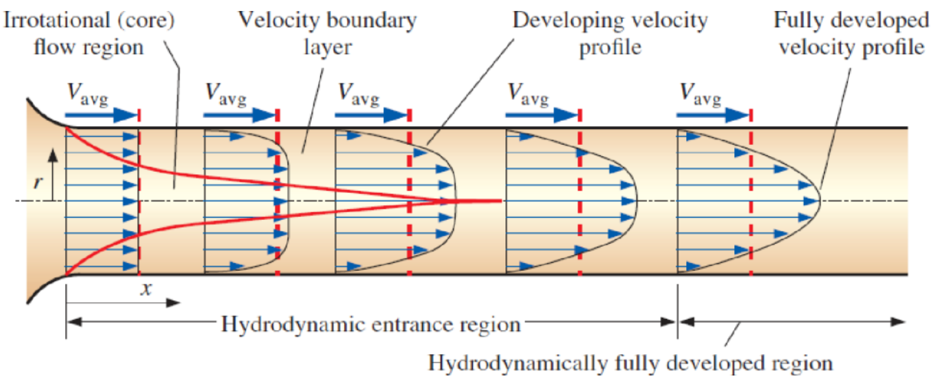


**Fig. 6.** Developing flow in the entrance region of pipe [29]

*2.4 Experimental Procedure*

To conduct the experiments, the following procedure was followed.

### *2.4.1 If there is a flow through the electric pump and no isolation between the foundation and the outriggers*

i. Water circuit is connected Figure 7, then fill the water supply tank, the flow meter should be in a vertical position and the test tube should be in a horizontal position.
ii. The excitation circuit was connected by connecting the hammer to the oscilloscope
iii. The measurement circuit is connected then connects the accelerometer to the test tube directly with fixing screws at a distance of 25 cm from one end of the test tube
iv. The accelerometer is connected to the wave amplifier and the latter is connected to the oscilloscope
v. Connecting the oscilloscope to the computer for the purpose of showing the readings
vi. The excitation is done by hammering on the distance to which the accelerometer is attached, and at the same time the operating program of the oscilloscope is activated in the computer for the purpose of knowing the excitation readings.
vii. Two readings are taken by knocking on the backing and at the area where the accelerometer is attached to the tube in case the tube is empty.
viii. Repeat step 7, but if the test tube is filled with water
ix. Turn on the pump and control the flow rate in order to make the flow amount 3 liters per minute
x. The same steps 6 and 9 were repeated, but with the pressure changing each time from 0 to 2 bar by 0.5 bar change each time.
xi. The previous steps (from 1 to 10) are repeated, but with the location of the accelerometer changed to 50 cm and 75 cm from the same end of the test tube
xii. Repeating the previous steps for both test tube models (Aluminium and copper) each time
xiii. Repeat the previous steps (from 1 to 12) with the change of liquid type from water to coolant

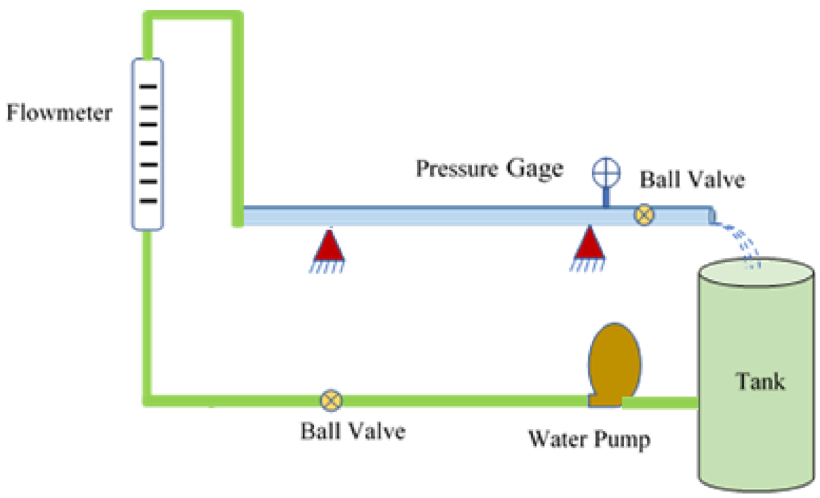


**Fig. 7.** Water circuit schematic

### *2.4.2 Natural frequency calculation*

i. The natural frequency of the used models was calculated by analyzing the readings obtained in the previous steps using the MATLAB 2017 program.
ii. The amount of deviation or displacement was calculated using the following relationship [32]

$$\mathrm{def\ (mm)} = \frac{\mathrm{amplitude\ (v)}}{(2*3.14*8000)^2} * 1000000 \quad (1)$$

From the readings obtained above

iii. The amount of damping was calculated in each case by the relation

$$\zeta=(w2-w1)/(2\omega n) \quad (2)$$

From the obtained readings Where ζ is the damping ratio, w1, and w2 are the frequencies which correspond to the half-power points, ωn is the natural frequency of vibration

## 3. Results and Discussion

### *3.1 For Aluminium Pipe*

For laminar fluid flow in the fully developed zone of a span pipe with fixed ends, forced vibration was explored experimentally. The results have been produced, and the consequences of the various parameters have been reviewed. Figure 8 to Figure 12 show diagrams of the deflection and the Table 2 shows the result of natural frequency values for different pressures and locations of the accelerometer position at Aluminium pipe conveying flow with the pipe length 1 m at (flow rate=3 l/min) and (14mm) diameters and two different type of liquids (water and coolant) for the Aluminium pipe in the case of flow at (0 bar) pressure to (2 bar) and for both liquids used (water and coolant) where placing the vibration exciter at (25, 50, 75 cm).

Figure 8 indicated to the deflection behavior in the case of (0 bar) pressure, where it has a value of (0 mm) at one end of the test tube at the first fixation point and begins to increase until it reaches the highest deflection value at the middle of the tube with a value of (0.033914) mm when using a coolant and a value of (0.0402526) mm when using water for the same boundary conditions, after which it begins to gradually decrease until it reaches zero value at the fixation point from the other end of the pipe meaning that there is a difference between the maximum value of deflection was 15.7 %.

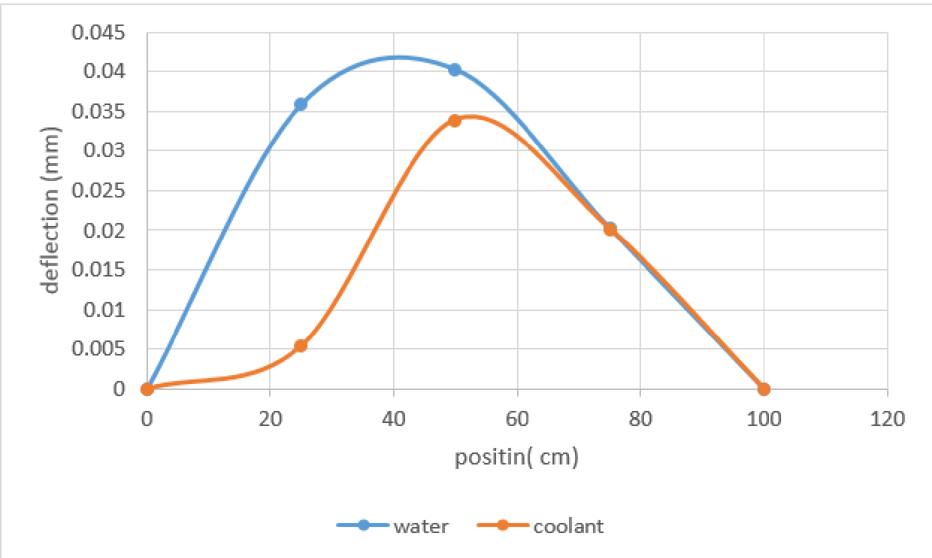


**Fig. 8.** Comparison of results of deflection with Aluminium pipe length, 0 bar

While Figure 9 indicated to the deflection behavior in the case of (0.5 bar) pressure, where it has a value of (0 mm) at one end of the test tube at the first fixation point and begins to increase until it reaches the highest deflection value at the middle of the tube with a value of (0.0402526) mm when using a coolant and a value of (0.0507) mm when using water for the same boundary conditions, after which it begins to gradually decrease until it reaches zero value at the fixation point from the other end of the pipe meaning that there is a difference between the max value of deflection was 20.6%.

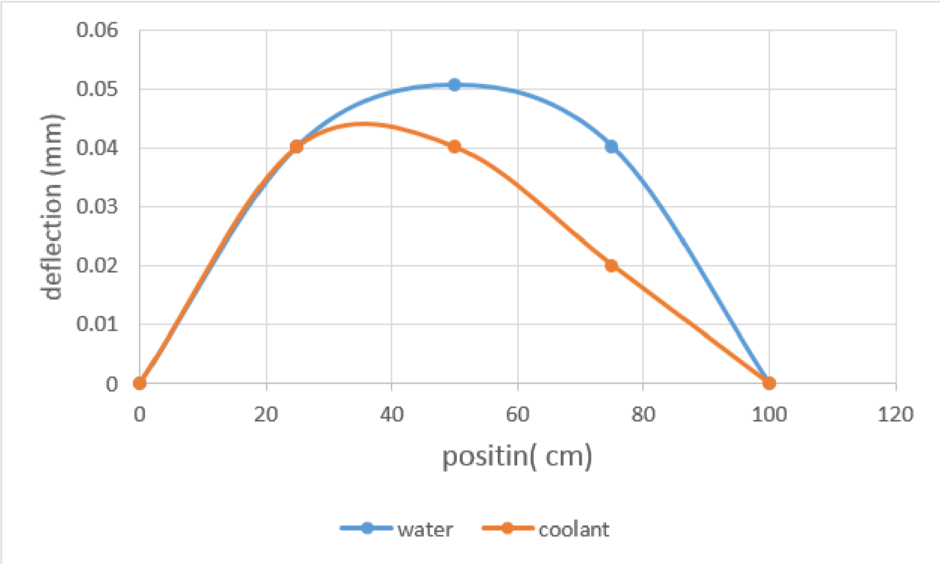


**Fig. 9.** Comparison of results of deflection with Aluminium pipe length, 0.5 bar

Figure 10 indicated to the deflection behavior in the case of (1 bar )pressure, where it has a value of (0 mm) at one end of the test tube at the first fixation point and begins to increase until it reaches the highest deflection value at the middle of the tube with a value of (0.01648) mm when using a coolant and a value of (0.0402526) mm when using water for the same boundary conditions, after which it begins to gradually decrease until it reaches zero value at the fixation point from the other end of the pipe meaning that there is a difference between the max value of deflection was 59 %.

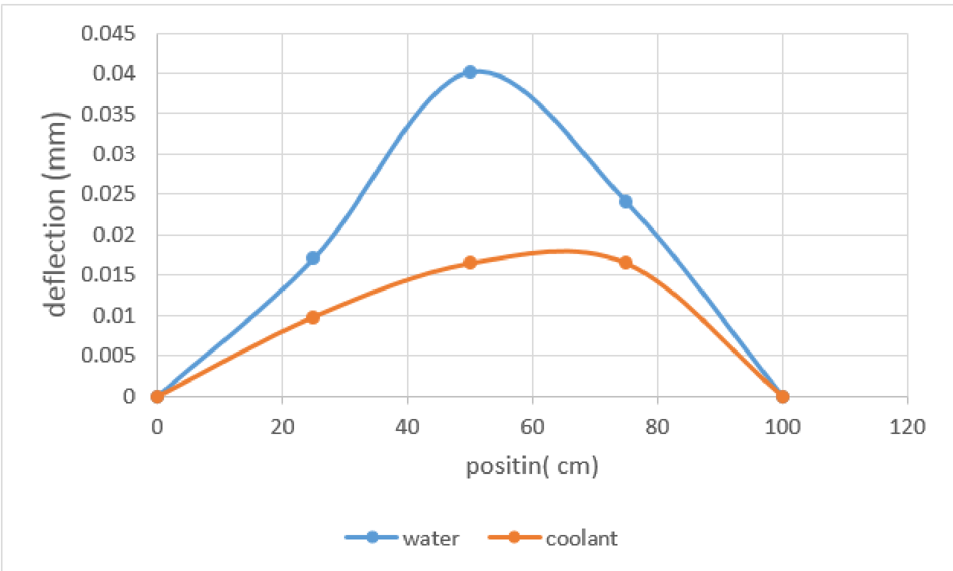


**Fig. 10.** Comparison of results deflection with Aluminium pipe length, 1 bar

While Figure 11 indicated to the deflection behavior in the case of (1.5 bar )pressure, where it has a value of (0 mm) at one end of the test tube at the first fixation point and begins to increase until it reaches the highest deflection value at the middle of the tube with a value of (0.035382) mm when using a coolant and a value of (0.0402526) mm when using water for the same boundary conditions, after which it begins to gradually decrease until it reaches zero value at the fixation point from the other end of the pipe meaning that there is a difference between the max value of deflection was 12.1 %.

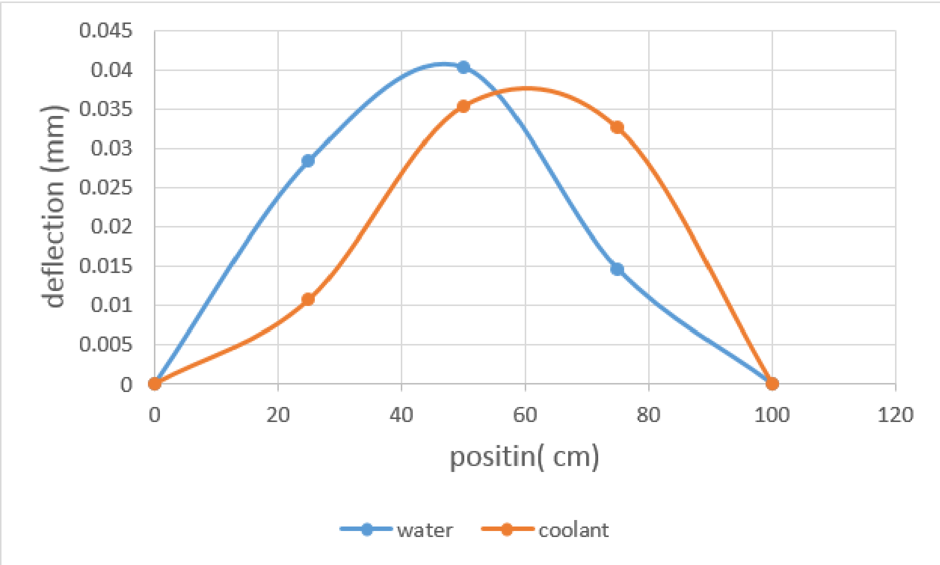


**Fig. 11.** Comparison of results of deflection with Aluminium pipe length, 1.5 bar

Figure 12 indicated to the deflection behavior in the case of (2 bar) pressure, where it has a value of (0 mm) at one end of the test tube at the first fixation point and begins to increase until it reaches the highest deflection value at the middle of the tube with a value of (0.0402526) mm when using a coolant and a value of (0.0409391) mm when using water for the same boundary conditions, after which it begins to gradually decrease until it reaches zero value at the fixation point from the other end of the pipe meaning that there is a difference between the max value of deflection was 2 %

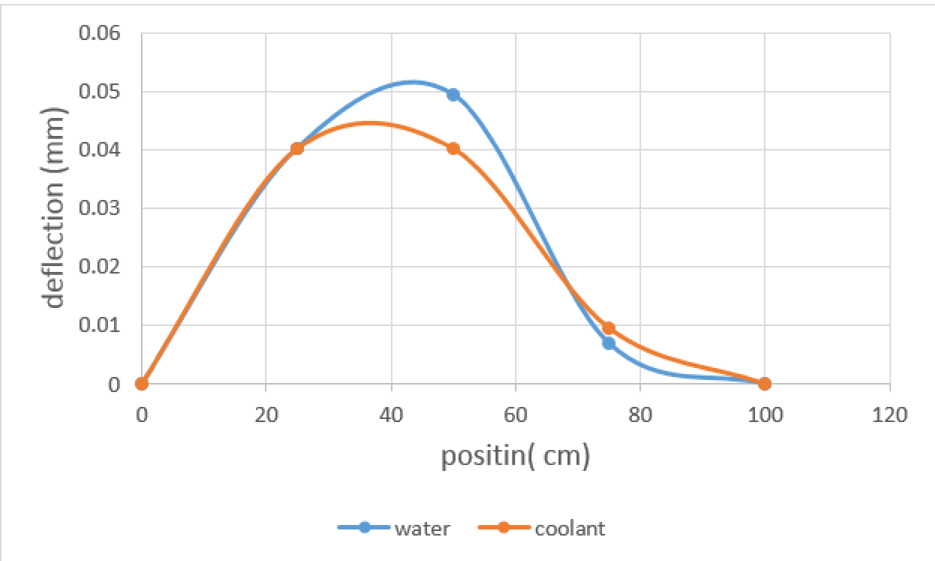


**Fig. 12.** Comparison of results of deflection with Aluminium pipe length, 2 bar

**Table 2**
Natural frequency values for different pressures and locations of the accelerometer position at Aluminium pipe

| Pipe material | Liquid type | Accelerometer position (cm) | Pressure (bar) | Natural frequency Hz | Damping (%) |
|---|---|---|---|---|---|
| Aluminium | Water | 25 | 0 | 17 | 0.188 |
| | | | 0.5 | 24 | 0.813 |
| | | | 1 | 18 | 0.266 |
| | | | 1.5 | 19 | 0.243 |
| | | | 2 | 23 | 0.729 |
| | | 50 | 0 | 34.9 | 1.13 |
| | | | 0.5 | 22 | 0.672 |
| | | | 1 | 19 | 0.252 |
| | | | 1.5 | 20 | 0.66 |
| | | | 2 | 27 | 0.829 |
| | | 75 | 0 | 23.5 | 0.411 |
| | | | 0.5 | 18.9 | 0.486 |
| | | | 1 | 29.9 | 0.227 |
| | | | 1.5 | 19.3 | 0.445 |
| | | | 2 | 18.5 | 0.032 |
| | Coolant | 25 | 0 | 14.9 | 1.63 |
| | | | 0.5 | 14.8 | 0.459 |
| | | | 1 | 13 | 0.861 |
| | | | 1.5 | 10.5 | 0.419 |
| | | | 2 | 32.6 | 0.147 |
| | | 50 | 0 | 19 | 0.252 |
| | | | 0.5 | 16.4 | 1.829 |
| | | | 1 | 20.4 | 1 |
| | | | 1.5 | 22 | 0.363 |
| | | | 2 | 22.8 | 0.263 |
| | | 75 | 0 | 22.2 | 0.144 |
| | | | 0.5 | 22.2 | 1.35 |
| | | | 1 | 21.5 | 1.004 |
| | | | 1.5 | 18.1 | 0.176 |
| | | | 2 | 21.5 | 0.539 |

### *3.2 For Copper Pipe*

For laminar fluid flow in the fully developed zone of a span pipe with fixed ends, forced vibration was explored experimentally. The results have been produced, and the consequences of the various parameters have been reviewed. Figure 13 to Figure 17 shows results of the deflection and the Table 3 shows the result of natural frequency values for different pressures and locations of the accelerometer position at copper pipe conveying flow with the pipe length 1 m at Re=2000, and 14mm diameters and two different type of flow (water and coolant) for the copper pipe in the case of flow at 0 bar pressure to 2 bar and for both liquids used (water and coolant) where placing the vibration exciter at 25,50,75 cm.

Figure 13 indicated to the deflection behavior in the case of (0 bar) pressure, where it has a value of (0 mm) at one end of the test tube at the first fixation point and begins to increase until it reaches the highest deflection value at the middle of the tube with a value of (0.0402526) mm when using a coolant and a value of (0.0472255) mm when using water for the same boundary conditions, after which it begins to gradually decrease until it reaches zero value at the fixation point from the other end of the pipe meaning that there is a difference between the max value of deflection was 14 %.

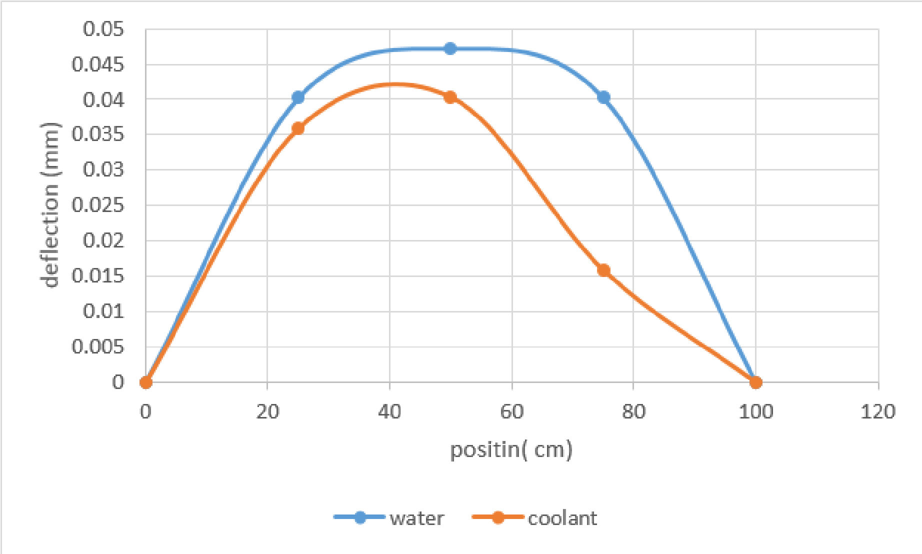


**Fig. 13.** Comparison of results of deflection with copper pipe length, 0 bar

Figure 14 indicated to the deflection behavior in the case of (0.5 bar) pressure, where it has a value of (0 mm) at one end of the test tube at the first fixation point and begins to increase until it reaches the highest deflection value at the middle of the tube with a same value of (0.0402526) mm when using a coolant and water for the same boundary conditions, after which it begins to gradually decrease until it reaches zero value at the fixation point from the other end of the pipe.

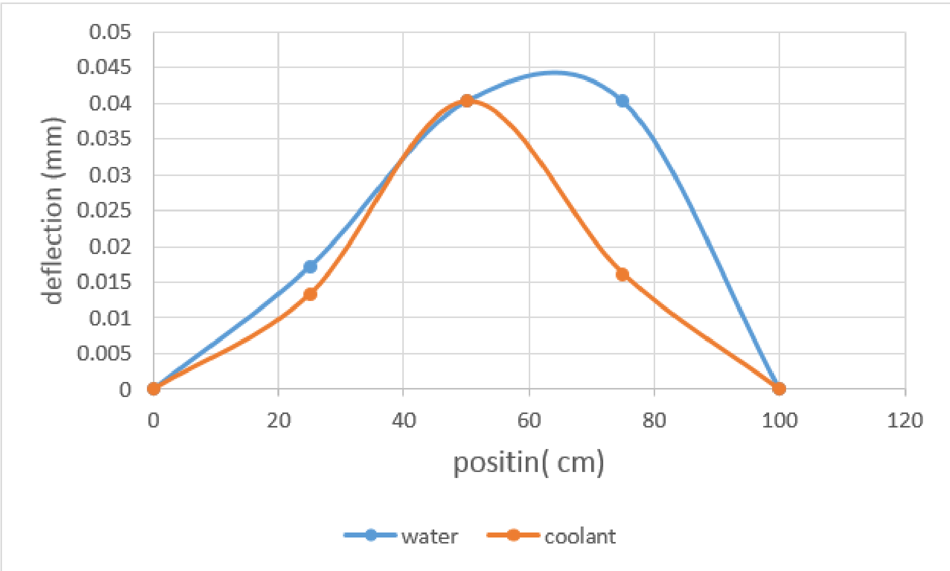


**Fig. 14.** Comparison of results of deflection with copper pipe length, 0.5 bar

Figure 15 indicated to the deflection behavior in the case of (1 bar) pressure, where it has a value of (0 mm) at one end of the test tube at the first fixation point and begins to increase until it reaches the highest deflection value at the middle of the tube with a same value of (0.0402526) mm when using a coolant and water for the same boundary conditions, after which it begins to gradually decrease until it reaches zero value at the fixation point from the other end of the pipe.

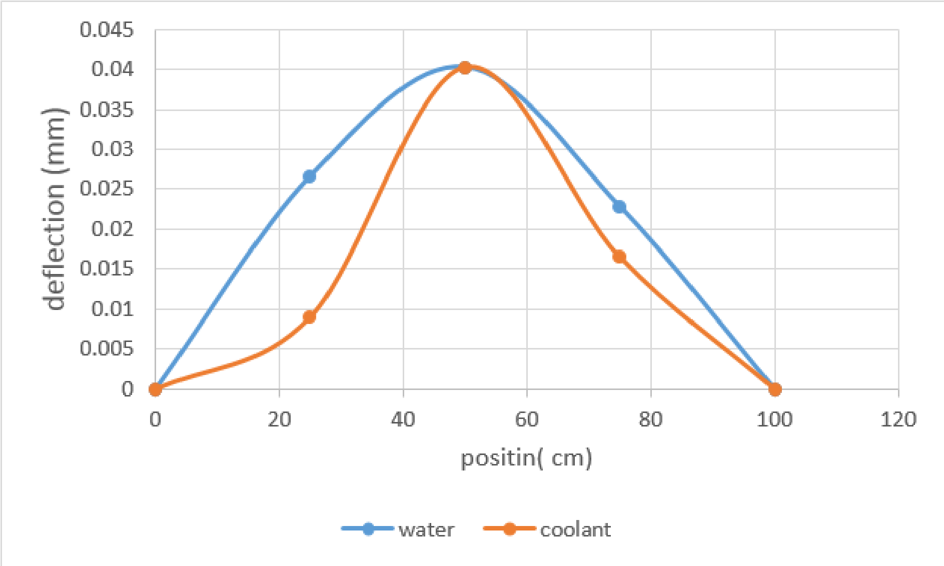


**Fig. 15.** Comparison of deflection with copper pipe length, 1 bar

Figure 16 indicated to the deflection behavior in the case of (1.5 bar) pressure, where it has a value of (0 mm) at one end of the test tube at the first fixation point and begins to increase until it reaches the highest deflection value at the middle of the tube with a same value of (0.0402526) mm when using a coolant and water for the same boundary conditions, after which it begins to gradually decrease until it reaches zero value at the fixation point from the other end of the pipe.

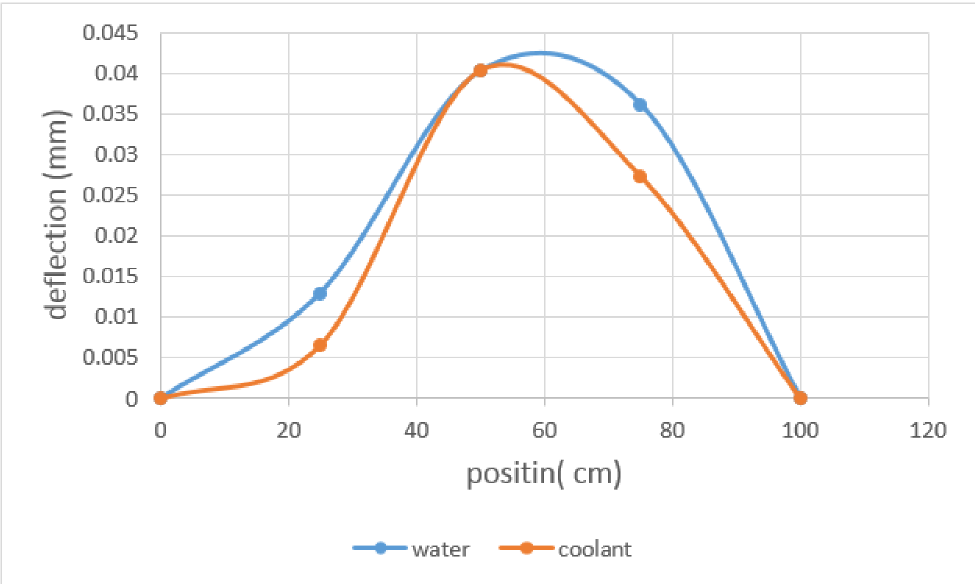


**Fig. 16.** Comparison of results of deflection with copper pipe length, 1.5 bar

Figure 17 indicated to the deflection behavior in the case of (2 bar) pressure, where it has a value of (0 mm) at one end of the test tube at the first fixation point and begins to increase until it reaches the highest deflection value at the middle of the tube with a value of (0.032044) mm when using a coolant and a value of (0.0402526) mm when using water for the same boundary conditions, after which it begins to gradually decrease until it reaches zero value at the fixation point from the other end of the pipe meaning that there is a difference between the max value of deflection was 20.3%

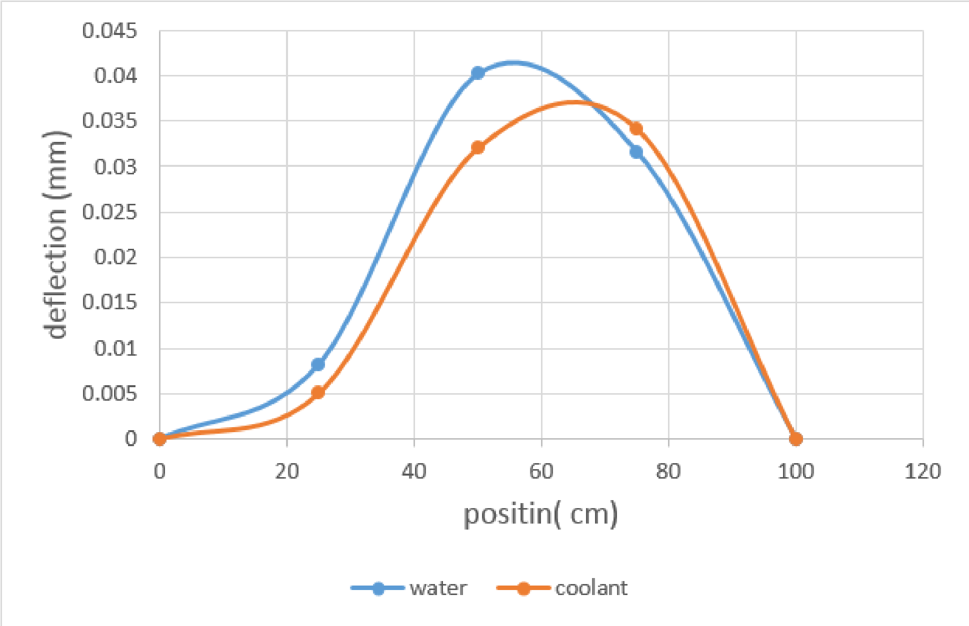


**Fig. 17.** Comparison of results of deflection with copper pipe length, 2 bar

From the above results, noted that the behavior of the displacement resulting when using both type of materials of pipes and fluids is a consistent behavior, as the displacement starts from zero at the point of fixation on one of the two sides and then begins to gradually increase until it reaches its highest value at the excitation area according to the type of tube and liquid The user then begins to decline until it reaches the value of zero at the point of installation at the other end.

When comparing the results of the copper and Aluminium tubes when using both liquids (water and coolant), the percentage of the deflection difference when using copper was less than using Aluminium when the pressure was increased. In some cases, the highest value of the deflection when using water was the same value when using the coolant, either in the case of a tube The percentage of Aluminium showed a somewhat high deflection when compared to copper when the pressure was increased.

It was observed from the results that the higher the pressure, the greater the percentage of the deviation of the copper tubes compared to the Aluminium tubes when using both liquids (water and coolant) at the same boundary condition noted the percentage of the deflection difference when using copper pipe (from 0% to 20.3%) was less than using Aluminium (from 2% to 59%) when the pressure was increased. That mean the Aluminium pipe better than copper pipe.

Also noted from the above results that the value of the displacement resulting from vibration and the internal pressure on the tubes when using the water liquid is higher than the corresponding value when using coolant and for the same boundary conditions, due to the high density and viscosity of the coolant liquid when compared to the density and viscosity of water, except for some cases where the displacement value is the same when both liquids are used Figures 14, 15 and 16. This is due to the high sensitivity of the accelerator device, or due to the presence of interference as a result of the electric current passing through the devices used in the research, or because of the presence of noise when using the electric pump, which causes the generation of signals that lead to wave interference that affects the signals read from the oscilloscope.

The pipeline system can be damaged by sudden amplified vibrations that were not taken into account when designing the system, and the vibrations generated by the flow are proportional to the natural frequency of the pipes. Therefore, it is important to predict and quantify the vibrations of the pipeline system during operation.

**Table 3**
Natural frequency values for different pressures and locations of the accelerometer position at copper pipe

| Pipe material | Liquid type | Accelerometer position (cm) | Pressure (bar) | Natural frequency Hz | Damping (%) |
|---|---|---|---|---|---|
| Copper | Water | 25 | 0 | 9 | 0.314 |
| | | | 0.5 | 22 | 0.409 |
| | | | 1 | 24 | 0.612 |
| | | | 1.5 | 25 | 0.528 |
| | | | 2 | 20 | 0.56 |
| | | 50 | 0 | 19 | 0.625 |
| | | | 0.5 | 29 | 0.137 |
| | | | 1 | 20 | 0.305 |
| | | | 1.5 | 23 | 0.974 |
| | | | 2 | 22 | 1.2 |
| | | 75 | 0 | 18.7 | 0.213 |
| | | | 0.5 | 25.9 | 0.154 |
| | | | 1 | 18.6 | 0.949 |
| | | | 1.5 | 19.5 | 0.861 |
| | | | 2 | 22.5 | 0.657 |
| | Coolant | 25 | 0 | 9 | 2.488 |
| | | | 0.5 | 30 | 0.98 |
| | | | 1 | 17 | 0.68 |
| | | | 1.5 | 13.4 | 0.354 |
| | | | 2 | 30 | 0.88 |
| | | 50 | 0 | 16.5 | 0.363 |
| | | | 0.5 | 16.6 | 0.650 |
| | | | 1 | 8.8 | 2 |
| | | | 1.5 | 18.7 | 0.363 |
| | | | 2 | 7.1 | 1.464 |
| | | 75 | 0 | 21.1 | 1.421 |
| | | | 0.5 | 19.7 | 0.69 |
| | | | 1 | 21 | 0.323 |
| | | | 1.5 | 13.3 | 1.05 |
| | | | 2 | 8.4 | 1.714 |

## 4. Conclusions

From the explanation of the results of this study, it can be concluded several things, including

i. The mass ratio has a significant effect on the stability boundaries of the stability. Conversely the fluid pressure is to shift the whole boundaries to slightly lower values.
ii. The effects of vibration caused by the flow due to the pipe conveying fluid increase the maximum deflection when the pressure increase
iii. The natural frequency of experimentally considered pipes decreases with the increasing of internal pressure
iv. Commonly, it was noted that conveying fluid pipes increases of the pressure will increase the damping ratio which mean increase the damping effect
v. the greater the percentage of the deflection of the copper tubes compared to the Aluminium tubes when using both liquids (water and coolant) at the same boundary condition noted the percentage of the deflection difference when using copper pipe (from

0% to 20.3%) was less than using Aluminium (from 2% to 59%) when the pressure was increased. That mean the Aluminium pipe better than copper pipe

vi. When liquids (water and coolant) were used, the deviation in the case of using coolant was less than the deviation in the case of using water and for both test tubes (copper and Aluminium).

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