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Experimental study of the effects of vibration induced by water flow in spiral pipe

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ABSTRACT

This paper attempts to study the effect of induced vibration by water flow in a spiral pipe. The fluid-induced vibration caused by fluid temperature and mass flow rate has been studied experimentally. A copper tube with a 10 mm inner diameter and a length of 15 meters was used to make the spiral pipe. Water flow rates of 4 to 7 LPM and fluid temperatures of 45 to 65 ºC were used in the experiments. The experimental result showed that, frequency and normal frequency of spiral pipe vibration were influenced by fluid temperature and mass flow rate. The frequency of vibrations has increased to its maximum value 2.989 Hz as the temperature rises to be 65 ºC. This has been explained due to the higher kinetic energy of higher temperature flows.

KEYWORDS

vibration in pipe, frequency, fluid at different temperature

INTRODUCTION

Fluid elastic instability is the most common flow-induced vibration mechanism in tube and shell heat exchangers that can cause short-term tube failure. Failures of this kind are often costly and potentially dangerous. Fluid elastic instability is induced by the relationship between the fluid's dynamic forces and the motion of the structures. When the energy absorbed by fluid forces exceeds the energy dissipated by damping at a high enough flow rate, instability occurs. Fluid elastic instability is the most common source of excessive vibration amplitudes. The critical velocity is the slowest speed at which the system becomes unstable. To ensure the safety of installations, the operating flow velocity should be strictly controlled below the critical velocity [1]. Proposed a method for detecting subsea spanning pipeline vibration using a spherical detector fitted with a triaxial accelerometer to analyze and compare both mathematically and experimentally the single acceleration component (SAC), acceleration modulus square (AMS), and AMS of the AC components (AMS AC) of the acceleration signals recorded by the SD [2]. The effect of open crack parameters and flow velocity profile structure within the pipe on the system's natural frequency and critical flow velocity was investigated by Eslami et al. [3].

The presence of a crack in the pipe decreases the usual frequency and critical flow velocity, causing system instability at lower flow rates than when the pipe is intact. The vital flow velocity of both intact and fluid conveying broken pipe is significantly affected by the flow velocity profile form within the pipe caused by the viscosity of real fluids, according to the findings. SANTOSH et al. [4] defined the compound effect of vibration and Nano fluid on heat transfer enhancement using three different flow conditions for Newtonian fluid, non-Newtonian fluid, and Flow rate, vibration amplitude, vibration frequency, and fluid rheology are all affected by the combined effect of vibration and Nano fluid. It has been discovered that using Nano fluids under vibration improves heat transfer by 300 percent over steady-state flow. Tajul et al. [5], the vibrations of blocked circular pipe flow pipes, which are used in almost every building and construction and are used to move fluid to a specific location, were investigated. A liquid containing foreign objects and impurities can unintentionally build up or clog an obstruction along the pipeline's interior surface.

Vibration calculation was used to investigate the impact of various blockage sizes within a transparent Polyvinyl Chloride circular vessel. [6] Berro and Moussou, a simplified method for estimating water pipe vibrations caused by unsteady fluid flows is proposed. The Laplace transform was used by Zhao and Sun [7] to propose a new transfer matrix for studying flow-induced vibration of a curved pipe conveying fluid. The device was put to the test by calculating the critical velocity of the flow. The effect of flow velocity on the natural frequency for cantilevered, clamped, and periodic cantilevered pipes. N. Gondrexon et al. [8] investigated the effect of low-frequency ultrasound on heat transfer and designed a new type of vibrating shell and tube heat exchanger. The heat exchanger's total heat transfer coefficient increased from 123 to 257 percent when subjected to ultrasonic vibrations. Qu et al. [9] suggested a metal bellows fatigue analysis based on orientation and displacement, which they found to be effective. With the support of EJMA regulations, Kim and Jang [10] created Bellows Designer, a programming app using MATLAB. The MATLAB GUI is used to make access to the program code simple, to improve security, and to minimize the chances of program errors.

Kim [11] looked into the effect of bellows failure on convolution geometry and end boundary conditions. So although Gawande SH and Pagar ND [12] used a mathematical model in Matlab and modal analysis to evaluate the deformation and axial natural frequencies response of bellows with eight. ANSYS 15 is a simulation program. When bellows are exposed to different end conditions, FE analysis yields nine and ten convolutions for various modes. According to simulation and experimental modal study, the number of convolutions in the bellows should be increased in order to reduce the axial natural frequency for a given flow rate and prevent resonance when designing the new configuration. Mohammed and Mahdi [13] used the finite element process, the dynamic behavior of a pipe conveying fluid at various cross-sections was investigated. The effect of three types of supports on vibration characteristics was investigated: flexible, plain, and rigid supports. Natural frequency was found to be higher for simple and rigid supports than for flexible supports, according to the research. For the cases of clamped-clamped and clamped pin pipes, the effect of welding on vibration characteristics was investigated experimentally and theoretically since residual stresses from welding strongly affect the normal frequency of the pipe conveying fluid.

The clamped-clamped and clamped-pinned pipes were found to be stable at low fluid velocities. The clamped pinned welded pipe becomes unstable at relatively high fluid velocities (super-critical) [14]. L. Wang et al. [15] simulated the vibration of fluid-transporting pipes using commercial software (ADINA). The fluid flows should be three-dimensional (3D) and incompressible, and the thin pipe structures should be modeled as shells. The evolution pattern of natural frequencies with increasing flow velocity was discovered to be close to that predicted by the inextensible theory for fluid conveyance in curved pipes. Ameen KA et al. [16] study the effect dynamic behavior of a copper pipe conveying fluid at different fluid temperatures and used three types of support (fixed - fixed, fixed - free and simply support - simply support) was experimentally investigated. Results obviously increase the frequency and amplitude of vibration with an increase in the temperature of the fluid. Al-azzawi et al. [17] study the practical to demonstrate the influence of vertical forced vibration in the free convection heat transfer coefficient of a long-fined sheet made of Aluminium and compare the results with a flat plate. The results showed that the relationship between the rate of free heat transfer and the vibration amplitude is proportional with the tilt angles.

It was also found that the heat transfer coefficient of free convection decreases with the increases of tilt angle. The flow in the pipe was studied in different ways, it was found that the measuring of pressure gradient through the distance of rig pipe are inversely changed with air volumetric. In addition, it has been analyzed the flow in double pipe heat exchanger with nanofluid, the effect of magnetic field, heat pipe, two-phase flow through cylinderical obstruction in vertical pipe, integral-fin tubes, fluid-structure interaction, under laminar and turbulent flow regime, heat transfer enhancement by using different geometry coiled tubes and shell and tube heat exchanger [18-32]. Aun SH et al. [33] investigated and experimental effects of induced vibration on characteristics of fluid flow and heat transfer an orifice installed in the pipe with heating the working fluid under different conditions and temperatures. The results are given by natural frequency parameters of the free vibration signals of the pipe structure show that using an orifice increases the pipe frequency parameters such as acceleration, velocity and displacement. In addition, these vibration fundamental parameters increase together increasing Reynold number as well as water inlet temperatures. The frequency is the highest value in the case of a low aspect ratio of an orifice. Moreover, the Nusselt number increases with increasing the Reynold number and with decreasing the orifice aspect ratios for all conditions. In the present study, the effect of vibration-induced hot fluid temperature in a spiral pipe.

EXPERIMENTAL SETUP AND PROCEDURE

A spiral heating system that was designed and fabricated in the Mechanical Engineering Department-engineering college of Diyala University-Iraq. The experimental system spiral includes the water heater, pump, control valve, flow meter, test section, thermocouples, and vibration sensor module 801S with sensitivity. The spiral pipe was select from a copper tube with an outer diameter of 12.8 mm and an inner diameter of 10 mm. The total length of the copper tube has been to be fifteen meters and divided into 11coils with inner and outer diameters of about 0.2 m and 0.6 m respectively. The pump is multistage centrifugal with a maximum flow rate of 40 l/min and it is used to circulate the hot water in the test spiral. One valve is equipped in the discharge section to control the water flow rate. The mainline, going out from the test pipe, is then back to the water heater by a hose plastic pipe to round the closed piping circuit. Digital temperature (TPM-10) sensor thermocouples are used to measure temperatures of different points along the tested pipe. However, the vibration sensor module 801S with sensitivity adjustable is located at the spiral pipe and the frequency due to the vibration in the pipe is measured by the vibration sensor 801S as shown in Figure 1. Figure 2 shows the schematic diagram of the vibration system.

Figure 1. Description of the experimental vibration system part.

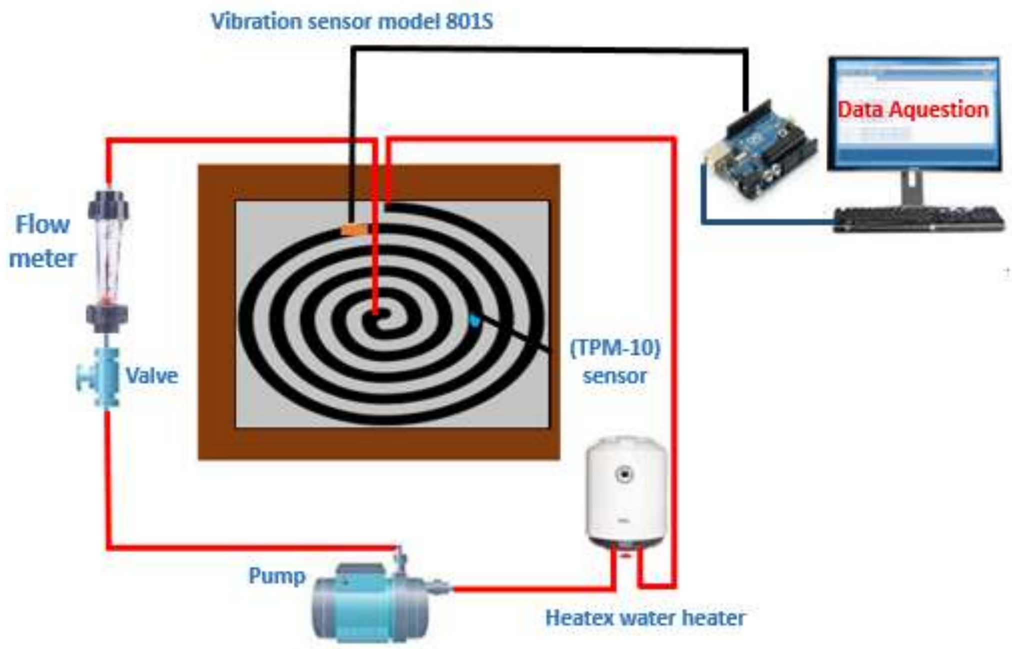


Figure 2. Schematic diagram of vibration experimental.

DATA REDUCTION

Natural frequency is the angular frequency of the oscillation that we measure in radians or seconds in equation 1 [34].

$$\omega_n = \sqrt{\frac{k}{m}} \tag{1}$$

Where:

ω_n is a natural frequency (rad/sec), k is element stiffness (N/m) and m is an element mass (Kg). The frequency is the number of cycles per unit of time in equation 2.

$$f_n = \frac{\omega_n}{2\pi} \tag{2}$$

Where:

f_n is the natural frequency (Hz)

Oscillation frequency The frequency of oscillation, or simply the frequency in equation 3, is the number of cycles per unit time.

$$f_n = \frac{1}{\tau_n} \tag{3}$$

Where:

τ_n is the period of oscillation (sec)

RESULTS AND DISCUSSION

In this study, experimental results were investigated to analyze the data that indicate a relationship between the fluid temperature and spiral pipe vibration. All the Experiments considered in this work were maintained at a constant mass flow rate of water (4 to 7) LPM. Figure 3 shows the variation of the fluid temperature versus the variation in the vibrational frequency values. Accordingly, the frequency of vibrations has increased to its maximum value of 2.989 Hz as the temperature rises to be 65 ºC. The frequency is observed to be increased with increasing the mass flow rate and fluid temperature. This is might be attributed to the increment of the kinetic energy of the fluid itself. The influence of fluid temperature on natural frequency is shown in Figure 4. The natural frequency is in general increasing as the flow rate and fluid temperature increases as well.

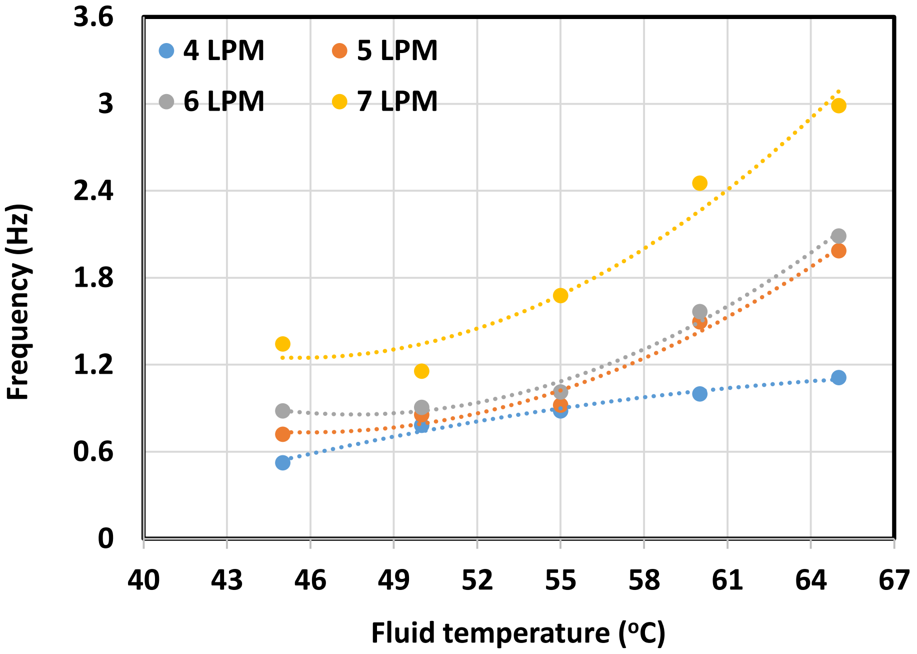


Figure 3. Show the variation of fluid temperature in frequency.

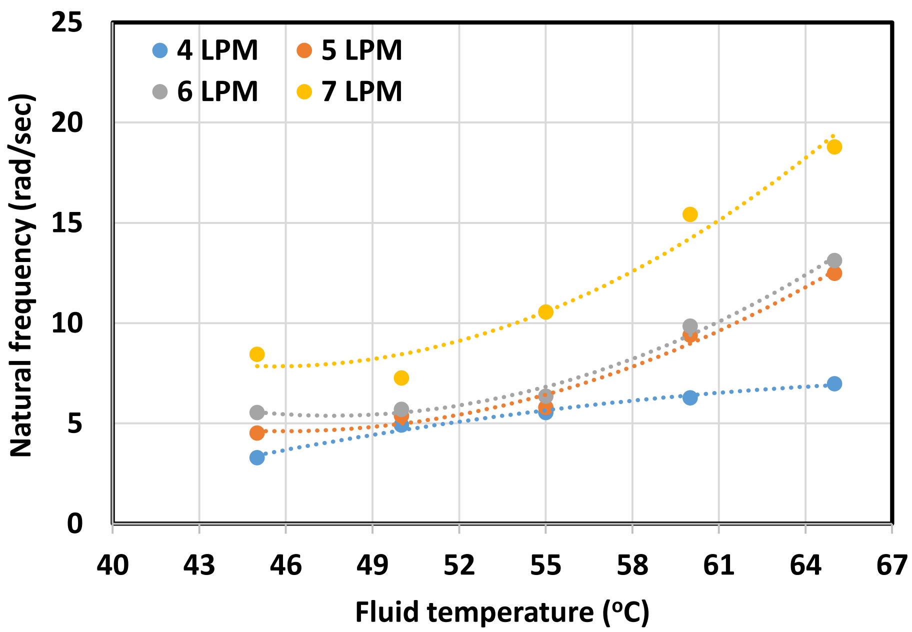


Figure 4. Show the relation between fluid temperature versus natural frequency.

Figure 5 implies the effect of the mass flow rate on the vibrational frequency. The results showed that, the excessive increase in the mass flow rate and fluid temperature can lead to notable increase in the frequency. This might be explained due to the increment of kinetic energy in the fluid. The influence of the mass flow rate on the natural frequency is shown in Figure 6. The natural frequency, caused due to the vibration effect, is increasing with excessive increment in mass flow rate and fluid temperature.

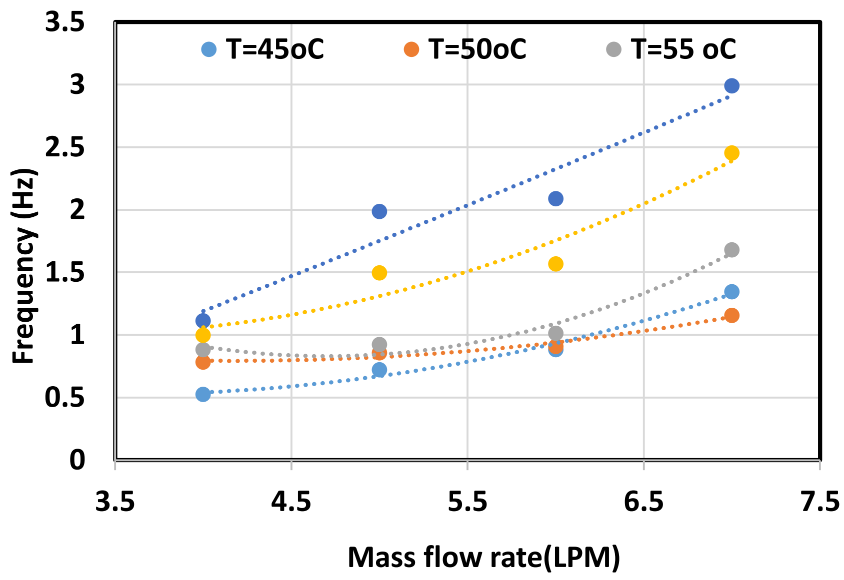


Figure 5. Mass flow rate and frequency.

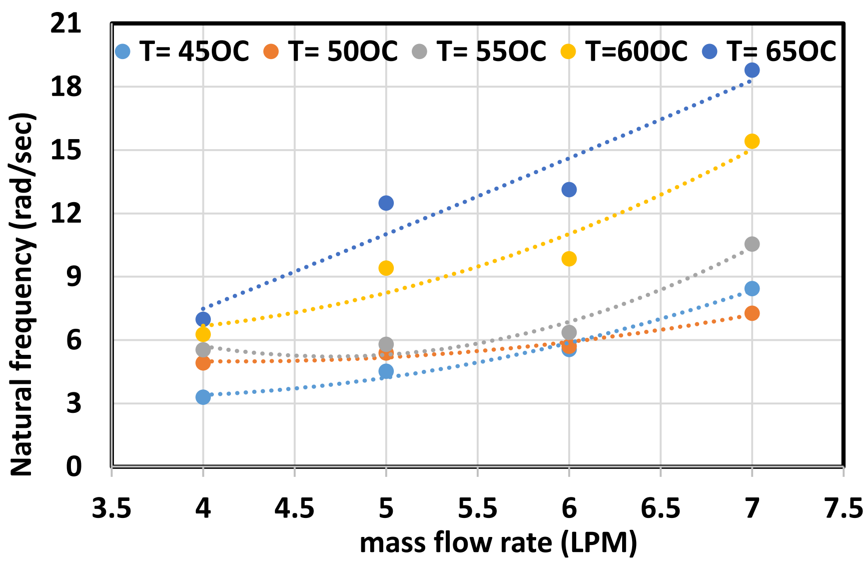
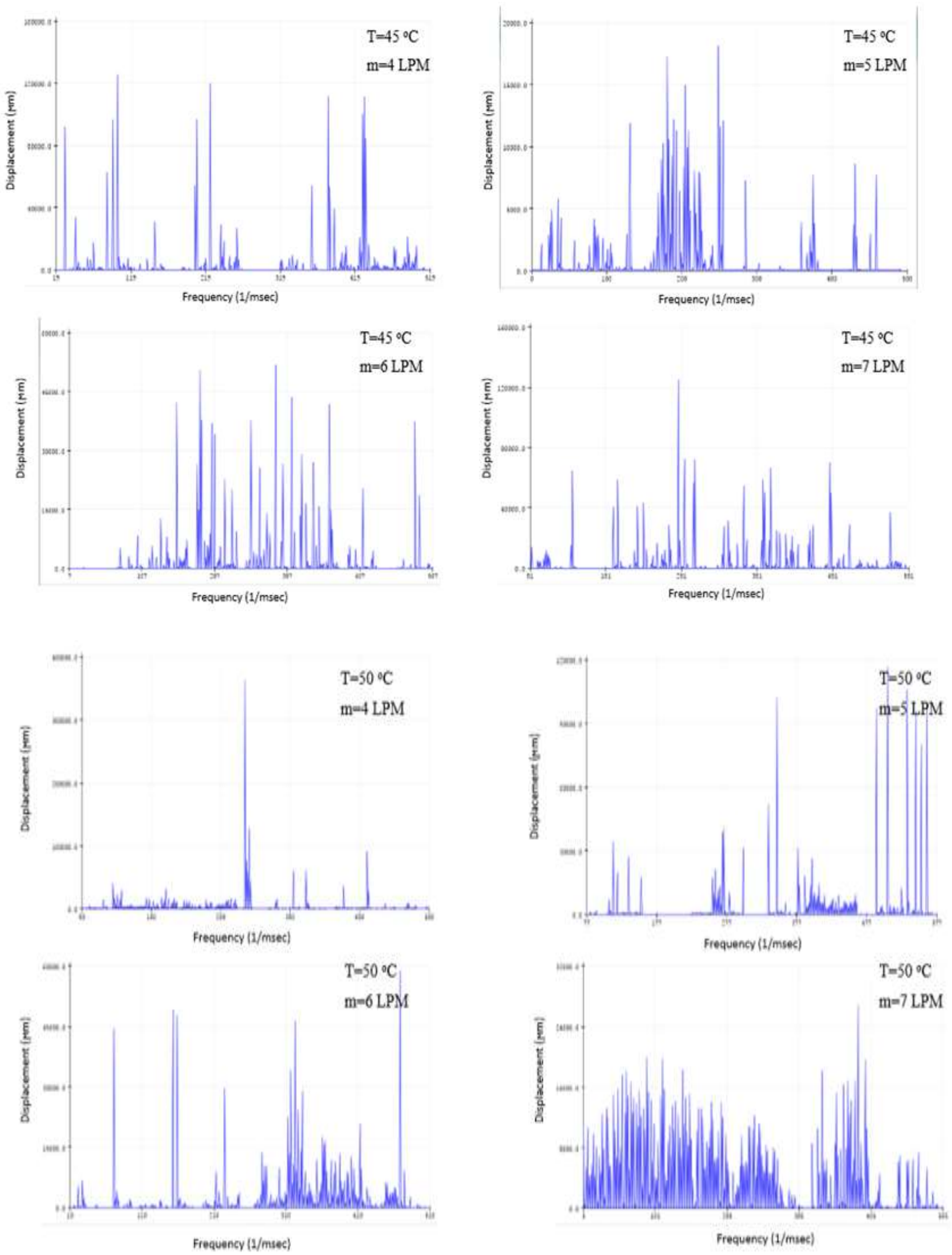
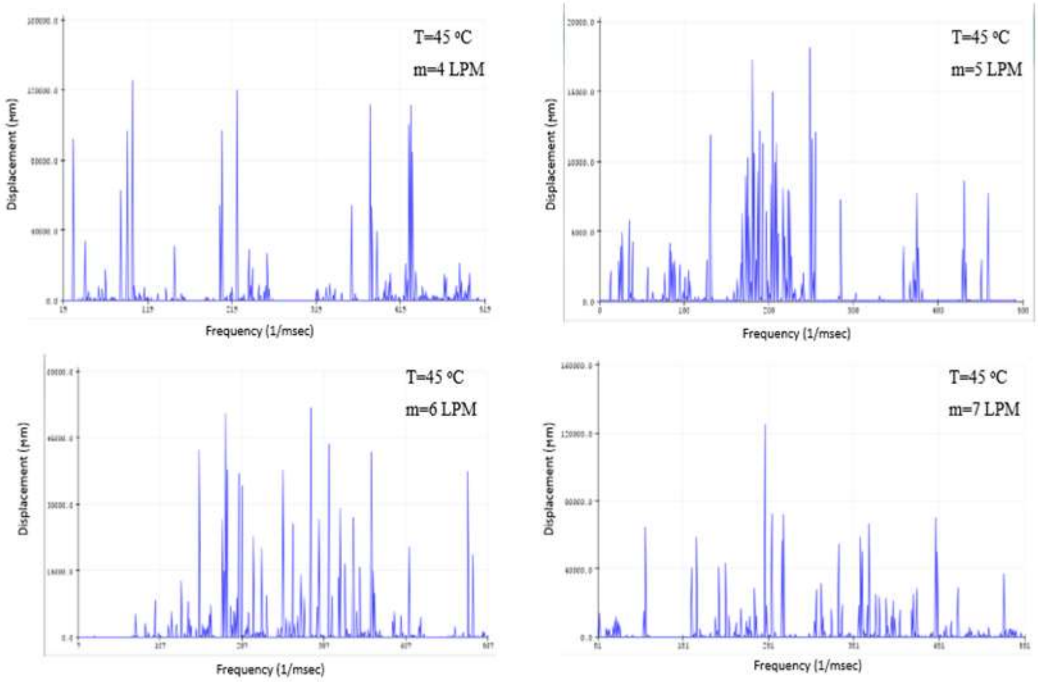


Figure 6. Mass flow rate and natural frequency.

Figure 7 shows one of the displacement responses of the frequency at different water inlet temperatures and various mass flow rates. Comparing the results of the effect of fluid inlet temperatures and flow rates on the fundamental parameters of vibration, one can see that the displacement responses will become more fluctuated at the water temperature of 65 ºC and the flow rate 7 LPM. Furthermore, the vibrational frequencies depicted in the considered figures are known as flow-induced vibrations because they are caused by turbulent flow in viscous media. In addition, the results demonstrate that while increasing parameters at fluid temperatures and mass flow rates, the displacement responses become more and more random and fluctuating. As the pressure rises and the fluid velocity falls, there is not enough effect to produce the higher frequencies. The vibration induced by the flow will decrease as the fluid temperature increased, as predicted. The other issue is the increase of pipe vibration with increasing water temperature due to increasing the elasticity of the pipe material. The results clearly show that flow-induced frequencies were generated by all of the flow rate values investigated in this analysis, as shown in the figures. The conjunction of friction between a wall of smooth pipe and a fluid contributes to the generation of vibration signals.


T=45 °C
m=4 LPM
T=45 °C
m=5 LPM
T=45 °C
m=6 LPM
T=45 °C
m=7 LPM
T=50 °C
m=4 LPM
T=50 °C
m=5 LPM
T=50 °C
m=6 LPM
T=50 °C
m=7 LPM
Displacement (μm)
Frequency (1/msec)

(a)


T=45 °C
m=4 LPM
T=45 °C
m=5 LPM
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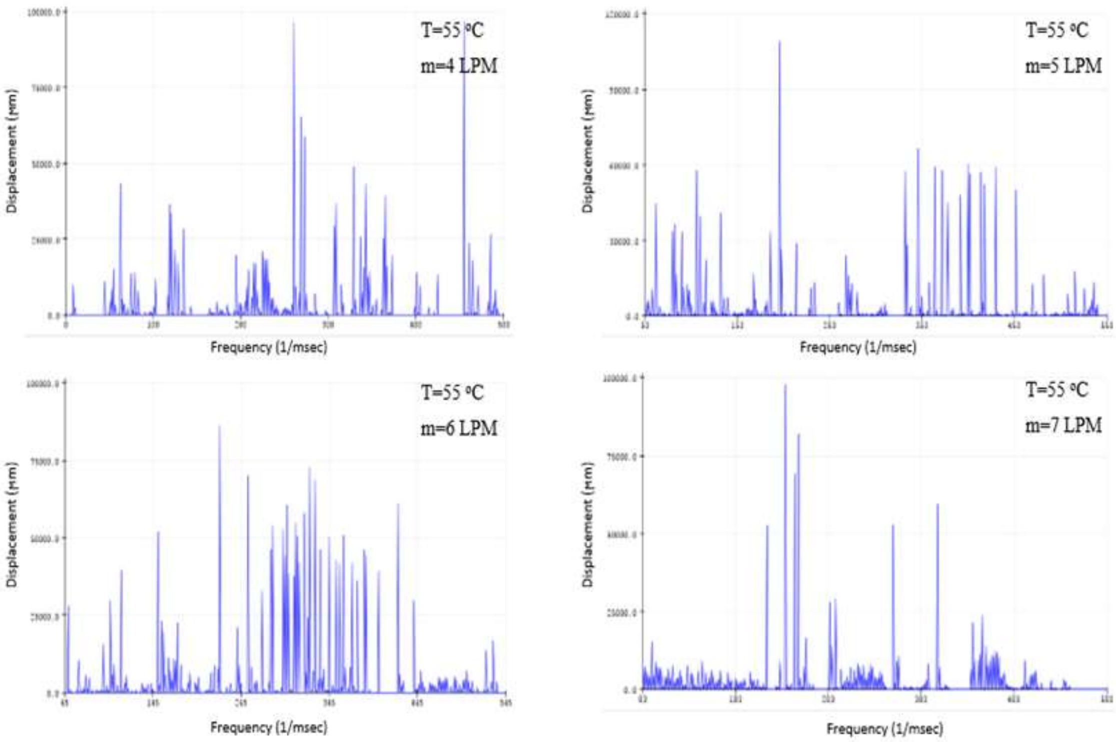
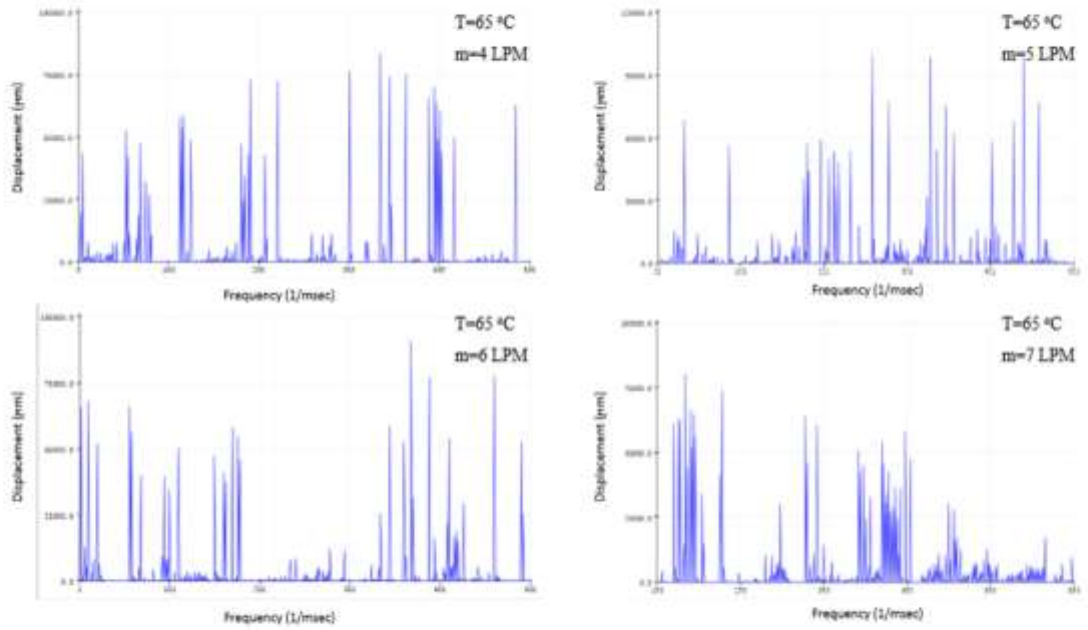
T=45 °C
m=7 LPM
Displacement (μm)
Frequency (1/msec)

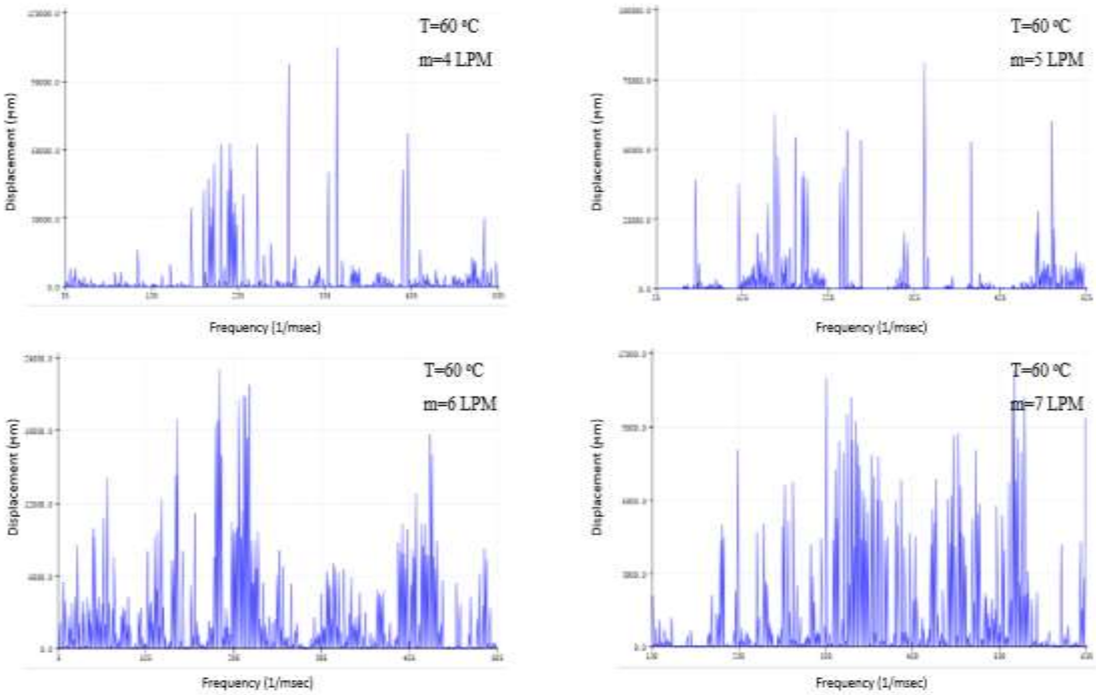
(b)


T=55 °C
m=4 LPM
T=55 °C
m=5 LPM
T=55 °C
m=6 LPM
T=55 °C
m=7 LPM
Displacement (μm)
Frequency (1/msec)

(c)



(d)



(e)

Figure 7. Represents displacement and frequency at {(a)T=45°C (b)T=50 °C (c)T=55 °C (d)T=60 °C (e)T=65 °C} at different mass flow rate.

CONCLUSIONS

In this study, an experiment of the effect of fluid temperature and mass flow rate of a spiral pipe on the frequency and natural frequency. The frequency and normal frequency of spiral pipe vibration are influenced by fluid temperature and mass flow rate. As the temperature rises to 65 oC, the frequency of vibrations increases to a maximum of 2.989 Hz. This is due to the flow of higher temperatures having higher kinetic energy.

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