Pressure Drop in Cracked Pipelines with No Leakage

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ABSTRACT

The current research work is carried out to investigate the effect of cracks on the flow characteristics of crude oil in the pipelines. The cracked pipes considered in the study were none fractured and with no leaking. Very little studies are exist in investigating the cracked pipelines, whilst the effects of fractures with leaking are widely investigated. The experiments were conducted in a horizontal pipe with a diameter of 24 mm and 2m long to measure the velocity and pressure. Cracks were made in the pipe with different sizes so different pipes were used, the pressure and velocity then measured at each run. It is found that the head loss in the area around the crack (named crack zone) was bigger than that in the up and down stream zones. Theoretically, the experimental work was simulated using ANSYS to solve the equations of motion and better analyze the flow behavior in the pipe. The pressure obtained from the solution of the governing equations were compared with the experimental measured pressure. The results reviled a direct relation between the crack size and the loss of pressure, the bigger pressure drop occur in case of bigger size of the crack.

KEYWORDS

Simulation, pipeline, head loss, crude oil.

INTRODUCTION

Pipeline systems are the utmost economic and innocuous approach of conveyance for oil, gases and other liquid products. As facilities of long-distance transference, pipelines need to satisfy high demands of protection, consistency and productivity. Everything from water to crude oil even solid capsule is being transported through millions of miles of pipelines all over the world. Transport and distribution network is very elaborate and continuously growing. This network is prone to many risks [1]. The risks are either intentional (like vandalism) or unintentional (like device/material failure and corrosion) damages [2]. However, pipelines are among safest means for transportation. It is important that dependable leak detection systems be used to promptly identify when a leak has occurred so that appropriate response actions are initiated quickly [3]. Leak detection technologies have been playing an important role in protecting the safety of pipeline transportation [4]. The leaking detection could be by hydrostatic testing, infrared, and laser technology. In this research, it is intended to detect the causes of fracture right from beginning before the problems raise. It is known that most of the fractures start from small crack then enlarge till damage the pipe. The investigations on cracks in pipelines are limited. Researchers focus on the fractured pipe where leaking occur. Crack in the pipe have a great impact on hydraulic efficiency of pipe lines and results in minimizing the pressure head and discharge in the pipe systems [5]. SQUIRT program was used to model the nature of fluid dynamics through cracked pipes when leaking occur [6]. As the crack is widened further, or the driving pressure is increased, the inertial forces begin to dominate the losses and viscous terms [7]. More interested investigations have been conducted regarding the effects of the cracking on the pipe line efficiency. [8] observed that the pressure profiles are independent of oil viscosity, although the formation of core flow reduces the pressure drop for viscous oils. [9] studied the correlation between the head loss of a fluid in cross fissures and the width as well as roughness of the fissures. Related to the models for the estimation of load losses in pipes, other researchers developed a theoretical experimental equation take in consideration the flowed and dense phases [10].

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This paper aims at finding the effects of crack on flow of crude oil in pipelines and to find its effects on pressure drop. This research paper provides a numerical analysis for the purpose of determining the impacts of cracks on the rate of oil flow and it is pressure drop in the pipe line system. To achieve this paper, diversified methods have been applied as a feasibility studies.

MATERIALS AND METHODS

The methodologies for achieving the main objectives of this paper has based on experimental setup and theoretical analysis. A 2m long steel pipe was used to feasibility studies in the laboratory for obtaining the results. The pipe was tested in both cases included cracked and compacted to identify the impacts of cracks on the flow patterns and discharge of crude oil theoretically and practically. Additionally, ANSYS program, CFD package applied in theoretical analysis. The details of both experimental method and theoretical analysis are illustrated as follows.

EXPERIMENTAL SETUP

The methodologies for formulating the research has based on the primary data, in which two tanks (Tank 1 and Tank 2) have been prepared for achieving the main objectives of the research. The pressure head in the tank 1 was greater than the head in the tank 2. Furthermore, the carbon steel pipe which was appropriate for transporting crude oil has been used in conducting the experiment. The inside diameter of the pipe was 20mm and the outside diameter was 25mm. Followed by the tank 1, there has been a valve to control the amount of discharge in the pipe. After that a pump was established for the purpose of increasing pressure in the carbon steel pipe. Moreover, a flow-meter was set up to read the discharge of oil in the pipe. As it has been shown in the Figure 1, two more valves have been connected beyond gauge 1 and gauge 3. As it has also been displayed in the system, three-gauge pressure were established linearly to calibrate the pressure head in three zones including, upstream, cracked zone and downstream. There have been different types of cracks in the last 60 cm of the pipe. The cracks were in different sizes and shapes in which started from 1cm to approximately 50cm.

THEORETICAL ANALYSIS

In this paper it is considered that the flow of an incompressible viscous fluid (crude oil) in a full pipe length. It studies how to express pressure losses caused by cracks in the pipe. What is exactly causing the drop of pressure in the present of cracks is the change in the cross-sectional area of the pipe. In addition to the frictional loss of the pipe and losses due to fittings.
Properties and Dimensions

The system for the study is defined as an oil flow through a pipeline with 2m length and 0.25m diameter and the pipe is used is carbon steel. The completely horizontal pipe is located in the environment, at temperature of 17ºC. In this initial part of the study, the fluid flow considered along the pipe is monophasic liquid crude oil with constant properties such as density of 841kg/m³ and viscosity of 0.003704kg/(m.s). Those hypothetical dimensions are deliberated for simulation determinations and the supposition was made so as to do a rudimentary investigation of the circumstance and understanding the physical spectacle at initial. The flow regime is considered turbulent since the velocity magnitude in the inlet zone is specified to be 0.2m/s [1]. The physical properties of the oil have been experimentally measured at the laboratory the values (841kg/m³, 74100J/kg, 1.96 at 20ºC and 0.003704kg/(m.s) for density, enthalpy, specific heat and viscosity respectively and they are correspondingly illustrated in Table 1. The velocity was 0.2m/s at 290k, the section area is 0.000314m² and the pressure is 16500.42Pa.

**Table 1. Crude oil properties.**

<table>
<thead>
<tr>
<th>Crude properties</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m³)</td>
<td>841</td>
</tr>
<tr>
<td>Viscosity (kg/m.s)</td>
<td>0.003704</td>
</tr>
<tr>
<td>A (m²)</td>
<td>0.000314</td>
</tr>
<tr>
<td>Pressure (Pa)</td>
<td>16500.42</td>
</tr>
<tr>
<td>Enthalpy (J/kg)</td>
<td>74100</td>
</tr>
<tr>
<td>Temperature (k)</td>
<td>290</td>
</tr>
</tbody>
</table>

In fluid dynamics, fluids are in motion. Generally, they are moved from place to place by means of mechanical devices such as pumps or blowers, by gravity head, or by pressure, and flow through systems of piping and/or process equipment. The first step in the solution of flow problems is generally to apply the principles of the conservation of mass (equation 1) to the whole system or any part of the system. Where the input is equal to the fluid output in case of no losses. The governing equations include also the momentum equation (2), state equation (3) and viscous shear stress equation (4).

\[
\frac{dρu}{dx} = 0 \quad (1)
\]

\[
\frac{1}{ρ} \frac{∂p}{∂x} + u \frac{∂^2 u}{∂x^2} = 0 \quad (2)
\]

\[
ρ = f(T) \quad (3)
\]

\[
τ = -\frac{1}{2} \frac{dp}{dx} r \quad (4)
\]

The equations have been simplified using the following assumptions; the fluid is Newtonian and incompressible, steady state and there are no chemical reactions.

Computational Analysis

The software is used to solve all the governing equations in fluid flow. The solutions of the four governing equations yield characteristics of the water flow such as: velocity u in x direction along the pipe and pressure P. The software is able to calculate the pressure by solving the momentum conservation equation [11]. After setting up the programmer all the physical properties of the crude oil have been entered to the software. The physical properties of the crude oil were including density, enthalpy, specific heat and viscosity were empirically measured at the laboratory and they are illustrated in Table 1. ANSYS Fluent software has been utilized to generate the mesh grid and drawing the pipe geometry, Figure 2 shows the pipe with crack. After designing the model the inner parts of the pipe have been filled up with fluid as demonstrated in the Figure 3.
Next, Boolean icon in the program was applied so that the inner portion of the crack will be filled up with the same fluid.

![Figure 2. Pipe with crack](image)

![Figure 3. Cracked pipe cross section filled with crude oil (Boolean).](image)

It is illustrated that the size of the mesh was fine relevant center and high smoothing, the minimum size of grids is 29202m, the maximum grid face size was equal to 292.02m and the maximum grade size is 584.03m, as shown in Figure 4. Pipes with different length and crack sizes were investigated as well as crackles pipe.

![Figure 4. Mesh of the cracked pipe.](image)
Boundary Conditions

The present simulation is carried out to analyze the dimensions and finding out the consequences of the cracks on pressure drop of the crude oil in the modelling pipe. It is assumed that the flow is steady state, the oil is Newtonian and incompressible. The velocity was 0.2 m/s at 290 k, the section area is 0.000314 m² and the pressure is 16500.4 Pa. Continuity and momentum are in one direction along the pipe length, no lateral velocity. Nine cases were studied with similar boundary conditions as shown in Table 2 and different cracks.

<table>
<thead>
<tr>
<th>Trials</th>
<th>Crack width (cm)</th>
<th>Crack length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>No crack</td>
<td>No crack</td>
</tr>
<tr>
<td>Test 2</td>
<td>0.05</td>
<td>1</td>
</tr>
<tr>
<td>Test 3</td>
<td>0.05</td>
<td>5</td>
</tr>
<tr>
<td>Test 4</td>
<td>0.05</td>
<td>12.5</td>
</tr>
<tr>
<td>Test 5</td>
<td>0.05</td>
<td>17.5</td>
</tr>
<tr>
<td>Test 6</td>
<td>0.05</td>
<td>30</td>
</tr>
<tr>
<td>Test 7</td>
<td>0.05</td>
<td>35</td>
</tr>
<tr>
<td>Test 8</td>
<td>0.05</td>
<td>40</td>
</tr>
<tr>
<td>Test 9</td>
<td>0.05</td>
<td>47.5</td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSION

It has been observed from the results provided by the Figure 5 below that there are three gauges have been used in practical. The gauges are classified as upstream gauge 1, cracked zone gauge 2 and downstream gauge 3. Each gauge has different features with respect to the pressure and size of the crack. From these results it can be seen that the pressure in the upstream has a maximum value as compared to the downstream which has a minimum value while the figure for the cracked zone is fluctuating at moderate. Simultaneously, the presented results are confirming that from the upstream gauge 1 less pressure is required for pipes with no cracks, but the pressure is increasing with having cracks. While the pressure value from second and third gauge there has been a disproportional relationship between the increased crack and pressure value. In other words, the greater cracks in the pipe, the smaller value of pressure is obtained.

Figure 6 represents the relationship between the pressure drop and cracks lengths in. The results presented that the pressure drop in the non-cracked pipes are less than those pipes containing cracks. This interpretation is true in terms of cracked zone and downstream. Whereas, until the crack has increased in both zones the pressure drop is raising according to the obtained results from Figure 6. The pressure drop in the downstream is lesser than the cracked zone which is the objective of the current research project. Furthermore, there is no pressure drop in the upstream because the gauge is setup at the beginning of the pipe.
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In Figure 7 the data is the same as the Figure 6, therefore the pressure drop is happening only in the downstream and cracked zone as shown below. The pressure drop is increasing slightly in both zones as the size of crack expands. As illustrated below, low pressure drop from gauge 2 and 3 were recorded at the beginning of the crack length however there has been a dramatic change while the flow has started.

The results obtained from Figure 8 are completely different with the previous outcomes. It has made a comparison between the experimental and the theoretical results dimensionless at the cracked zone. It has been revealed that the results obtained by both investigations are equal in increasing the pressure drop. The pressure drop is smaller in the pipe with no-crack in comparison with the other pipes. However, the pressure drop in CFD results is less than that in the practical experimentation due to having minor losses in the built up rig such as; valves and fittings.

The results attained in Figure 9 are similar to the Figure 8 but it represents the downstream measured and theoretical data. Similarly, the greater value of cracks is resulting in the higher value of pressure loss. The
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The magnitude of pressure drop by gauge 3 is increased erratically from the small size of cracks then it has small fluctuations and finally reaches the peak value at the maximum size of crack length which is equal to 0.475m in the downstream section of the pipe. It has been observed that the obtained data are approaching from each other and they had a close relationship with a small deviation due to pressure loss produced by the joints and connections in the pipe.

![Figure 9. Comparison of theoretical with practical differential pressure (downstream)](image)

CONCLUSION

The important of this research article is to show the probability of pressure drop in cracked pipelines. The pipelines divided to three parts; part of the pipe where the crack exist called crack zone. The other two parts are up and downstream zone. The results are showing obvious pressure drop in the pipes with the cracks. It is concluded that the pressure drop in the crack zone is higher. Furthermore, it can be said that the pipes with cracks are not fully fit to use for the oil transportations. If losses in pressure observe in the pipelines, rather than the losses due to friction and fittings, it might be due to cracks. The results of this paper is valid only on the pipes with cracks only before leaking occur. It is recommended to continue work on the current research project by investigating the accumulation of the crude in the area around the crack. The accumulation with time will block the pipe at the crack zone which usually lead to fracture and damage.

REFERENCES


