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Numerical Study of Effect of Using Nanofluids Flowing in Simply Supported Pipes on Vibrations Characteristics

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K E Y W O R D S

Nanofluids, Fluid Structure Interaction, Vibration.

A B S T R A C T

In general, internal vibrations within the pipelines caused by fluids being passing through a pipeline system can cause. These pipeline system can damage by the sudden amplified vibrations that weren't considered at the design of the system, and flow induced vibrations resonate with the pipes natural frequency. Therefore, it is important to predict and identify the pipeline system vibrations during its lifetime. In this study by using MATLAB code as a CFD solver, it studied the forced and free vibrations caused by fluid flows at Reynolds number ranged as $0 < Re < 2500$ for laminar flow and ranged as $10^4 < Re < 10^5$ for turbulent flow. The working fluid has chosen as of (Al_2O_3, TiO_2, SiO_2 and water) with different nanoparticle volume fraction of (0 to 2% vol.). These fluids flow in simply supported pipe with different lengths and diameters. The results presented the effect of pipe and fluid parameter upon the fluid critical velocity and fundamental natural frequencies. The results showed that the pipe natural frequency increased with increasing with decreasing the pipe length and diameter. In addition, it showed that the pipe natural frequency decreased when using the different nanoparticle depressed in the water and with increasing the volume fraction.

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1. Introduction

In the practical applications, there are two types of vibrations: instability and resonance. The resonance vibrations occur when a structure is excited at a natural frequency. In this case, the energy absorbed by the structure at each oscillation cycle and when damping is low this can build up more amplitudes that are dangerous. The static instability occurs when a negative fluid stiffness overcomes a positive structural stiffness as examples are wing gate valve and stall flutter vibration. However, the dynamic instability occurs when a negative fluid damping overcomes a positive structural damping as example of tube bundle and galloping of slender structures vibrations [1].

The induced vibration was studied in many experimental and numerical researches by using many techniques. By using the Arnold–Warburton theory, the vibration of pipes is studied simplified theory for thin shells valid in a lower frequency regime by [2]. They used the spectral finite element method (SFEM) to describe the vibrational response numerically, by applying the exact solutions of the motion equations. [3] studied process plant equipment and the piping systems in the production process of gas and oil with two-phase flow of liquids and gas. In the case of two phase flow, the flow momentum variation due to the presence of phases with distinct densities can cause vibration in the pipe wall.

[4] studied the stability and vibration of the mild steel straight pipe. The pipe conveyed water at turbulent steady flow with different velocities and solved finite element method (FE). They showed that the clamped-pinned and clamped-clamped welded pipes when conveying nanofluid are stable for small fluid velocity (sub-critical). [5] used using precise integration method PIM to study the dynamic behavior for simply supported pipes carrying pulsating fluid. Their results indicated that PIM is rapid approach for dynamic analysis of the flow induced of supported pipes and efficient method. [6] presented a analysis for pipes carrying nanofluid natural frequency by using ADINA system. The nanofluid flows are supposed to be three-dimensional (3D) fluid control volume and the pipe structures are modelled as shells in this approach. Their results showed that the natural frequencies evolution trend increased with increasing the velocity of the fluid flow for curved pipes conveying nanofluid. [7] studied different parameters such as stiffness and viscous coefficients of foundation by using finite element analysis in order to investigate the natural frequency of a simply supported pipeline conveying fluid flow set on viscoelastic foundation. Its results showed that two components of foundation. Where, critical flow velocity in the pipe increasing with increased the foundation stiffness tended. The internal flow in the subsea spanning pipeline generated a flow-induced vibration which is one of the important phenomena that contribute to failure of pipelines, this phenomenon was studied by [8]. They used a two-way coupling fluid-structure interaction (FSI) analysis of piping vibration and response. However, the fouling in the heat exchangers can be considered as common problems in petrochemical companies that cause the wall vibrations [9]. This problem was established by using ANSYS to determine the normal and fouling models of a fluid-conveying pipeline. The numerical results showed that, as the fouling severity and inlet velocity increase, the vibration acceleration and wall load increase as well and this can cause wall vibrations. [10] used a mathematical model for dynamics and stability of pipe conveying nanofluid with guided supports. The mathematical model is derived by using Hamilton's energy expressions and Euler-Bernoulli beam theory to get the motion equation and vibration fundamental transverse natural frequency is computed. The effect of a crack to the flow-induced vibration characteristics of supported pipes is investigated by [11]. The pipe is nanofluid loaded via interaction with the nanofluid. Nanofluid loading has two main effects on vibrating pipes: first, the nanofluid mass loads the pipe, meaning that the pipe's natural frequencies are altered due to added mass. Secondly, viscous loading is provided to the pipe near the wall due to shear force between the pipe and the nanofluid.

In present study, an analytical and numerical simulation was attempted by a using Finite Element Model (FIM) coded by MATLAB program in order to arrange the simply supported pipe global matrices for carrying nanofluid. By developing, the motion governing in form of partial differential equations to describe the lateral vibrations of the pipe is employed to develop the stiffness and inertia matrices corresponding to two of the terms of the equations of motion. The effect of the parameter of pipe length, pipe diameter, nanofluid types and nanoparticles concentration upon the pipes natural frequency and fluid velocity ratio were studied in the present work.

2. Problem Description

The physical model presented in Figure 1. The model consists of simply supported circular pipe with length of (L) that pinned at both ends; it has a cross-sectional area of (Ap), the pipe mass per unit length of (mp) and flexural rigidity (EI). This pipe conveyed a nanofluid with mass per unit length mf and flows with velocity of (U) and pressure p. The assumptions made for the analysis given by [12].

1. Linear, homogeneous and isotropic elastic pipe material.
2. The nanofluid is incompressible.
3. Uniform velocity of nanofluid.
4. Pipe diameter is much smaller than its length.
5. Planar fluid motion of the pipe.
6. No axial or lateral motion at pipe ends.

The deflecting pipe it is accelerated, as the nanofluid flows through the pipe and the pipeline lateral vibration will be generated. The force of nanofluid per unit length (F) affected upon the element of nanofluid by the walls of tube, this force acting opposes to the fluid accelerations as presented in Figure 2. By balancing the forces in the Y direction on the nanofluid element for small deformations such as:

$$F - \rho A \frac{\partial^2 y}{\partial x^2} = \rho A \left(\frac{\partial}{\partial t} + v\frac{\partial}{\partial x}\right)^2 y \qquad (1)$$

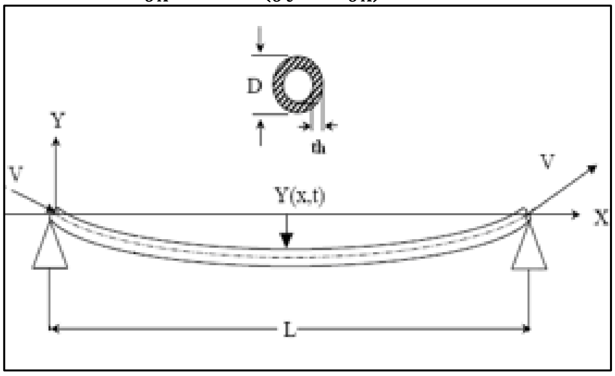

Figure 1: Simply supported pipe conveying fluid

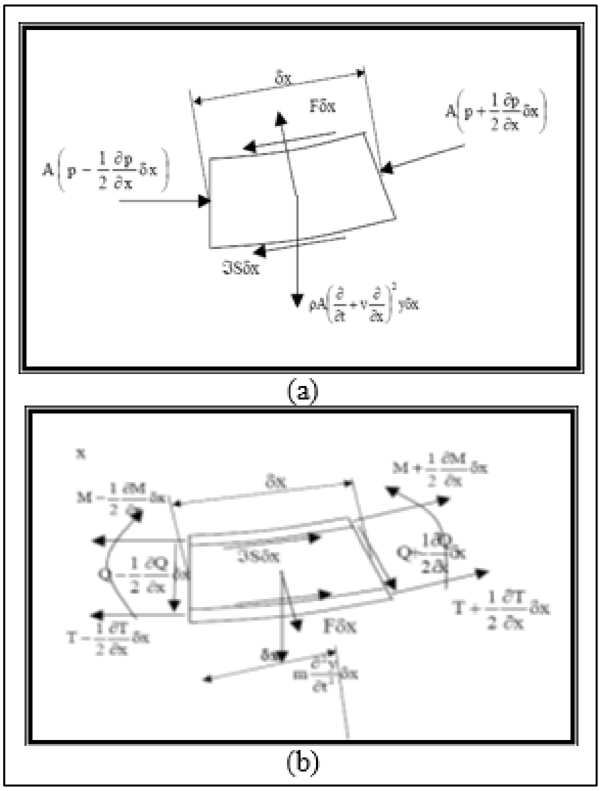

Figure 2: Forces and moment acting on the pipe element, forces and their moments applying on the elements of (a) Nanofluid (b) Pipe

In the other side, the nanofluid pressure gradient along the pipe length is acting in the opposite of the nanofluid shear stress due to friction between the nanofluid and the tube walls. The summation of these forces that acting parallel to the pipe axis given by [11]:

$$A\frac{\partial p}{\partial x} + \varphi S = 0 \qquad (2)$$

Thus, the equations of motions of the pipe element given by [11]:

$$\frac{\partial T}{\partial x} + \varphi S - Q\frac{\partial^2 y}{\partial x^2} = 0 \qquad (3)$$

The forces on the element of the pipe that accelerated the pipe element in the (y) direction to produce small deformations by [11]:

$$\frac{\partial Q}{\partial x} + T\frac{\partial^2 y}{\partial x^2} - F = m\frac{\partial^2 y}{\partial t^2} \qquad (4)$$

This pipe deformation related with the transverse shear force Q by [12]:

$$Q = -\frac{\partial M}{\partial x} = EI\frac{\partial^3 y}{\partial t^3} \qquad (5)$$

Eliminating Q and F and combining the above equations yields [12]:

$$EI\frac{\partial^4 y}{\partial t^4} + (\rho A - T)\frac{\partial^2 y}{\partial t^2} + \rho A\left(\frac{\partial}{\partial t} + v\frac{\partial}{\partial x}\right)^2 y + m\frac{\partial y}{\partial t^2} \qquad (6)$$

By eliminate the shear stress from above equation to get:

$$\frac{\partial(\rho A - T)}{\partial x} = 0 \qquad (7)$$

By applying the boundary conditions that where the tension in the pipe is zero at x=L, and the ambient pressure for the fluid pressure is equal to p=0 at x=L:

$$(\rho A - T) = 0 \qquad (8)$$

For a pipe conveying nanofluid free vibration, the equation of motion is yields as [12]:

$$EI\frac{\partial^4 y}{\partial x^4} + \rho A v^2\frac{\partial^2 y}{\partial x^2} + 2\rho A v\frac{\partial^2 y}{\partial t\,\partial x} + M\frac{\partial^2 y}{\partial t^2} \qquad (9)$$

Finite Element Model

A pipe span Figure 3 from its equilibrium position has a transverse deflection y(x, t). The nanofluid flows through a deflected pipe. The nanofluid accelerated due to the lateral vibration of the pipeline and the pipe changing curvature. As discussed before the free vibration equation of motion for pipe conveyed nanofluid given by (Eq.9), by applying the finite element method to approximate the unknown given as:

$$w = \sum_{i=1}^{n} N_i\, a_i \qquad (10)$$

The pipe element shape functions, derived as:

Suppose a length of the pipe of (L) at distance x from the left end at point (R) given by:

$$L_2 = \frac{x}{L}, \quad L_1 = 1 - \left(\frac{x}{L}\right)$$

By using shape functions as [12]:

$$N_1 = L_1^2(3 - 2L_1), \quad N_2 = L_1^2 L_2 L, \qquad (11)$$

$$N_3 = L_2^2(3 - 2L_2), \quad N_4 = -L_2^2 L_1 L \qquad (12)$$

Substituting the values of L_1 and L_2 we get:

$$N_1 = (1 - x/l)^2\,(1 + 2\,x/l)\,, \quad N_2 = (1 - x/l)^2\,(x/l) \qquad (13)$$

$$N_3 = (3 - 2\,x/l)\,(x/l)^2\,, \quad N_4 = -(1 - x/l)\,(x/l)^2 \qquad (14)$$

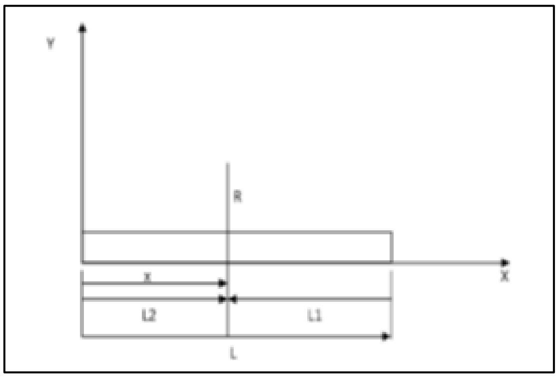

Figure 3: Pipe span conveying nanofluid

Pipe Stiffness Matrix Formulating

The beam element defined by a two dimensional, the shape functions displacement matrix given by:

$$[\mathrm{W(x)}] = [\mathrm{N_1\ N_2\ N_3\ N_4}]\begin{bmatrix} w_1 \\ \theta_1 \\ \theta_2 \\ w_2 \end{bmatrix} \qquad (15)$$

Thus, the two dimensional shape functions displacement, given as N_1, N_2, N_3 and N_4, At point R, the internal strain energy given by [12]:

$$\mathrm{U_R} = \frac{1}{2}\sigma\epsilon \qquad (16)$$

But, for elastic material, the Hooks Law of the relationship for stress and strain ($\mathrm{E} = \sigma/\epsilon$) Eq. (16) becomes:

$$\mathrm{U_R} = \frac{1}{2}\mathrm{E}\epsilon^2 \qquad (17)$$

Assuming plane sections remain same,

$\epsilon = \frac{\partial u}{\partial x}$ and $u = z\frac{\partial w}{\partial x}$ then

$\epsilon = z\frac{\partial^2 w}{\partial x^2}$

Now, for the whole beam, the Eq.(17) was integrated for internal energy given by [11]:

$$\mathrm{U_R} = \int_0^L \int_A \frac{1}{2}\mathrm{E}\left(z\frac{\partial^2 w}{\partial x^2}\right)^2 dx\, dA \qquad (18)$$

The beam element moment of inertia (I) given by:

$$\mathrm{U_R} = \int z^2\, dA \qquad (19)$$

The Eq.(18) formed as:

$$\mathrm{U_R} = \mathrm{EI}\int_0^L \frac{1}{2}\left(\frac{\partial^2 w}{\partial x^2}\right)\left(\frac{\partial^2 w}{\partial x^2}\right) dx \qquad (20)$$

Eq.(18) in form of displacement matrix can be written as:

$$\mathrm{U_R} = \frac{1}{2}\mathrm{EI}\int_0^L (W'')^T\,(W'')dx \qquad (21)$$

From Eq.(15) and substitute the values of W and W^T in Eq.(21) and integrating every element in the matrix along length of (L) yields the stiffness matrix of the beam element:

$$[K_1]^e = \frac{EI}{l^3}\begin{bmatrix} 12 & 6l & -12 & 6l \\ 6l & 4l^2 & -6l & 2l^2 \\ -12 & -6l & 12 & -6l \\ 6l & 2l^2 & -6l & 4l^2 \end{bmatrix} \qquad (22)$$

Force of Nanofluid to Pipe Formulating

Suppose at the point R, the kinetic energy (T) is (y) component of velocity given by:

$$T = \frac{1}{2}\rho_{nf}A\left[\left(\frac{\partial W}{\partial t}\right)^2 + v_{nf}^2\left(\frac{\partial W}{\partial x}\right)^2 + 2v_{nf}\left(\frac{\partial W}{\partial t}\right)\left(\frac{\partial W}{\partial x}\right)\right] \quad (23)$$

Due to the nanofluid flow, the force acting on pipe span can be calculated by integrating Eq.(23) along length of (L) to get [11]:

$$T = \int_L \frac{1}{2}\rho_{nf}Av_{nf}^2\left(\frac{\partial W}{\partial x}\right)^2 \qquad (24)$$

Rearranging the equation [9]:

$$T = \frac{1}{2}\rho_{nf}Av_{nf}^2\int_L \left(\frac{\partial W}{\partial x}\right)\left(\frac{\partial W}{\partial x}\right) \qquad (25)$$

By substituting and integrating over pipe length the shape functions values equations, yields [12]:

$$[K_1]^e = \frac{\rho_{nf}Av_{nf}^2}{30l}\begin{bmatrix} 36 & 3 & -36 & 3 \\ 3 & 4 & -3 & -1 \\ -36 & -3 & 36 & -3 \\ 3 & -1 & -3 & 4 \end{bmatrix} \quad (26)$$

Dissipation Matrix Formulation

The dissipation matrix refers to the force that causes the nanofluid by recalling Eqs.(23) and (25) as [11]:

$$D = \int_{L} 2\rho_{nf} A v_{nf} \left(\frac{\partial W}{\partial t}\right)\left(\frac{\partial W}{\partial x}\right) \quad (27)$$

Now, substituting the values of shape functions and integrating over the pipe span length L to get:

$$[D]^e = \frac{\rho_{nf} A v_{nf}}{30}\begin{bmatrix} -30 & 6 & 30 & -6 \\ 6 & 0 & 6 & -1 \\ -30 & -6 & 30 & 6 \\ 6 & 1 & -6 & 0 \end{bmatrix} \quad (28)$$

$[D]^e$ represents the elemental dissipation matrix.

Inertia Matrix Formulation

Suppose the kinetic energy of a particle in the pipe has an element area of (dA), element length of (x), element volume (dv) and element mass (dm), can expressed by:

$$T = \frac{1}{2} m v^2 \quad (29)$$

Eq.(29) integrated with mass expressed as (dm = ρ.dv) to get:

$$T = \int_{v} \frac{1}{2} \rho \vec{W}^2 \, dv \quad (30)$$

And element volume given b

$$dv = dA.dx \quad (31)$$

From Eq.(31) into Eq.(30), substituting volume value of (dv) and integrating to get:

$$T = \frac{-w^2}{2} \int_{A} \int_{L} \rho \vec{W}^2 \, dA.dx \quad (32)$$

Substituting the value of $\int \rho dA$in equation (32) yields;

$$T = \frac{-\rho A w^2}{2} \int_{L} \vec{W}^2 \, dx \quad (33)$$

The shape functions was substituted from Eqs.(11) to (14) into Eq.(33):

$$[M]^e = \frac{Ml}{420}\begin{bmatrix} 156 & 22l & 54 & -13l \\ 22l & 4l^2 & 13l & -3l^2 \\ 54 & 13l & 156 & -22l \\ -13l & -3l^2 & -22l & 4l^2 \end{bmatrix} \quad (34)$$

Now, start with a null matrix of 6×6 has six degrees of freedom for each node for translation and rotation of. The two stiffness matrices of 4×4 element were inserted to get the global stiffness matrix given by:

$$K_{Global} = \frac{EI}{l^3}\begin{bmatrix} 12 & 6l & -12 & 6l & 0 & 0 \\ 6l & 4l^2 & -6l & 2l^2 & 0 & 0 \\ -12 & -6l & (12+12) & (-6l+6l) & -12 & 6l \\ 6l & 2l^2 & (-6l+6l) & (4l^2+4l^2) & -6l & 2l^2 \\ 0 & 0 & -12 & -6l & 12 & -6l \\ 0 & 0 & 6l & 2l^2 & -6l & 4l^2 \end{bmatrix} \quad (35)$$

Boundary Conditions

For simply supported pipe that conveying nanofluid flow, to solve Eq.(35), this equation is modified to global stiffness matrix of 4×4 as:

$$K_{Global} = \frac{EI}{l^3}\begin{bmatrix} 4l^2 & -6l & 2l^2 & 0 \\ -6l & (12+12) & (-6l+6l) & 6l \\ 2l^2 & (-6l+6l) & (4l^2+4l^2) & 2l^2 \\ 0 & -6l & 2l^2 & 4l^2 \end{bmatrix} \quad (36)$$

3. Numerical Solution

In order to numerically solve the global matrices for the pipe with simply supported condition that conveying three types of nanofluids of (Al2O3, TiO2, SiO2 and water) with different nanoparticle volume fraction of (0 to 2% vol.), MATLAB code program was used in this study. The code was wrote to solve the global matrices that given by Eqs.(35) and (36). The elemental matrices of the straight pipe conveying nanofluid was developed to obtain the pipe onset of vibration instability and natural frequency. The natural frequency and critical velocity equations that can apply for the simply supported pipe which carrying nanofluid [2]:

$$\omega_n=(\pi/L)^2 \sqrt{(EI/M)}$$ (٣٧)

$$v_c=(\pi/L) \sqrt{(EI/(\rho_{nf} A))}$$ (38)

In this study the following parameter such as the pipe density, pipe length and pipe modulus of elasticity. Also, the density and velocity of the nanofluid that flowing through the pipe and the thickness of the pipe were summarized in Table 1 for working fluids and Table 2 for the pipe specifications, theses parameter were used in the MATLAB program.

Table 1: Fluid parameter and flow conditions

Material	**Type**	**Density $\rho(kg/m^3)$**	**Particle diameter, dp(nm)**	**Volume fraction Vol. (%)**	**Inlet Reynolds number**	**Diameter**
Fluid	Water	997.5	-	0	Laminar	520, 1050, 1500, 2000
					Turbulent	5200, 6250, 73000,83000
	Al_2O_3	3920	47	0.05,0.1,0.15,0.2,0.6,1,2	Laminar	515, 1030, 1550, 2060
					Turbulent	5160,6255, 72300,82700
	TiO_3	4170	30	0.05,0.1,0.15,0.2,0.6,1,2	Laminar	516,1030, 1550,2070
					Turbulent	5170, 6190, 72300,82600
	SiO_2	2200	22	0.05,0.1,0.15,0.2,0.6,1,2	Laminar	514, 1030, 1540, 2060
					Turbulent	٥١٥٠, 6177, 72072,82370

Table 2: Pipe parameter

Material	**Type**	**Density ρ(kg/m3)**	**Modules of elasticity E (Gpa)**	**Length L(m)**	**Diameter D(mm)**	**Thickness t1(mm)**
Pipe	Stainless steel AISI 316	8000	207	1,1.5,2,2.5	10,15,20,25	0.1

4. Results and Discussion

The MATLAB program was employed for the vibrational analysis of the pipe with simply supported ends boundary conditions. The pipe conveyed three types of nanofluids, and the parameters of the flow such as pipe length, pipe diameter, nanofluid concentrations, and velocity of nanofluid. Results were presented in the form of tables and graphs. For example, the critical velocity of fluid and vibration fundamental frequency were presented in Table 3. The relation between pipe length and the pipe fundamental natural frequency with various fluid Reynolds number of simply supported pipe mounted on viscoelastic foundation. As the Reynolds number is increase, the natural frequency of the pipe is decrease. This behavior is taken place since the global stiffness of the system is constant as depicted in Figure 4. Furthermore, Figure 5 presented the relation between pipe diameter and pipe fundamental natural frequency seems to be linear function at constant Reynolds number, however as the natural frequency increased with increasing the pipe diameter increase due to increasing the fluid turbulence and its fluctuating and generate the vorticities and this increasing the pipe natural frequency.

The effect of pipe length on the pipe fundamental natural frequency plotted in Figure 6, the results showed that the pipe natural frequency increased with increasing with decreasing the pipe length at a given Reynolds number value for example the pipe natural frequency increased by 50% if the pipe length decreased from 2.5 to 1.5m at Re=1000.

Table 3: Fundamental frequency for a simply supported pipe flow velocity L=2 m, D=20 mm

Velocity of water (u)	Critical Velocity of water (u_c)	Velocity ratio (u_r)	Fundamental frequency (w_f)	Fundamental frequency (w_f)	frequency ratio (w_r)
Laminar flow					
0	22.6709	0	21.8985	21.8763	1.001
0.05	22.6709	0.0031	21.8979	21.8763	1.001
0.1	22.6709	0.0062	21.8969	21.8763	1.0009
0.15	22.6709	0.0093	21.8955	21.8763	1.0009
0.2	22.6709	0.0124			
Turbulent flow					
0	22.6709	0			
5	22.6709	0.3111	19.8454	21.8763	0.9072
6	22.6709	0.3733	18.8872	21.8763	0.8634
7	22.6709	0.4355	17.7019	21.8763	0.8092
8	22.6709	0.4977	16.2483	21.8763	0.7427

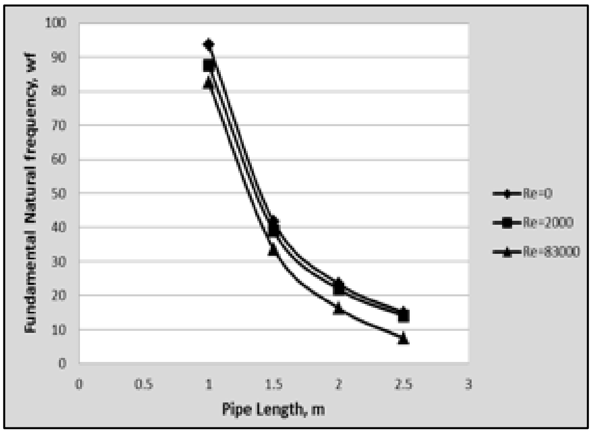

Figure 4: Reduction of fundamental frequency ratio with increasing pipe length for a simply supported pipe and using water

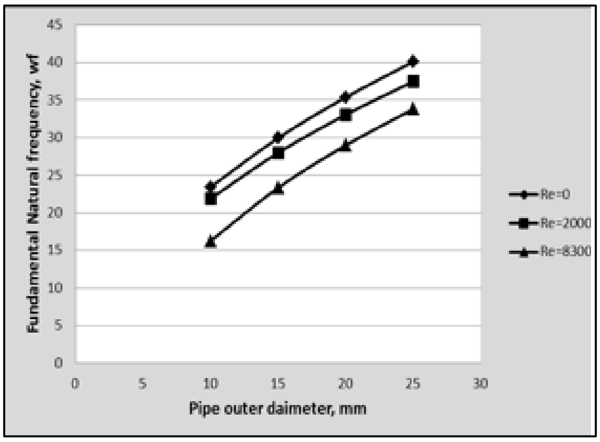

Figure 5: Increasing of fundamental natural frequency with pipe diameter for different Reynolds number and using water

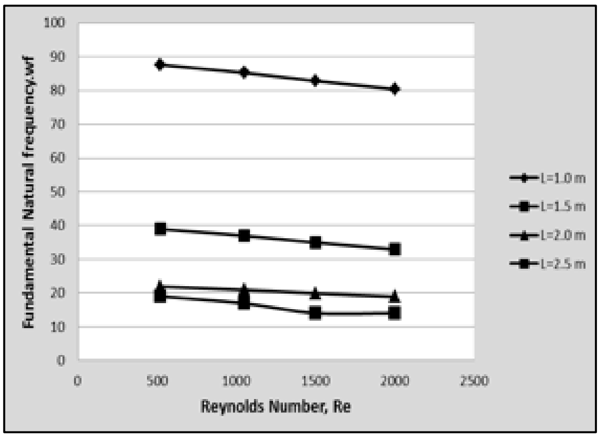

Figure 6: Effect of the inlet Reynolds number on the fundamental natural frequency for different pipe length and using laminar water flow

Nevertheless, the effect of increasing the pipe length on the fluid velocity ratio (v/vc) presented in Figure7. The figure showed that that the fluid velocity ratio increased linearly with increasing the fluid Reynolds number at any pipe length. However, the velocity ratio increased with increasing the pipe length at constant Reynolds number. As well known for a pipe without foundation, increasing the pipe length leads to reduce the pipe stiffness and raise its mass thus decreasing the critical flow velocity. This behavior is differing for a pipe with viscoelastic foundation. Where there is a reduction in the critical flow velocities with increasing the pipe length then at some pipe length the critical velocity start to rise, then after reducing again and continue with compacted values. It has thus found that the criterion for global instability as the length is increased becomes closely related to the local properties of the waves in the pipe. It is important to record that at some ranges of pipe length, the foundation viscosity effect seems extreme and obvious.

The variation of critical flow velocity with Reynolds number presented in Figure 8 for turbulent flow. The results showed that the velocity ratio increased with small percent in range of Re between 1.2×10^4 to 6.5×10^4 but when increased Re to 8.5×10^4 the increasing of velocity ratio becomes more dramatically with constant pipe length.

In addition, the velocity ratio increased with increasing the pipe length at constant Re, but it decreasing with increasing the pipe diameter for laminar as shown in Figure 9.

In addition, when increasing the pipe diameter for laminar flow the velocity ratio will increased as presented in Figure 10.

The ratio of pipe fundamental natural frequency ratio (wf/wn) with fluid Reynolds number relation at turbulent water flow plotted in Figure 11, the figure concluded that the frequency ratio appear a straight relation function with increasing the Re from 1.2×10^4 to 6.5×10^4 for pipe lengths of 1.0 and 1.5 m, but when using the pipe length of 2.0 and 2.5 m show that the frequency ratio decreasing with increasing the Re. In addition, the frequency ratio was increasing with decreasing the pipe length.

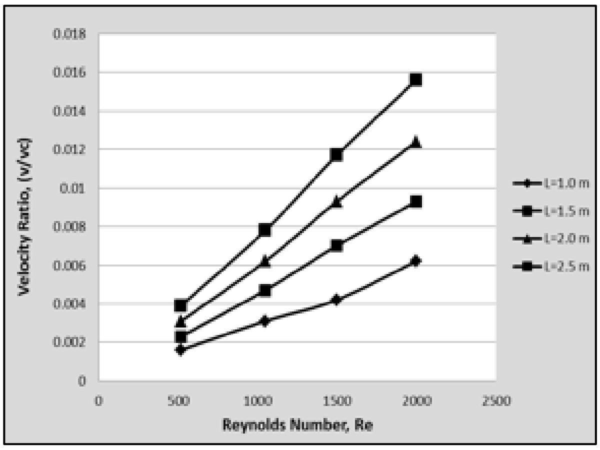

Figure7: Effect of the inlet Reynolds number on the ratio of the velocity with different pipe length and using laminar water flow

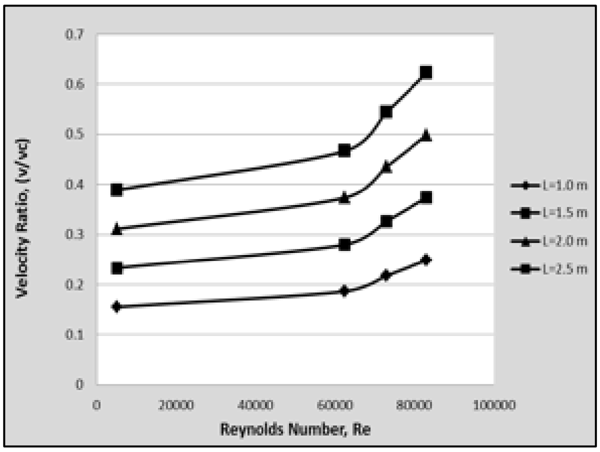

Figure 8: Effect of the inlet Reynolds number on the ratio of the velocity with different pipe length and using turbulent water flow

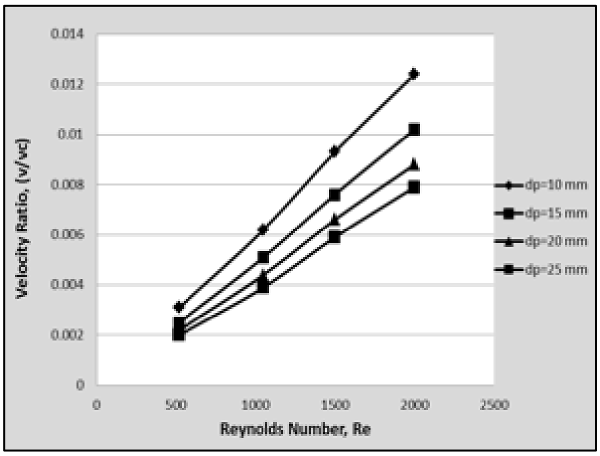

Figure 9: Effect of the inlet Reynolds number on the ratio of the velocity with different pipe diameter and using laminar water flow

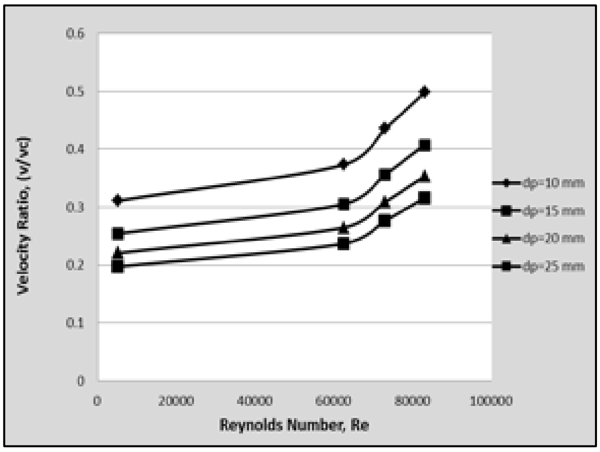

Figure 10: Effect of the inlet Reynolds number on the ratio of the velocity with different pipe diameter and using laminar water flow

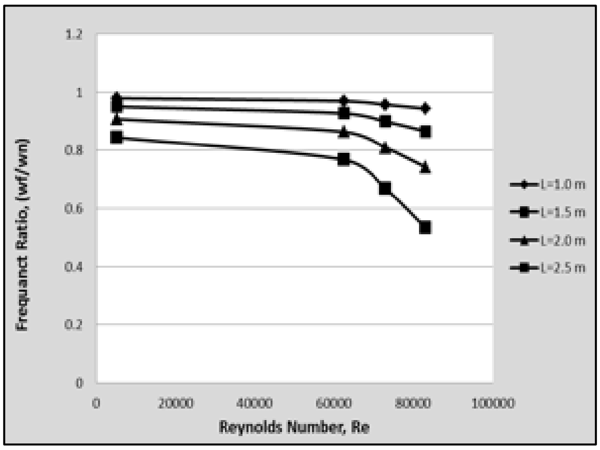

Figure 11: Effect of the inlet Reynolds number on the ratio of the fundamental natural frequency ratio with different pipe length and using turbulent water flow

The main aim of this study is studding the effect of using nanofluid on the vibration characteristics of the simply supported pipe, thus the values of velocity ration at laminar flow of three nanofluids (Al_2O_3, TiO_3, SiO_2) and the water as a working fluids in this calculations plotted in Figure 12. the results showed that the using SiO_2 nanofluid will give an increasing percent in velocity ratio of (8.4%) above the using the water alone, but when using the $_{TiO3}$ nanofluid the percent will decreasing to (5.3%) finally if using the Al_2O_3 nanofluid will get (3.2%) percent at constant Re=2500.
Figure 13 appears a sufficient increasing in the fluid velocity ratio increasing percent when using the turbulent flow condition as following (28%, 16% and 7%) at $Re=6.5\times10^4$ for using SiO_2, TiO_3 and Al_2O_3 nanofluids respectively.
The effect of these nanofluids on the pipe fundamental natural frequency was presented in Figure 14. It showed that the pipe fundamental natural frequency decreased when using the different nanoparticle depressed in the water, but the maximum decreasing occurs when using TiO_3, SiO_2 due to high nanoparticle diameter and this will increasing the fluid density that flowing in the pipe.
Moreover the using nanofluid will effect on the frequency ratio by decreasing it along increasing the turbulent Re as shown in Figure15. Well the minimum frequency ratio presented at using SiO_2 at Re=6.5×104. in the studying the nanofluids effects it should be to study the effect of the volume fraction of the nanoparticles as presented in Figure16. The figure drawing between the fluid velocity ratio and the volume fraction of the nanoparticles it concludes that the velocity ratio increasing with increasing the nanoparticles volume fraction by a leaner function for the two cases of laminar.
Moreover, for turbulent nanofluid flow as presented in Figure 17 due to increasing the fluid velocity with increasing the nanoparticles volume fraction for the three nanofluids employed in this study.

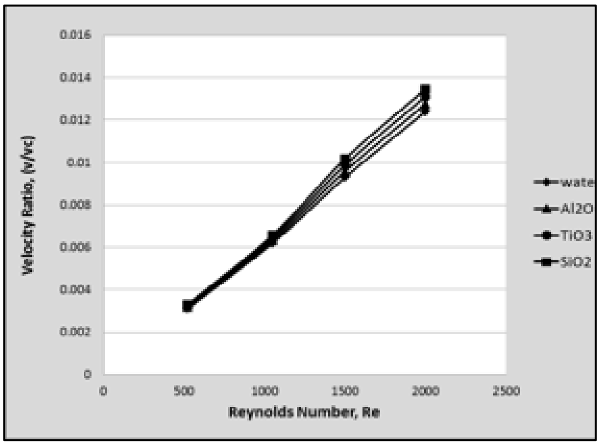

Figure 12: Effect of the laminar inlet Reynolds number on the ratio of the fluid velocity with different working fluids

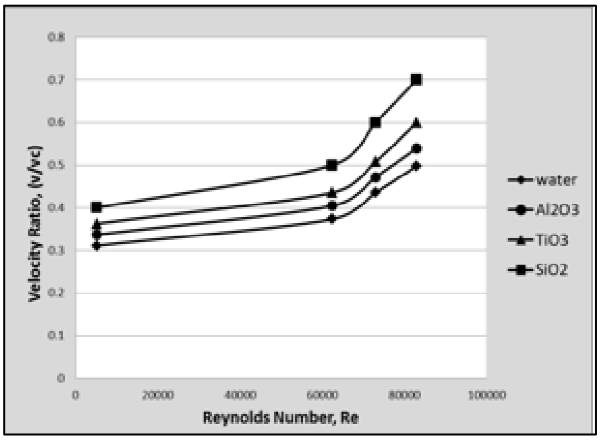

Figure 13: Effect of the turbulent inlet Reynolds number on the ratio of the velocity with using different working fluids

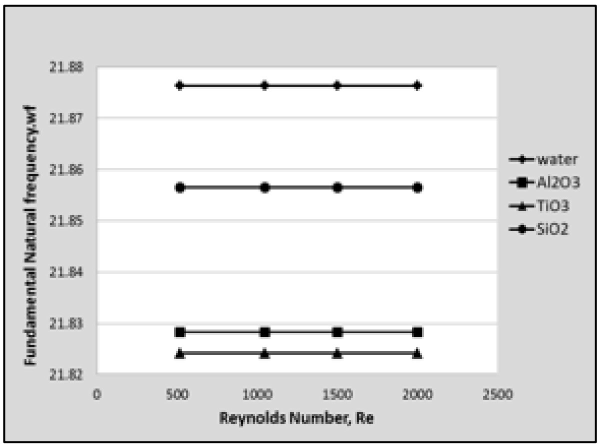

Figure 14: Effect of the laminar inlet Reynolds number on the fundamental natural frequency with using different working fluids

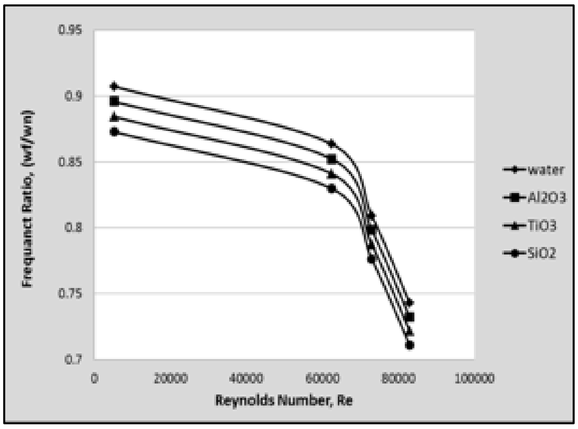

Figure 15: variation of fundamental frequency ratio with turbulent Reynolds number using three types of working fluids

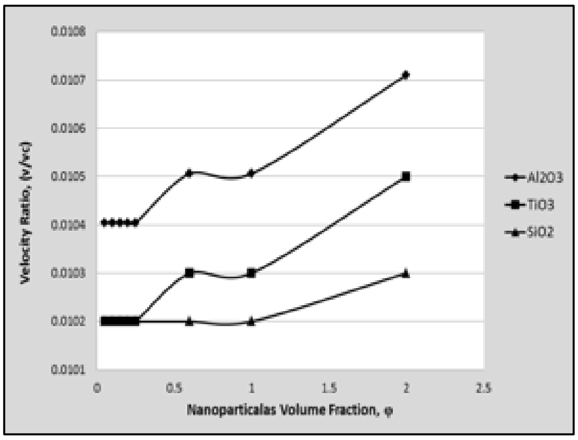

Figure 16: variation of ratio of the fluid velocity with nanoparticles volume fraction for three working fluids at Re=2000

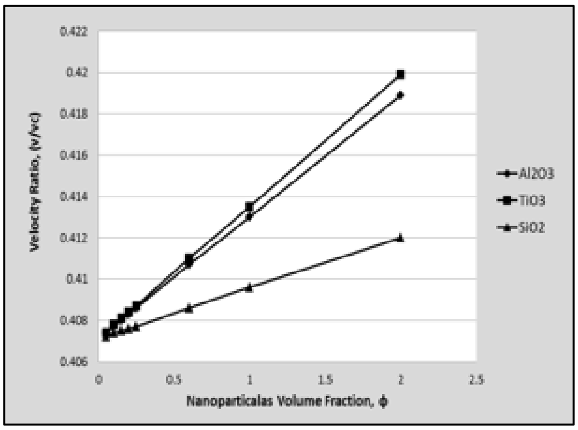

Figure 17: Variation of ratio of the fluid velocity with nanoparticles volume fraction for three working fluids at Re=83000

5. Conclusions

In this work, the three type's nanofluid of (Al_2O_3, TiO_2 and SiO_2) induced vibration flowing in simply supported pipe with different length and diameter was taken in consideration. Due to inertia effect of fluid, coriolis force, dynamic load due to inertia effect and the fluid rotation kinetic force come from the fluid flow velocity, the dynamic characteristic of a pipe conveying water or nanofluid appears a mechanical load. In this study, the one dimensional beam finite element was applied to investigate the dynamic behavior of the thin slender pipe with appropriate numerical computational method for analysis solved by MATLAB code. The fundamental natural frequency of vibration and fluid velocity interaction was investigated. The concluding remarks obtained theoretically on the natural frequency ratio of the pipe conveying different nanofluids. It is observed that the frequency of vibration increases with the decrease pipe diameter and decreases with increase in pipe length and increasing the Reynolds number, and it has smallest value when using TiO3nanofluid. Moreover, the fluid velocity ratio increased with increasing the pipe length and Reynolds number, but it decreased with increasing the pipe diameter. The highest value of the fluid velocity ratio was found by using Al_2O_3 nanofluid.

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Nomenclatures

S: inner perimeter of the pipe (m)
Φ: shear stress on the internal surface of the pipe (pa)
Q: transverse shear force in the pipe (pa)
T: longitudinal tension in the pipe (pa)
M: mass per unit length of the empty pipe (kg/m)
M: mass per unit length of the pipe and the (kg/m) nanofluid in the pipe, M = m + ρA.
Ni: interpolating shape functions (-)
ai : set of unknown parameters (-)
L: length of the pipe element (m)
A : area of cross-section of the pipe (m^2)
V_{nf}: velocity of the nanofluid flow (m/sec)

Greek Symbols

ρnf: density of the nanofluid (kg/m_3); σ : stress at the point R (N/m^2)
ϵ : strain at the point R (N/m^2); ε: effectiveness (%)
μ: dynamic viscosity (Pa.s); ν: kinematic viscosity of fluid (m^2/s)
ρ: fluid density (kg/m^3)