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Experimental Study of the Vibration Effect on the Fluid Discharge Time in Annular Cantilever Pipes Conveying Fluid

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Abstract: The problem of pipe conveying fluid under vibrational effect took a very fine and precise attention because of the importance of vibrational affected fluid behavior. Experimentally workwas carried out on building a rig of gravitational flow under the effect of excitation by vibrated force placed on different locations beneath the pipe end for different frequencies. The rig was provided with the necessary measurement equipment to study the effect of vibration on thedischarge time. It has been proven, experimentally that the position and value of excited vibration have effect on the discharge time. The minimum discharge time registered at maximum stiffness and in excited frequency nearest from the natural frequency (shaker at 18.5 cm of clamped end) and for 25 rad/sec frequency.

Key words: Pipe conveying fluid, discharge time, vibration, frequency, equipment, Iraq

INTRODUCTION

Pipes conveying fluid have many practical applications. They are encountered, for example, inthe form of vibrated pipes in engines. The importance of pipe flow under vibration effect isclear in oil rigs and oil exporting terminals when unrespecting slightly change flow rate meansan economical risk in a shade of globe economic meltdown.

Goldenblatt (1947) considered a pipeline divided diametrically into two sections with countercurrent equal velocity flows in each section, neglecting the influence of fluid pressure. Ashley and Havilland (1950) attempted to describe vibrations of the Trans-Arabian pipeline by analyzing the dynamics of a simply supported pipe span using an approximate power series solution.

The discretized dynamic equations by using finite difference schemes of the case of the instability of submerged and inclined concentric pipes are presented by Wang and Bloom (2001). At a small deformation of the inner tubular beam, the governing equation was derived. It is concluded that the buckling and flutter conditions were instabilities for the case of steady state flow. Depending on Winkler Model foundation, the instability of infinitely long fluid conveying pipes using wave propagation approach were investigated by Doare and Langre (2002). The results are presented in two terms, firstly as a static neutrality (for clamped clamped ends and pinned pinned), secondly as a dynamic neutrality (for clamped free ends). The transverse vibrations of highly tensioned pipes with vanishing flexural stiffness and conveying fluid with time-dependent velocity were investigated by OZ and Boyaci (2000). Horacek (1993) looked at the dynamical behavior and stability of a cylindrical shell containing and immersed in an axially flowing in viscid and incompressible fluid. Coaxially located rigid cylindrical walls confined the internal and external flow regions. The unsteady fluid forces were derived from linearized potential flow theory and approximated by slender-body theory. Shell motion was described by semi-membrane theory of shells which was acceptable for the lower natural frequencies of shells of medium length. These theories give very simple estimations ofcritical flow velocities for divergence (buckling) of pinned-pinned shells and similarly, the estimations of natural frequencies of shells in the case of stagnant fluid, moreover, the solution gave a very clear picture of stability and the possibilities of bending-wave propagation along infinity long shells.

Honma and Tosaka (1997) present the dynamic stability analysis of the elastic rod subjected tonon-conservative loads by the use of domain decomposition boundary element method to bevery effective. When this method was used, the obtained numerical solutions tend to be on thesafe side value for the critical load and attracting attention as an effective numerical method fornon-self-ad joint eigen value problem. Kim and Choo (1998) studied the effects of instability of the concentrated mass subjected to a pulsating follower force (axial location and translation inertia) by analysing the

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dynamic stability of a free-free Timoshenko beam. The change incombination resonance types are examined, the variation between critical forces and the instability regions width considering the shear deformation.

A new model of pipe conveying fluid fixed at both ends by using vibration analysis was presented by Lee and Chung (2002). By using beam theory and non-linear strain theory for Euler-Bernoulli and Lagrange, respectively and depending upon the extended Hamilton's principle and Galerkin discretized method, the motion equations of the displacements inlongitudinal and transverse directions were derived. When the equations become as a linearized, the natural frequencies and the neighbourhoods of the equilibrium position were measured.

By using the non-linear discretized equations of the integration method of generalized time, the displacements of time histories were measured. The dynamic analysis of a multi-span pipe conveying fluid subjected to external load was made by Wu and Shih (2001). Shizhong *et al*. 1998) used a finite element technical to explain the effects of fluid velocity flow on thenatural frequency of simply supported elastic pipes. The results are presented in terms the pressure and solid-liquid coupling stiffness. It was found that the values of the natural frequency decreases with increasing flow velocity. In 1999, Feng and Zhao (1999) studied the stability analysis of the Timoshenko elastic pipes conveying fluid by using powerseries method, the relationships between natural frequencies, critical velocities and rotator inertia are estimated.

Recently, the study by Xie *et al*. (2016) is the primary work that demonstrates to us the flow inside oscillate pipe. they demonstrate how the stream inside a pipe changes when the amplitude of motions is changed. They do this by forcing a re commended second-modes tanding-wave movement to the pipe and they show how changing the value of the movement makes the flow inside the pipe changing from a laminar flow to a turbulence flow. In the present research, the effect of excitation by vibrated force placed on different locations beneath the pipe end for different frequencies will be studies.

MATERIALS AND METHODS

Natural frequency equation of cantilever pipe conveying fluid: The used pipe in this research is cantilever pipe as shown in Fig. 1. The equation of motion of pipe conveying fluid by Yi-Min *et al*. (2010):

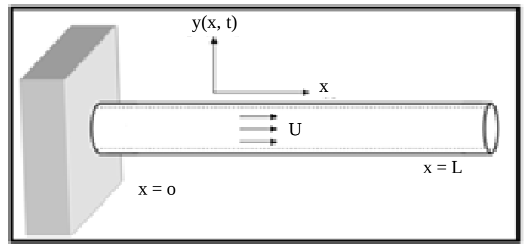

Fig. 1: Cantilever pipe conveying fluid

Table 1: Specification of the testing pipe

Parameters	Values
Outer diameter	20 (mm)
Wall thickness	2.5 (m)
Length	1 m
Mass density	1627.7 (kg/m^2)
Modulus of elasticity	1.579 (GPa)
Moment of inertia	5369*10^{-12} (m^4)

$$EI\frac{\partial^4 y}{\partial x^4}+(m_0U^2+pA)\frac{\partial^2 y}{\partial x^2}+2moU\frac{\partial^2 y}{\partial x^2}+ \\ 2m_oU\frac{\partial^2 y}{\partial x\partial t}(m_o+m)\frac{\partial^2 y}{\partial t^2}=0 \quad (1)$$

The boundary condition of the clamped-free pipe is:

- 1-at x = 0, y(0, •) = y'(0, •) = 0
- 2-at x = L, y''(L, •) = y'''(L, •) = 0

To evaluate the first natural frequency for the cantilever pipe (Yi-Min *et al*., 2010) started from equation of motion by using Galerkin method, he got the following Eq. 2:

$$\omega_1=(1.875104L)^2\sqrt{\frac{EI}{m+m_o}}*\sqrt{1-\frac{(\frac{1.1376m_o}{m+m_o}+0.2441)m_oU^2}{EI(1.875104L)^2}} \quad (2)$$

Experimental procedures

Test rig: Figure 2 shows a photograph of test rig and some instruments used in the undergoing experimental study. A horizontal PVC pipe with specification shown in Table 1 specially usedas water line of one meter length and 48 cm height was fixed at one end into a cement block toensure getting clamped end support and was attached to the plastic hose by using valve, the other end of the plastic hose was connected to a tank at a height of 98 cm.

Instrumentation: The photographs of the instruments that were used in the vibration tests are shown

Fig. 2: Photograph of testing rig

in Fig. 2. Water was used as the flowing fluid which was supplied to the testing model by gravitational flow from tank which was the water supply.

In the vibration test, a shaker was seated in proper positions to vibrate the model (tested pipe). This shaker was driven by a power amplifier by a sine signal generator. The screen of the oscilloscope has been displaying the frequency with the phase. The vibration motion is often converted into an electrical signal. The voltage output of the device is due to the cyclic deformation of the piezoelectric crystals. The instruments and equipment's used in the vibration test are:

- Vibration exciter type B&K 4808; Permanent magnet types for vibrating small test objectsand samples with wide frequency range and force rating up to 112N
- Function generator type GFG-8015G; It has sine plus +10% Freq. Mod. Modes with Lin/Log sweep from 10 Hz to 20 kHz in one continuous range
- Power amplifier type B&K 2719; It is 75 VA, small, handy, power amplifier with selectable drive current limits of 0.6 and 8 A
- Programmable digital storage oscilloscope type UT3025C
- Centrifugal pump to filling the tank
- Timer to determine the discharge time

The block diagram of the instruments used in the vibration tests is shown in Fig. 3.

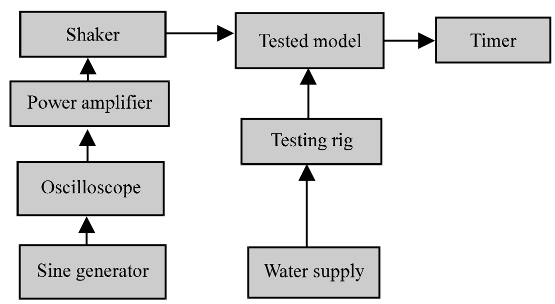

Fig. 3: Block diagram of the testing elements used in measuring the discharge time

Experimental procedures

Simple experiments: Simple experiments were carried out to determine the modulus of elasticity. To evaluate thepipe mechanical major characteristic which is the modulus of elasticity, a tensile test with computerized tensile device was used.

The value of load and extension will be transformed automatically in the computerized unit ofthe device to give a graph of load versus extension, the slope of the best fitted curve of the load-extension chart was used together with basic relation of strength of materials to determine the modulus of elasticity.

Another test was used to ensure the results using the three point bending method, the computerized unit of the device was given a graph of load versus deflection, this chart with basic relation of strength of materials was used also to determine the modulus of elasticity.

Vibration test: The water in the tank was at determined level before start of the experiment, the frequency wasapplied by formatting the sine generator and the screen of the oscilloscope to display the frequency with the phase. A signal was transmitted to the shaker through a power amplifier from oscilloscope to excite the pipe by controlled signal. Then the valve was opened to maximum and the timer wasused together to determine the discharge time. This procedure was carried out to investigate the effect of frequency value and position of the Shaker on the discharge time. A shaker was connected to the pipe at different places from the starting point (at which the cement block was placed) (18.5, 35, 50, 75 and 90 cm) with vibration of selected frequencies (10, 25, 50, 100, 500, 1000 and 2000 rad/sec) with constant mechanical power (12.75 W).

RESULTS AND DISCUSSION

The experimental approach presented is mainly to investigate the effect of vibration on the discharge time. A shaker connected to the pipe at different places from the starting point (which the cement block is placed) (18.5, 35, 50, 75 and 90 cm). With vibration of selected frequencies (10, 25, 50, 100, 500, 1000 and 2000 rad/sec) the results shown in Table 2. A plot of time versus frequency at many shaker positions is shown in Fig. 4.

It can be seen in Fig. 4, the results curve have a higher peak at 18.5 cm fixing and peakvalue height is lowering as the fixing tends to the free end of the pipe. As for as the vibrator inaction, its amplitude is rather small (compared with the size of the experiment), it could beregarded as a fixing, so, at 90 cm the behavior of vibrator in the setup is a support. At lower frequency the time of discharge decreases when it goes up until it is the minimum time and increases relatively slowly to the same value of discharge, this is according to the combination of the kinetic energy that is given into the system as a phonons (the quantizing unit of physical energy like the photon of the electromagnetic wave) and shear stress in the structure of volume enclosed in the pipe skeleton (the pipe shape defines the liquid in it), so, at moderately low frequency it helps to increase the amount of discharge slightly but for increasing frequency, more turbulence occurs because of the disruptions in the fluid according to its inertia, blocking the stream of flow,

Table 2: Variation of the discharge time with frequency and shaker position

	Discharge time (min) (rad/sec)				
Frequency	At 18.5 cm	At 35 cm	At 50 cm	At 75 cm	At 90 cm
10	11.22	11.21	11.18	11.23	11.25
25	10.11	10.21	11	11.21	11.24
50	10.15	10.27	10.6	11.07	11.23
100	10.51	10.7	10.9	11.22	11.24
500	11.15	11.22	11.23	11.24	11.24
1000	11.25	11.25	11.26	11.26	11.26
2000	11.26	11.26	11.26	11.26	11.26

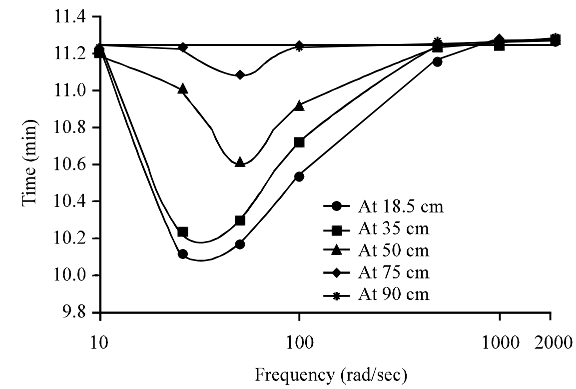

Fig. 4: Plot of discharge time verse frequency at many shaker positions

decreasing the difference that the vibration did to discharge as shown in Fig. 5 (the photographing was by using classical camera with (10.1 megapixel) resolution.

The mass of the pipe and water are 0.2236 and 0.1767 kg, respectively and the relation of the average velocity of flow is:

$$U_{av} = \frac{\forall}{At} = \frac{342}{t}\ \text{msec} \quad (3)$$

The flow rate of the fluid is:

$$Q = AU_{av} = 286.5*10^{-6}*\frac{342}{t} = \frac{0.0979}{t} m^3/\text{sec} \quad (4)$$

By substituting the discharge time in Eq. 3 giving small average velocity between 0.5-0.56 msec, so, the natural frequency of the pipe with flow convergent when we using Eq. 2, the natural frequency with and without flow is 18.6 and 24.3, respectively. It can be seen in the Fig. 4, the maximum discharge time occur when the pipe vibrating by frequency nearest and less than from the natural frequency of the pipe because of the value of the amplitude is high. From Eq. 4, the maximum flow rate of the water is 161.5 cm^3/sec at minimum discharge time. The inertia resistance increases with acceleration (the

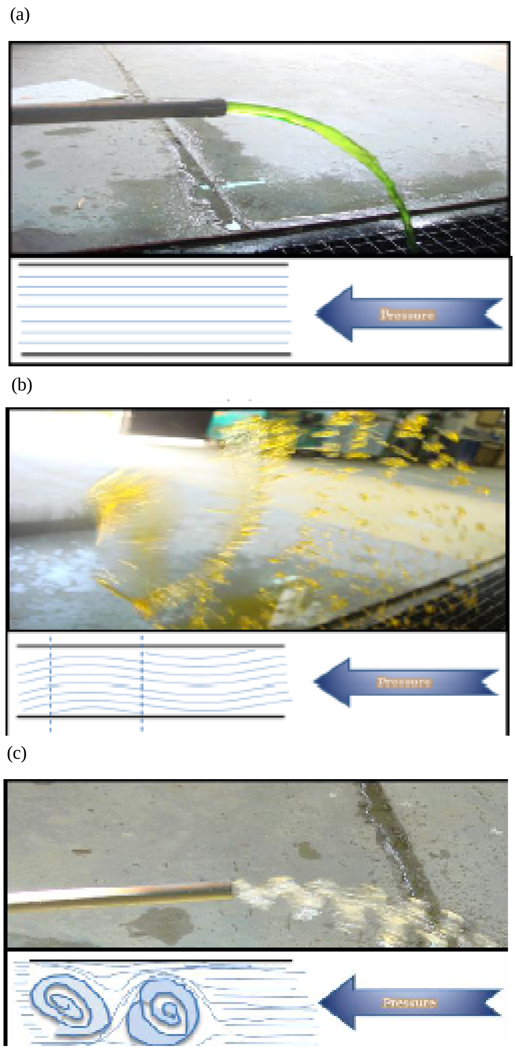

Fig. 5: Behaviour of water in the pipe because of frequency value when the distance between the clamped end and excited vibration is 18.5 cm at: a) 10 rad/sec frequency; b) 25 rad/sec frequency and c) 500 rad/sec frequency

acceleration increases with increase inflexibility), so, the increase in the distance of the vibrator at a fixed point of the pipe the less acceleration will be occur. The shearing energy increases with adding energy to the system (asvibration energy) as kinetic energy, the phonons. At moderate acceleration the kinetic energy ishigher than shear energy, so, the time will decrease slightly and the same principle applies to acceleration, so, the longer the free end the more kinetic energy will be added to the system and the shear energy increases. But more vibration energy and acceleration will cause rapid increasein shear energy and shear force so more vibration energy will cause turbulence choke the flowas shown in the schematic (Fig. 6).

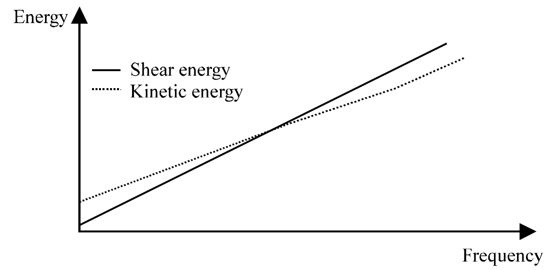

Fig. 6: Schematic relation between energies for different frequencies

CONCLUSION

Following the main summarized conclusions raised by this research: discharge time increases with increasing the distance between the clamped end and thepoint of excitation through the frequency range that studies in this research. The fastest time of discharge was recorded at vibrator fixing of 18.5 cm from the clamped end at frequency (25 rad/sec). The maximum discharge time occur when the pipe vibrating by frequency nearest from natural frequency of the pipe because of the value of the amplitude is high. The discharge time decreases with increasing frequency until it reaches the minimum time, then it will increase. The effective criterion is the stiffness (that is governed byfixing) condition, the nearest Shaker position to the clamped end, the faster discharge time will be recorded. Also, the excited frequency that nearest from natural frequency decreases the discharge time because of the amplitude is high.

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