ANNALS of the ORADEA UNIVERSITY.
Fascicle of Management and Technological Engineering, Volume VI (XVI), 2007

METHOD TO INVESTIGATE VIBRATION INDUCED BY CRUDE OIL SLUG FLOW THROUGH A PIPELINE NETWORK

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Keywords: vibration, slug flow, pipeline transportation

Abstract: The pipeline transportation of mixture of different materials, water (hydro transportation) and air (pneumatic transportation) is widely used in industry. Designing of a piping system in such cases is complex, which involves a large amount of resources needed to perform a complete fluid-structure interaction analysis. This means that the design of a multiphase transportation system can be costly. A new method to design a multiphase piping system is to be developed. The method takes into account first the worst case scenario dynamics that could occur in a multiphase fluid transportation. This paper proposes a method to investigate the vibrations induced by crude oil slug flow through a pipeline network.

1. INTRODUCTION

The pipe network is widely used in engineering to handle multiphase fluids supplies between technological installations, ash slurry transport (as solid material in finely divided form) and water (as a transport vector), and then pumping of the mixtures through a piping system (i.e. using a membrane pump). The pneumatic conveying delivery system of a laser printer is another example that uses a two-phase mixture, to transport powder from the ink cartridge to the printer head.

Pipe networks are used to collect the crude oil from oil fields to the three phase separators, as shown in Figure 1. The crude oil contains three phases, oil, gas and water, sometimes mixed with mud, and has to pass through different configurations of the hydraulic runs, such as: elbows, valves, bifurcations, reduction and expansion pipe sections and others. One situation could occur; the liquid phase could be grouped in a short compact column of liquid between two columns of gas.

When the short column of compact liquid between two columns of gases, namely slug, traveling through the pipes, induces significant impulsive forces on the pipe line structure, developing transitory stress and vibration on the pipe structure, resulting in with abrasive and corrosive effects, usually, leading to cracks, especially in the elbow sectors. The same effects can occur if the slug is passing through valves, bifurcations, section variations and other modifications of the piping geometry.

To reduce the above-mentioned effects, different sections of the pipeline structures are placed in supports and vibration dampers. The positions and characteristics of supports and vibration dampers are determined by experimental investigation of structure response or by numerically modeling the dynamics of this structure.

These forces can be determined by laboratory investigation using a dedicated setup including force sensors, slug position sensors, a ninety-degree transparent PVC elbow, and a special positioning of the pipe in order to avoid the slug to break apart before reaching the elbow area.

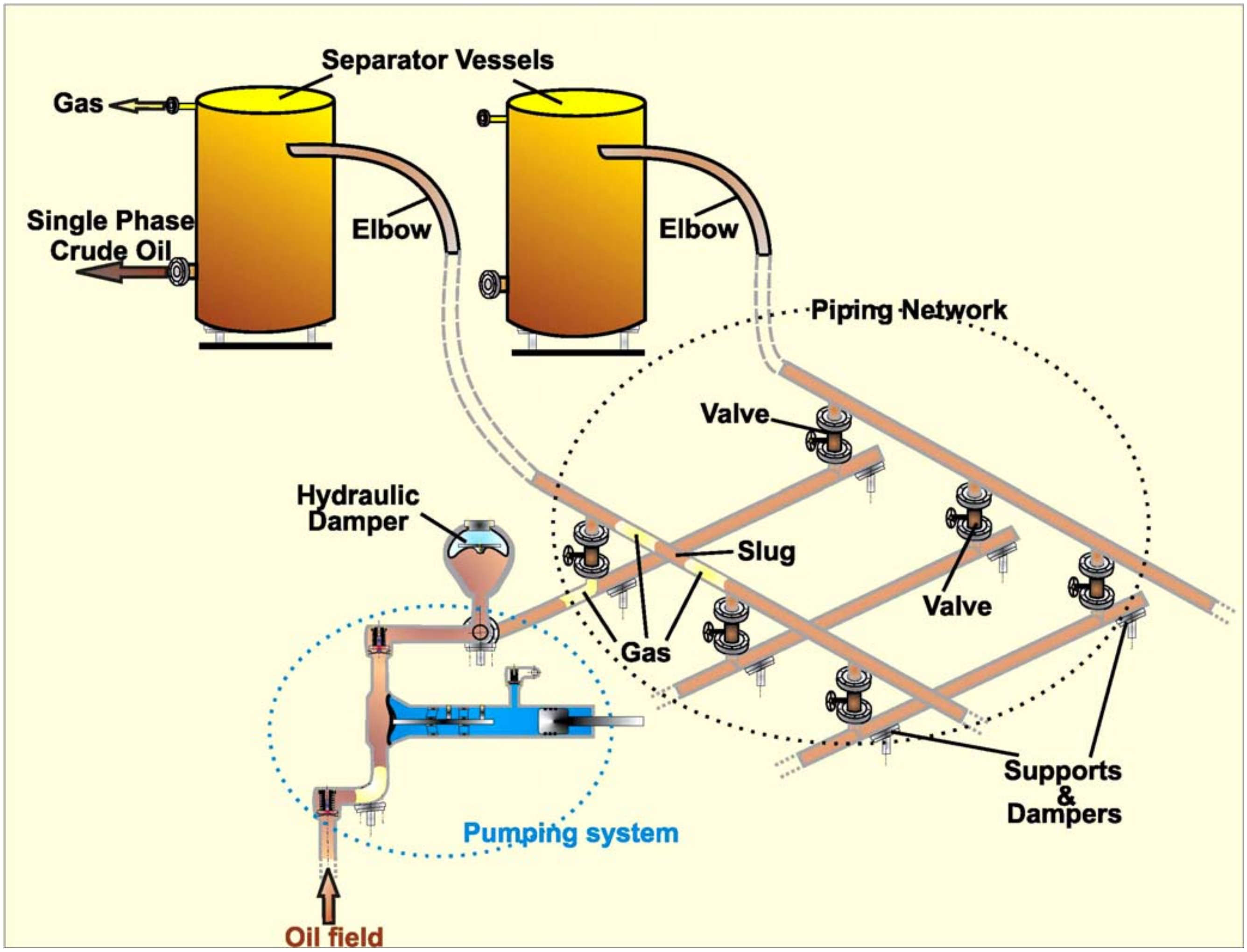


Fig.1 A pipeline network serving a three phase separator of crude oil including slugs

2. NUMERICAL INVESTIGATIONS CARRIED OUT IN THE PAST

Tocarciuc[1,2] has carried out numerical investigation of a water compact slug flow through a pipe elbow varying pipe angle, inlet gas flow velocity and pipe diameter. The results were quite promising. Analytical form has been determined for forces arising in the elbow area in the elbow plane:

$$F_x(D,\upsilon,\alpha,t)=\Theta(D)\cdot\Im_x^{40}(\upsilon,t)\cdot\Psi_x(\alpha) \tag{1}$$

$$F_y(D,\upsilon,\alpha,t)=\Theta(D)\cdot\Im_y^{40}(\upsilon,t)\cdot\Psi_y(\alpha) \tag{2}$$

where, $\Im_x^{40}(\upsilon,t)$ and $\Im_y^{40}(\upsilon,t)$ represent the analytical functions for a 40mm diameter 90-degree pipe elbow, $\Theta(\Phi)$ is a pipe diameter function and $\Psi_x(\alpha)$ and $\Psi_y(\alpha)$ are functions of elbow angle.

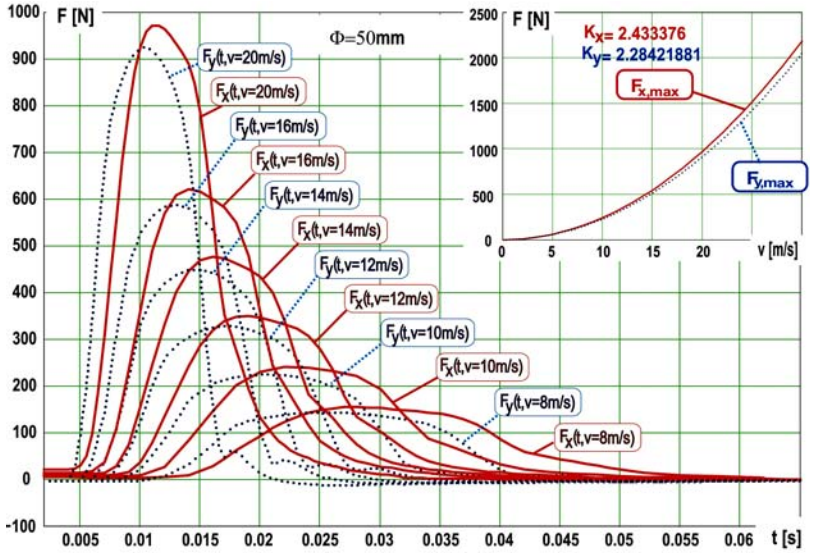


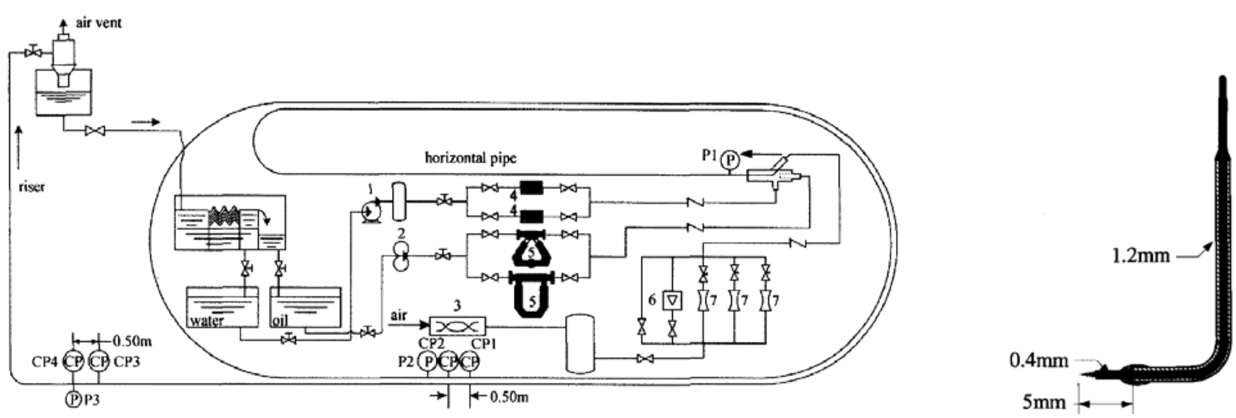
Fig.2 Time history of the impulsive force components F_x and F_y, corresponding to 200 mm long isolated water slug flow through Φ50 pipe elbow [1]

From Figure 2 one can see that the forces arising in the elbow area have an impulsive shape, from this we can deduce that vibration level could increase in the case of a slug flow through a pipeline.

3. EXPERIMENTAL INVESTIGATIONS CARRIED OUT IN THE PAST TO INVESTIGATE SLUG FLOW THROUGH PIPELINES

Slug flow may appear in a power plant piping system, as this phenomenon is described in some studies carried out by Fenton [3], Bozkus [4], Yang and Wiggert [5], Bozkus, Baran and Ger [6].

Wang, Guo and Zhang [7] propose in their work an experimental setup to research the development of liquid slug length in gas-liquid slug flow along horizontal pipeline, shown in Figure 3.a. In this installation a centrifugal pump is used to recirculate the fluid.



a) ***b)***

Figure 3. a) Experimental setup to investigate gas-liquid slug length in a gas liquid slug flow along a horizontal pipeline; b) Electric impedance sensor

The particularity of this type of installation is that the cost is very high, due to the long hydraulic run made of stainless steel pipe. To determine which phase passes the phase sensor, an nail sensor is used as can be see in Figure 3.b. This sensor determines when a phase change is starting, due to electrical impedance measured. This sensor first is calibrated with one phase flow.

Another research carried out by Al-Safran, Sarica, Zhang and Brill [8] to investigate the slug flow characteristics in the valley of a hilly-terrain pipeline is using an experimental setup presented in Figure 4. The piping system is made of acrylic pipes with the inner diameter of 50.8[mm]. To determine the presence of the slugs eleven capacitive sensors are used.

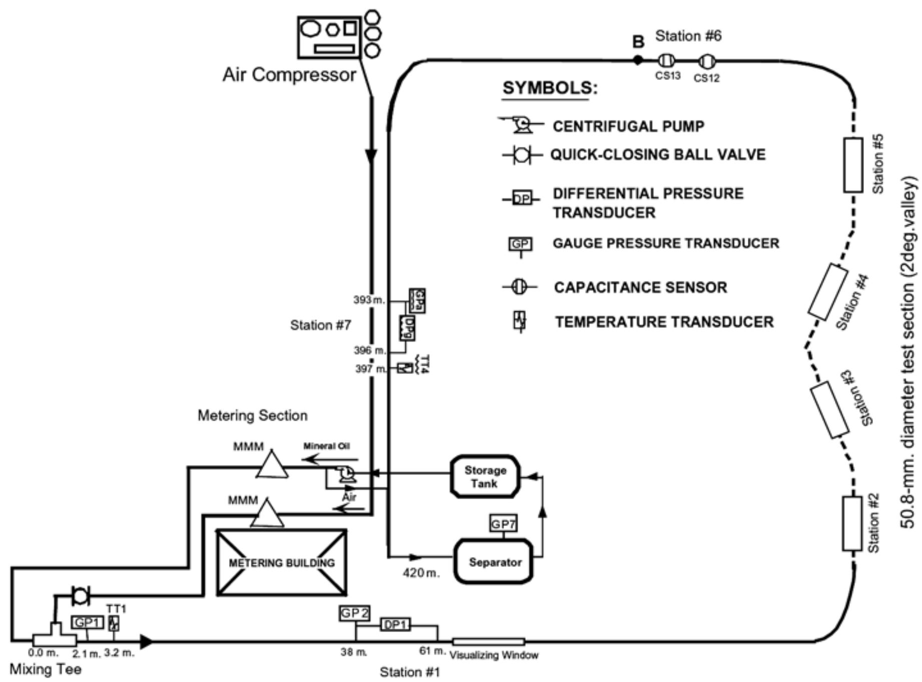


Figure 4. Experimental setup to investigate flow characteristic in a hilly-terrain pipeline

Bozkus, Baran and Ger [6] propose a method to investigate the flow of an water slug flow through a pipe elbow. This interest has the roots in the problem that occurs often in the piping system of a power plant. After a maintenance period, when the installation is turned on, the water collected in the lower sectors hits elbows or partially opened valves, causing vibration of the piping structure. They propose an installation consisting in a 90-degree pipe elbow that is made of transparent PVC. In order to avoid the water slug to dissipate before it reaches the elbow area, the inlet branch of the elbow has a small inclination angle. The outlet branch of the elbow shows up. At the end of the outlet branch a ball valve is positioned, driven by a trigger. After the ball valve, the two-phase fluid flows in a tank. To create the pressure at the inlet branch of the elbow, a pressure vessel is used. This vessel is decoupled from the compressor during tests in order to avoid any interference or negative influence to the measuring system. The measuring system consists in a pressure transducer, placed at the outlet branch of the system, but before the ball valve. The data acquisition system consists in a data acquisition card, computer that controls the opening electromagnetic ball valve and cables. The elbow is fixed with support on the concrete floor of the laboratory. With a high speed camera the flow is recorded for a further analysis.

4. EXPERIMENTAL SETUP TO INVESTIGATE VIBRATION INDUCED BY CRUDE OIL SLUG FLOW THROUGH A PIPELINE NETWORK

The proposed experimental setup is presented in Figure 5 and consists of (1) collector tank, (2) a electromechanical ball valve controlled by (10) computer. The oil slug is propelled by air from (8) pressure vessel through the pipeline. The pressure vessel is detached from (9) 8 bar compressor during the experiments to avoid interference with structure. To repeat the experiment, through orifice (7) it is inserted crude oil into the pipe until the space between the orifice and wax paper introduce in-between 2 flanges (5) is filled. The forces in the second support are measured using two pairs of strain gauges for forces in x and y directions, mounted in Wheatstone bridge with the amplifier (11). To determine the presence of the slug at the elbow area, a two-wire sensor (4). This sensor has the two wires made of stainless steel, mounted at distance each of other of 2[mm], in the diagonal-vertical section of the pipe. These two wires are fixed by a cooper-alloy nut on a pre-stressed stainless steel ring. This ring is than mounted on the inlet branch of the pipe elbow. The signal from these strain gauges is recorded by a A/D system installed on computer (10).

This system can be used for different pipe configurations as double spatial elbows or triple ones, as far as for different components of the hydraulic run as elbows, bifurcations, T-junctions, and others.

Strain gauges can be mounted in full Wheatstone bridge to measure the bending moment along z axis.

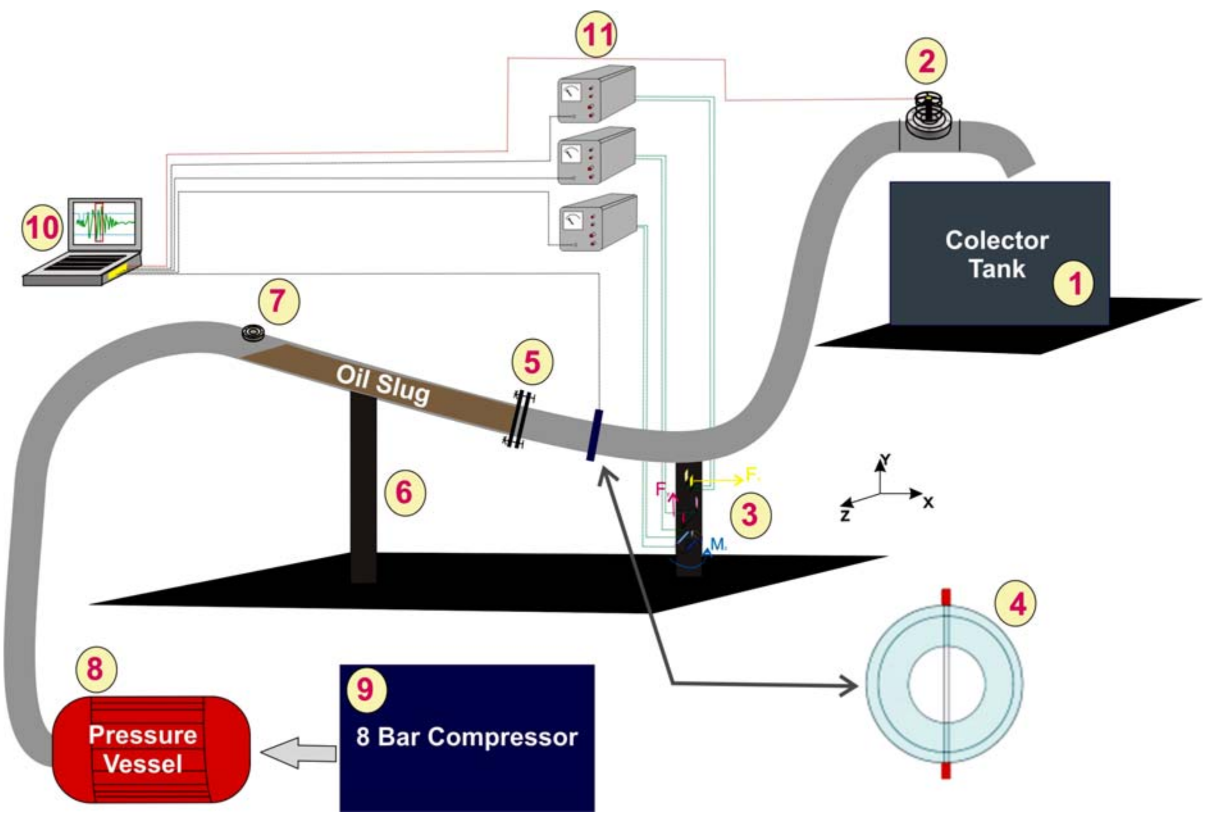


Figure 5. Experimental setup to investigate vibrations induced by crude oil slug flow through pipeline network

5. CONCLUSIONS

A review of recent research has been done, pointing out some problems that could occur in multi-phase fluid transportation system. Because of the complexity it is not easy to fully understand the phenomenon. However, some authors made significant research in this area.

The author proposes a method to investigate vibrations induced by crude oil slug flow through a pipeline network, method that is as simple as possible, and also simple to apply. The cost is lower that big setup for which stainless steel pipes are used. Because it is not at industrial scale, it can be built in a area of 4m x 4m.

The experimental setup has the advantage that the slug will note dissipate after a certain distance, because the inclination of the inlet branch of elbow does not allow this as demonstrated Z. Bozkus, O. U. Baran, M. Ger [5] in their work.

Further investigations should be made to determine how the viscosity of oil influences the flow, if it is reasonable to built a by-pass between the inlet branch of the elbow and the outlet branch of it to transfer pressurized gas from the back of the oil slug towards after it, in this way the propelling pressure being decreased.

ACKNOWLEDGEMENT

The author gratefully acknowledges the financial support of The National University Research Council of Romania to carry out this research. Grant Td no.2739/2006

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