Analysis of Flow Patterns in 55 Kilometers of Gas Transmission Pipelines due to Changes in Gas Supply Flow Rate

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Abstract. Pressure drop will cause a decrease in the temperature of natural gas in the pipe. This causes a two-phase flow to form along the pipe. The prediction of the two-phase gas-liquid flow pattern is needed in the oil and gas industry. The changes in gas supply will affect the flow pattern in the pipeline. The flow pattern in the pipe will be analyzed by Unisim software. The flow pattern result shows that there are instabilities of flow patterns along the pipe due to changing topographic conditions. When the pipe elevation drops to zero, as in kilometers 40-55, the flow pattern formed is constantly stratified flow. The results of stratified flow patterns indicate that the flow patterns do not cause sudden changes in liquid flow rate on the Receiving Facility (RF) equipment.

1. Introduction

Transmission pipe is a pipe to transport natural gas from natural gas supply or natural gas fields to transmission sections, distribution network areas for certain commercial areas, and/or natural gas consumers [1]. Natural gas that flows in the pipe can form condensate due to the pressure drop along the pipe. Pressure drop will cause a decrease in the temperature of natural gas in the pipe. This causes a two-phase flow to form along the pipe. The Receiving Facility Unit at the end of the transmission pipe which consists of a separator device is needed to separate the condensate before it is used by consumers.

Prediction of flow pattern in a pipeline is very important to determine several variables such as pressure drop, hold-up, dan critical heat flux [2]. In all flow orientations (horizontal, vertical upward, and downward), the frictional pressure gradient will increase with increasing superficial gas velocity [3]. Moreover, the pressure drop will also increase by the momentum change due to sudden enlargement and contraction [4]. Two-phase gas-liquid flow map in a horizontal pipe was first developed by Baker in 1954 [2]. Baker developed that the two-phase gas-liquid flow pattern in a horizontal pipe depends on several parameters such as gas mass velocity, liquid mass velocity, gas and liquid density, liquid viscosity, and surface tension [5]. Furthermore, the Baker model flow pattern continues to develop into several models. One of the flow pattern models developed from the Baker model is the Beggs and Brill model. The flow pattern of this model is based on the relation between the Froude Number of the gas phase and the volume fraction of the liquid phase [5].

The shape/pattern of two-phase flow depends on several parameters such as liquid and gas-phase density, liquid and gas viscosity, liquid and gas flow rate, and surface tension. Anderson and Russell [6] explained that the types of flow patterns that formed in horizontal flow are bubble flow, plug flow,
stratified flow, wave flow, slug flow, annular flow, and mist or spray flow. Based on these types, stratified flow-wave flow-annular flow are classified as segregated flow, plug flow-slug flow are classified as intermittent flow, and bubble flow-mist flow are classified as distributive flow.

The prediction of the two-phase gas-liquid flow pattern is needed in the oil and gas industry. Changes in flow patterns occur due to changes in gas velocity. There are a wide range of methods with different accuracy, from simple to complex. The used method depends on the conditions of how it will be used [7]. Generally, the two-phase flow pattern is determined using the calculation method [8]. However, the two-phase flow pattern in this paper will be determined using software simulation. The shape of the flow pattern obtained from software simulation will also determine the location of the Receiving Facility (RF) placement. This study will discuss the effect of the two-phase gas-liquid flow pattern that occurs in a gas transmission pipe with a length of 55 kilometers on changes in gas flow rate.

2. Methods
Based on discussion above, there are several variables that are needed flow pattern along the pipeline from simulations. Pressure, temperature, flow rate, gas composition, and elevation pipe are input variables for software. Flow patterns along the pipe are obtained by using Unisim software. The simulation runs in steady-state with Peng Robinson fluid properties. The flow pattern model used is the Beggs and Brill Model [5]. The simulated pipelines are 55 kilometers along with the Line Break Control Valve every 16 kilometers and two-phase separator equipment at the Receiving Facility. The specification of the pipeline is 16” carbon steel pipeline. The gas supply flow rates tested at Unisim are 15, 40, and 80 MMSCFD. Gas entering the pipeline for all variations of the gas supply flow rate is at a pressure of 59.12 bar and a temperature of 43.3°C. Numbering on the types of flow patterns formed along the pipe is carried out to facilitate analysis. The numbering used is stratified flow as 1, wave flow as 2, annular flow as 3, plug flow as 4, slug flow as 5, bubble flow as 6, and mist or spray flow as 7.

Flow pattern in the pipeline can be seen in Unisim with several steps. The first is input several data such as gas component and fluid package. The fluid package that will be used in this study is Peng-Robinson. The next step is making the process flow diagram, including the gas transmission pipeline with Line Break Control valve in every 16 kilometers and two-phase separator equipment. This system runs in steady-state condition. After the process flow diagram is made, operation data such as pressure, temperature, gas composition, flow rate, pipe elevation, type of pipe, pipe length, separator size, and several parameters in the valve are needed to run the system. The flow pattern data can be seen in “performance” along the pipeline. The pipe elevation is shown in Figure 1 and the gas composition is shown in Table 1.

![Pipe elevation](image-url)
### Table 1. Gas composition

| Composition | Composition (% mole) |
|-------------|----------------------|
| CO2         | 0.0507               |
| Nitrogen    | 0.0008               |
| Metana      | 0.8693               |
| Etana       | 0.0340               |
| Propana     | 0.0239               |
| i-Butana    | 0.0052               |
| n-Butana    | 0.0062               |
| i-Pentana   | 0.0024               |
| n-Pentana   | 0.0015               |
| Heksana     | 0.0040               |
| H2O         | 0.0020               |

### 3. Simulations and discussion

The gas supply flow rates simulated at Unisim are 15, 40, and 80 MMSCFD. Every flow rate will be analyzed how the gas supply flow rate will be affected on flow pattern result.

#### 3.1. Flow pattern when flow rate is 15 and 40 MMSCFD

The flow pattern formed when the gas supply flow rate 40 MMSCFD does not differ from the flow pattern at the flow rate of 15 MMSCFD. The flow pattern when flow rates 40 and 15 MMSCFD can be seen in Figure 2. At gas supply flow rates 40 and 15 MMSCFD, there are only two types of flow types namely slug flow and stratified flow. Most types of slug flow are formed in kilometers 1-4.5. The most stratified flow type is at kilometers 40-55. The slug flow pattern is formed when the elevation of the pipe tends to rise from low elevation to high elevation. In this situation, condensate will accumulate at low elevations to form slug flow. When the elevation of the pipe decreases from high to low, the formed flow pattern tends to be a type of segregated flow (annular flow and stratified flow) because there is no condensate accumulation at this elevation.
3.2. Flow pattern when flow rate is 80 MMSCFD

Figure 3 shows the flow pattern that forms along the pipe when the gas supply flow rate is 80 MMSCFD. The graph shows that the most slug flow patterns are formed at kilometers 1-3.5, while the rest are scattered at several points. At kilometers 4-4.5, an annular flow pattern is formed. The majority of the types of flow that form along the pipe are stratified flow with the most number of flow patterns formed at kilometers 40-55. The flow pattern will be constant under stratified conditions at kilometers 40-55 because the elevation at that point decreases then is constant at zero elevation.

![Figure 3. Flow pattern when flow rate is 80 MMSCFD](image)

3.3. Comparison of flow patterns when flow rates are 15, 40, and 80 MMSCFD

Comparison of flow patterns at each flow rate variation is done to determine the effect of changes in flow rate on the formed flow pattern. When the three types of flow patterns are compared, as shown in Figure 4, the flow patterns that are formed are not too different. The flow patterns differ only in kilometers 4-4.5, 9-9.5, 35-35.5, and 38-38.5. Another difference that can be seen is the flow pattern formed at the 80 MMSCFD gas supply flow rate, there are three types, namely stratified flow, annular flow, and slug flow, whereas at flow rates 40 and 15 MMSCFD the type of flow pattern that is formed is only stratified and slug flow.

![Figure 4. Flow pattern when flow rate is 15, 40, and 80 MMSCFD](image)
The annular flow pattern occurs when the superficial velocity of the gas is very high. The pattern of annular flow in the pipe is characterized by the formation of a liquid layer in the pipe wall with a gas flow flowing in the middle of the pipe so that the liquid layer forms an annulus. In the gas flow section, there are trapped liquid granules. In this study, annular flow only occurs at kilometers 4-4.5 with a gas supply flow rate of 80 MMSCFD.

3.4. Relation between flow patterns and superficial velocity of the gas

Table 2 is a comparison of the superficial velocity of gas at flow rates of 80, 40 and 15 MMSCFD obtained from the simulation.

| Pipe Length (km) | 80 MMSCFD | 40 MMSCFD | 15 MMSCFD |
|------------------|-----------|-----------|-----------|
|                  | Gas Superficial Velocity (ft/s) | Gas Superficial Velocity (ft/s) | Gas Superficial Velocity (ft/s) |
| 3.5              | 15.13     | 6.39      | 2.30      |
| 4                | 15.16     | 6.39      | 2.30      |
| 4.5              | 15.19     | 6.39      | 2.30      |
| 8                | 15.34     | 6.36      | 2.27      |
| 9                | 15.38     | 6.35      | 2.26      |
| 9.5              | 15.41     | 6.35      | 2.26      |
| 34.5             | 18.31     | 6.36      | 2.17      |
| 35               | 18.36     | 6.35      | 2.17      |
| 35.5             | 18.40     | 6.35      | 2.17      |
| 37.5             | 18.63     | 6.36      | 2.17      |
| 38               | 18.71     | 6.37      | 2.17      |
| 38.5             | 18.75     | 6.37      | 2.17      |

In Table 2, it can be seen that the greater the gas supply flow rate, the superficial velocity will also be greater. The superficial gas velocity at a flow rate of 80 MMSCFD is higher than the flow rate with variations of 40 and 15 MMSCFD. The high speed of superficial gas will cause the annular flow pattern to occur at a gas supply flow rate of 80 MMSCFD. Besides, the superficial gas velocity at kilometers 3.5-4.5 and 37.5-38.5 at gas supply flow rates 40 and 15 MMSCFD is relatively constant so that there is no change in the type of flow pattern type from the previous kilometer. At kilometers 3.5-4.5, when the gas supply flow rate is 80 MMSCFD, the slug flow is changing into the annular flow. In Figure 3, it can be seen that the annular flow occurs after the slug flow pattern. Slug flow occurs when the gas flow rate in the pipe is high, causing the wave of the liquid layer to rise until it touches the top of the pipe wall and forms a slug. When the gas flow rate is increasing again, an annular flow type will form.

Other different flow patterns are located at kilometers 8-9.5, 34.5-35.5, and 38-38.5. At kilometers 8-9.5 and 34.5-35.5, when the gas supply flow rates are 40 and 15 MMSCFD, the flow pattern changes from previously stratified flow to slug flow when the gas velocity tends to decrease. On the other hand, at the same length, when the flow rate is 80 MMSCFD, the flow pattern is constantly stratified flow. Incompatibility also occurs at kilometers 37.5-38.5. At this length, when the gas supply flow rate is 80 MMSCFD, the flow pattern that previously slug flow changes to stratified flow even though the superficial velocity of the gas at that point rises. If seen from the existing theories, when the superficial velocity of the gas rises, the slug flow pattern will become annular flow. The instability phenomenon of changes in flow patterns that occur can be caused by changing pipe elevations. When the elevation of the pipe drops to zero, such as when the pipe length is 40-55 kilometers, the flow pattern that occurs remains stratified flow.

At each variation of the gas supply flow rate, the flow pattern will be stable at 40-55 kilometers because the topographic condition drops then flat. At that point, the flow pattern is only stratified flow.
(stable two-phase). The results of this flow pattern will be taken into consideration in determining the location of the Receiving Facility where there is two-phase separator equipment at that location. The Receiving Facility placement must be in a stratified flow pattern because the design of the gas station system must be in a stable flow pattern (stratified flow). The pattern of slug flow will be dangerous for the separator because of the liquid flow rate that comes suddenly (unpredictable). The flow pattern change is not affecting the separator equipment size modification.

4. Conclusions
Stratified flow patterns are formed when the elevation of the pipe tends to go down. The instability or anomaly of flow patterns that occur along the pipe is caused by changing topographic conditions so that the elevation of the pipe changes. The results of the flow patterns formed along the pipe in every flow rate changes do not cause sudden changes in liquid mass for the Receiving Facility equipment because the results of the flow patterns at kilometers 40-55 are stratified flow (stable two-phase). It means that the flow rate change makes no change in equipment size modification. It is not recommended to place a Receiving Facility when the pipe elevation changes due to the unstable flow pattern. It is intended that the amount of liquid and gas that enters the separator at the Receiving Facility can be predicted so that the design of the separator equipment can be carried out. The flow pattern of the fluid that enters the Receiving Facility must be in a stratified flow state because, in that flow pattern, the amount of liquid and gas phases that flow in the pipe is constant.

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