Effect of Inlet Pressure on Slug Development in a Multiphase Flow Pipeline

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Abstract

Akakus Oil Operations (AOO) could have a great opportunity to save a lot of money for the IR field development plans by avoiding the construction of the standalone IR Gas and Oil Separation Plant (GOSP) and rather sending and treating the IR production in GOSP A-NC115, where there is an additional capacity available. One of the possible options is to use multiphase pump stations as a booster and the existing 28 km long pipeline of 18" in diameter that is located between the Early Production Facility (EPF) in the IR field and the GOSP A-NC115. However, the multiphase slug flow phenomenon could hinder the utilization of the IR pipeline unworthy, and the aim of our study is to assess and investigate the flow pattern and behavior of the transported mixture (1161 E05 $barrels/day$ at 95 psia) at different inlet pressures of 300, 350, 400, 450, and 500 psia. A deeper look was taken into these parameters, using semi empirical Tulsa Unified Model to calculate the pressure gradient and flow patterns and regimes. The inlet pressure was manipulated to identify the optimum operating conditions for the IR pipeline that would result in barely any flow complications. The main outcomes of the study revealed that at an inlet pressures below 450 psia there is a flow risk associated with the transportation of the IR field multiphase fluid through the existing pipeline. However, at pressures higher than 450 psia no slugs were observed in the calculations and the bulk velocity was substantially lower than the erosion velocity, indicating that the IR pipeline could operate at these circumstances by installing a multiphase pump station. In the study for the design safety margin it is recommend for AOO to use inlet pressure of 500 psia.

Keywords: Slug; multiphase flow; oil transportation.

1. Introduction

Fluids produced from hydrocarbon fields are composed of a mixture of oil, gas and water, often with corrosive components, sometimes laden with solid particles, and are a potential for many flow instabilities. Frequently they are directly exported for long distances, in multiphase conditions, towards processing facilities [1].
Liquid slugs in multiphase pipelines can have disastrous consequences ranging from increased corrosion, production impairment, and compressor damage to flooding of separators and damage to process equipment. The key to avoiding problems with slugging in pipelines is to determine the type and magnitude of the slug now and into the future. Predicting slug characteristics is essential for the optimal, efficient, safe and economical design and operation of multiphase gas-liquid slug flow systems [2].
The problem of slugging once predicted can be solved by installing a multiphase pump to boost the required flow production while maintaining satisfactory pressure levels at pipeline inlet and outlet. The multiphase production system can be optimized by adjusting the various parameters (flow production, pump speed, pipeline equipment pressure)
This paper is regarding the pipes transferring the multiphase production from the IR field to GOSP A NC-115. The pipes are already installed and it would be economically undesirable to replace them with new ones, but there are a few parameters we could control to ensure a safe, efficient flow. We

took a deeper look into those factors and using the ASPEN HYSYS software, we tried to manipulate them to maximize the efficiency of the flow.
The main objective of this study is to assess and evaluate the transport gas, oil, and water from the IR field to the main GOSP at A-NC115 through an 18" pipeline using a multiphase pump while ensuring an efficient and economically desirable flow. To satisfy the main goal, the following objectives were carried out:

- Flow assurance investigation focusing on the slugging phenomena and flow regime distribution during the transportation of the main pipeline using Aspen HYSYS software.
- Specifying the optimum inlet pressure in the pipeline.
- Finding a balance between a pressure that works and its cost to ensure great results at reasonable prices.

2. Overview of IR Field

The existing pipeline linking the Early Production Facility (EPF) in the IR field and the NC-115 GOSP A is 18 inches in diameter with a length of about 28 km. IR field initial plan was to develop the field in two phases; Phase I will see the use of early production facilities, as used on other NC186 fields. Phase II will include permanent facilities with a new production hub and GOSP to be constructed at the IR field and oil will be exported using NC186 infrastructure. However, the operating company has changed their plan and decided to develop the IR field by utilizing the extra treatment capacity available at GOSP A-NC115. The IR Field hydrocarbon stream composition is characterized by minor non-hydrocarbon contents of CO_2 and N_2 (less than 2.0%) with no sulphur content. The fluid is classified as ordinary black oil with API gravity of 43 and C_{7+} content of about 62%. The GOR is typically law (166 scf/stb) and this is recognized with small fractions of C_1 and C_2 (around 11% together)

3. Pipeline Landscape and Characteristics

Al Sharara 18″ pipeline characteristics, linking the IR field with the main GOSP A NC-115, were used in our study to simulate the multiphase flow, including the pipe diameter, pipeline topography, design temperature, design pressure, ... etc. The main pipeline characteristics are highlighted below [4]:

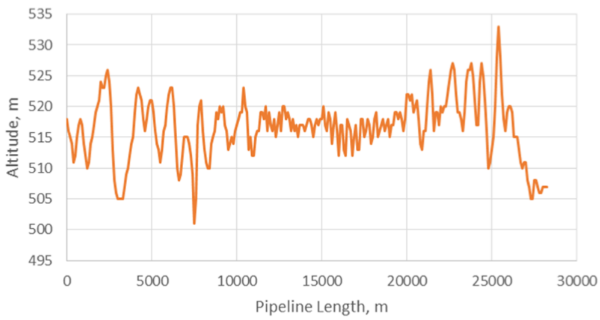

Figure 3.1: Changes in pipe elevation along its length

- Nominal Diameter: 18″
- Wall Thickness: 0.625″
- Design Pressure: 1350 psig
- Design Temperature: 200 F
- Design Code: B31.4
- Pipe material: API-5L X42
- Fitting ANSI Class: 600
- Length: 28260 m
- Pipe Wall Conductivity: 45 W/m-K
- Pipeline is buried. Center line depth: 4.03 ft

It is also very important to identify the pipeline landscape and topography and to be properly reflected in our pipeline simulation study and to take into account how the change in elevations might affect other multiphase flow properties and therefore the slug formation. Figure (3.1) shows the changes in the pipe elevation along its length.

4. IR Multiphase Transport Assessment

The main objective of the study was to ensure a safe efficient transportation of a multiphase crude oil mixture, when a multiphase pump is using an 18 inch pipeline a distance of 28 kilometers. One of the most important aspects that will guarantee a safe efficient flow is to avoid any conditions that might lead to slug development in the pipeline. Since most of the parameters that influence the slug formation are fixed (i.e. flow rate, environmental conditions, pipeline diameter and length, and terrain profile), inlet pressure is the only controllable parameters that was optimized to minimize the slug formation

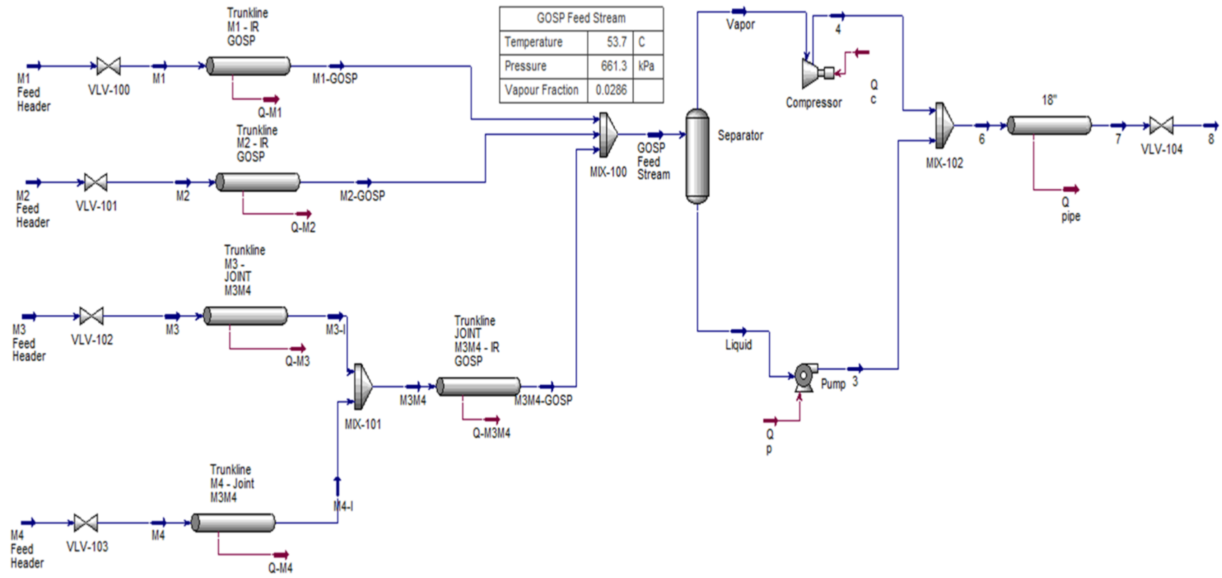

Figure 3.2: Aspen HYSYS simulation of the I/R layout

but at the same time be financially acceptable. Tulsa unified model incorporated in the commercial software Aspen HYSYS software was used to calculate the pressure gradient and flow patterns and regimes. Peng Robinson equation for state was used to model the three phase equilibrium conditions. The layout of R existing facilities was perfectly reflected in the Aspen HYSYS, Figure (3.2), to simulate the multiphase flow of IR fluid to GOSP A NC-115 at different conditions. A number of sensitivity run analyses were carried out to simulate the multiphase flow at different inlet pressures of 300, 350, 400, 450, and 500 psia. Figure (4.1) shows how the pressure fluctuates along the length of the 18″ IR pipeline at different inlet pressures. A decrease in the overall pressure with respect to length was observed in the all four below cases. The sudden increase in the pressure at few points along the pipe is attributed mainly to the increase in the hydrostatic pressure due to change in pipeline elevation and the possibility of a riser existing at that point. At an inlet pressure of 300 psia (2068 kPa) we can see that pressure fluctuates between a maximum of 2100 kPa and a minimum of 1300 kPa. As the inlet pressure is increased to 400 psia (2758 kPa) we can see the fluctuation in the pressure reaches a maximum of 2800 kPa and a minimum of 2100 kPa. As the inlet pressure keeps on increasing for the rest of the figures, the fluctuation in pressure increases, reaching a maximum value of 3500 kPa at an inlet pressure of 500 psia (3447 kPa), at the beginning on the pipeline. The difference between the maximum pressure and the minimum pressure is around 800 kPa in all cases. However, the values increase as the inlet pressures increase.

The temperature profile was predicted using energy balance modeling of the fluid moving in the pipe with a known flow rate. Surrounding environmental conditions such as temperature and heat transfer coefficient were used based on the type of sand. Thermal conductivity of the pipeline was selected based on the material of construction. The change in temperature fluctuations along the IR pipeline are demonstrated in the Figure (4.2). This figure demonstrates how the temperature fluctuates along the pipe length with changing inlet pressures. As with the change in pressure, the values of temperature increase as the inlet pressure increases, reaching a maximum inlet temperature of around 57.82 °C at an inlet pressure of 500 psia and a minimum inlet temperature of around 55.35 °C at an inlet pressure of 300 psi nearing the end of the pipeline. The range of fluctuation between the maximum and the minimum temperature change decreases slightly as the inlet pressure increases. Starting with a fluctuation range of around 1.5 °C at an inlet pressure of 300 psia, and ending with a fluctuation range of around

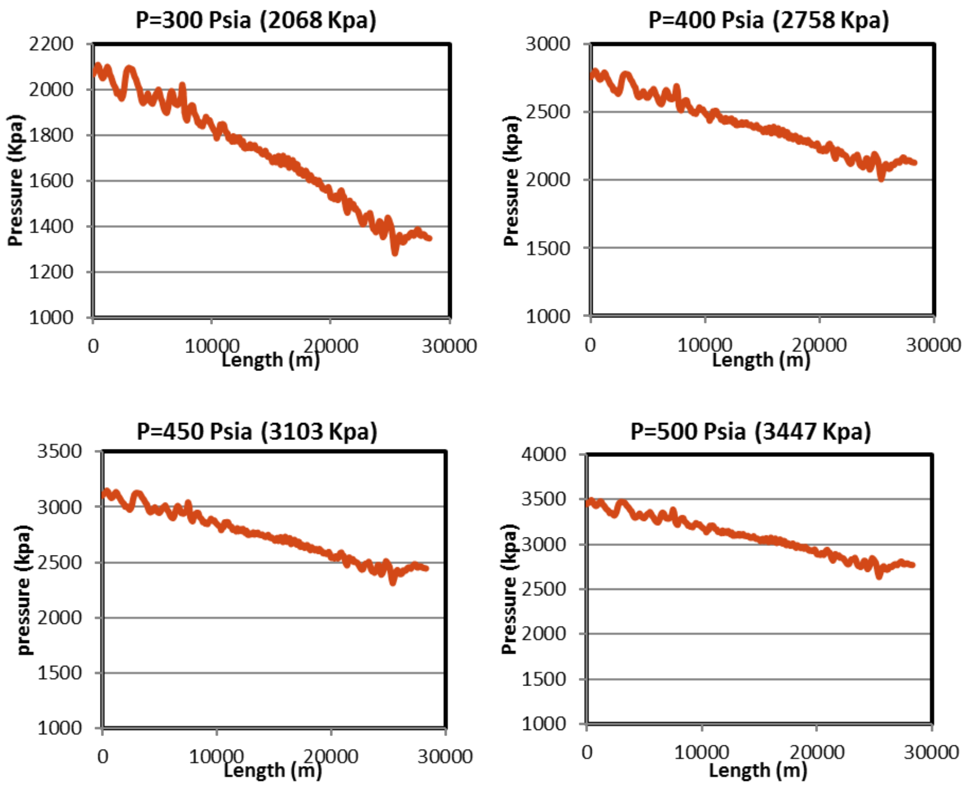

Figure 4.1 Pressure profiles at different inlet pressures

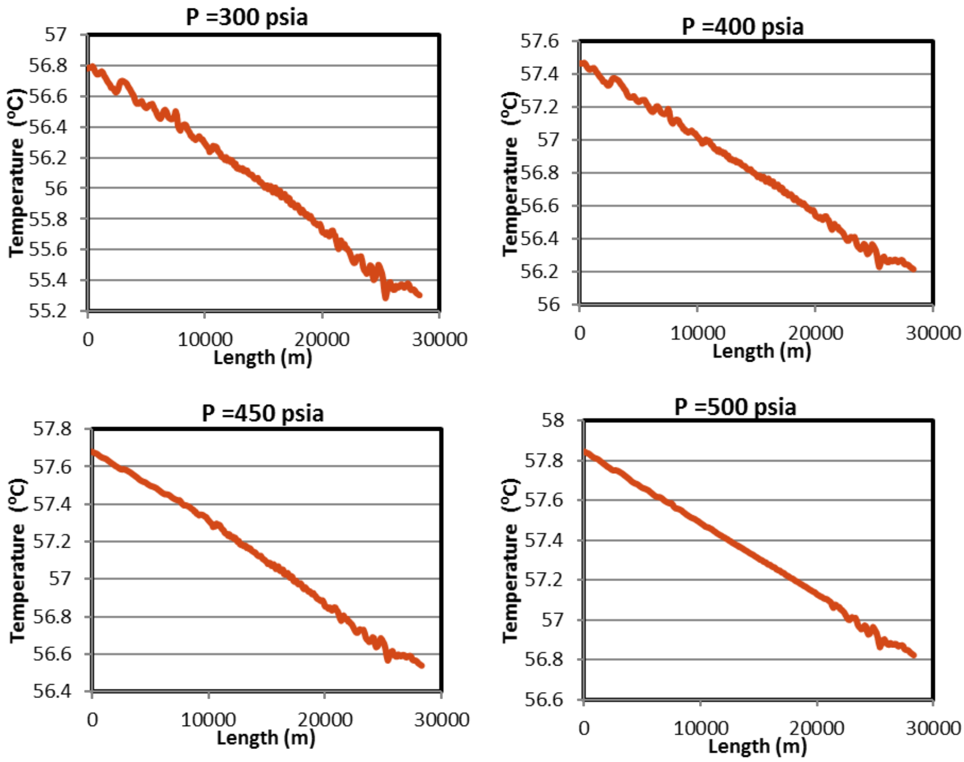

Figure 4.2 Temperature profiles at different inlet pressures

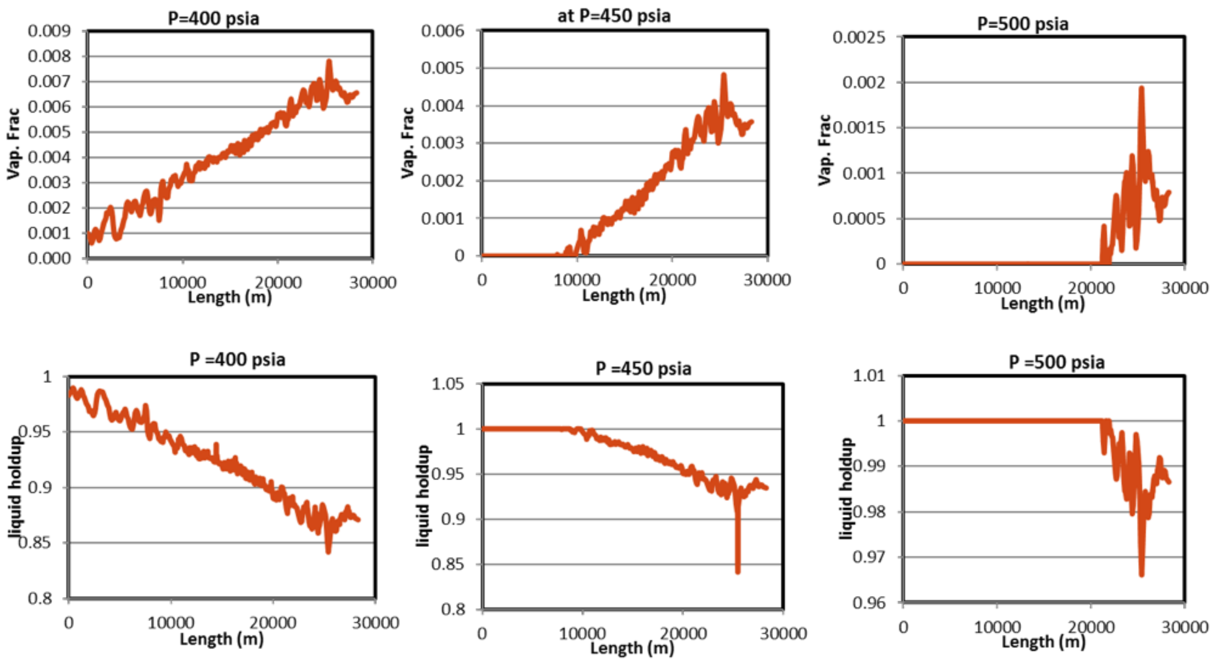

Figure 4.3: Vapor fraction and liquid holdup at different inlet pressures

0.9 °C at an inlet pressure of 500 psia. The fluctuation in temperature along the pipe is due to the pipeline topography and the impact of outside temperature.

Figure (4.3) shows the change in vapor fraction and liquid holdup at inlet pressures of 400, 450 and 500 psia. As the inlet pressure increases, the vapor fraction eventually disappears at the initial distances of the pipeline. In the case of 500 psia inlet pressure, the vapor fraction ultimately reaches a value of 0 and stabilizes for a long distance of more than 20 km before starting buildup. The decrease in the vapor and increase in liquid fractions as the inlet pressure increases is the cause of vapor transferring, at high pressures, into liquid and accordingly will help minimizing the slug formation and improves the flow efficiency. Another important aspect of the multiphase flow is the calculation of vapor and liquid velocities and their changes along the pipeline as a function of the inlet pressure applied on the system. In multiphase systems high fluid velocities are often desirable to decrease the chances of slug flow or particle settling. High velocities, however, will increase the energy with which liquid droplets impact on pipe and vessel walls, which, if they have sufficient force will cause erosion or accelerate corrosion [5]. The change of vapor and liquid velocities profiles at studied inlet pressures of 400, 450 and 500 psia, are completely aligned with the change of vapor fraction and liquid hold-up and have similar trends as the figure above. Figure (4.4) illustrates quantitatively the distribution of different flow regimes expected to occur at different inlet pressures. Pie charts demonstrate the distribution of different flow patterns/regimes expected to occur. At an inlet pressure of 300 psia, the dominating flow is the slug flow. At an inlet pressure of 400 psia, the slug flow distribution reduced to 29%. As the pressure increases, the slug flow percentage decreases, reaching a value of 1% at a pressure of 450 psia. As the inlet pressure is further increases to 500 psia no slug flow can be seen. The bulk velocity is defined as the average or the mean velocity of the flow inside the pipeline, while the erosion velocity is the velocity at which an erosion might start to occur. It is very important the bulk velocity be safely lower than the erosion velocity to avoid any unforeseen erosion complications. Figure (4.5) shows the projected two different velocity profiles at the optimum considered high inlet pressures of 450 and 500 psia. From this figure, it is clear that the bulk velocity is adequately below the erosion velocity confirming that the flow will be in safe side at these inlet pressures.

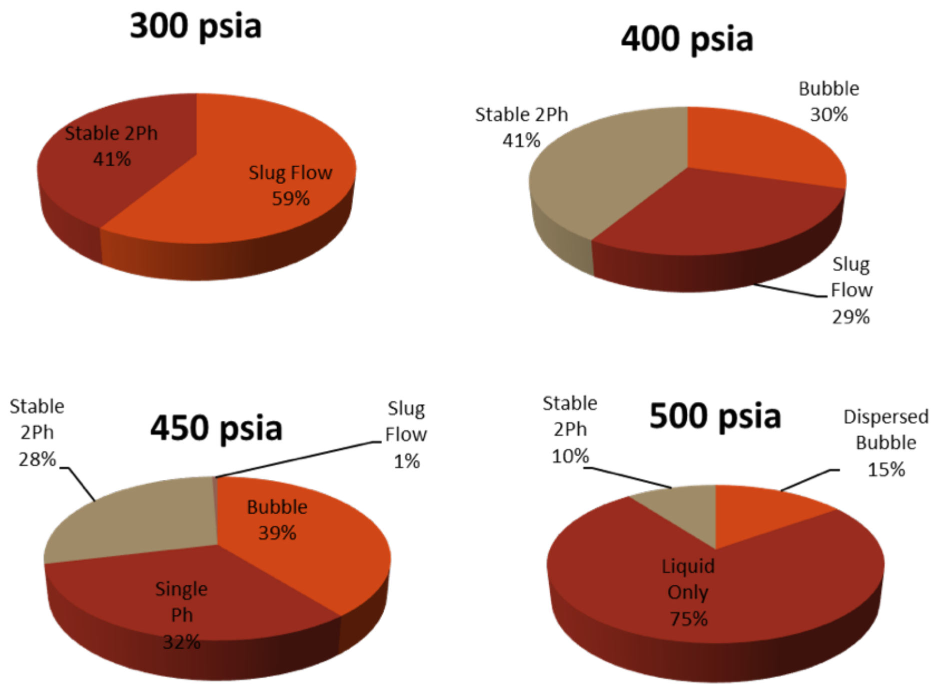

Figure 4.4: Flow regimes an distribution at different inlet pressures

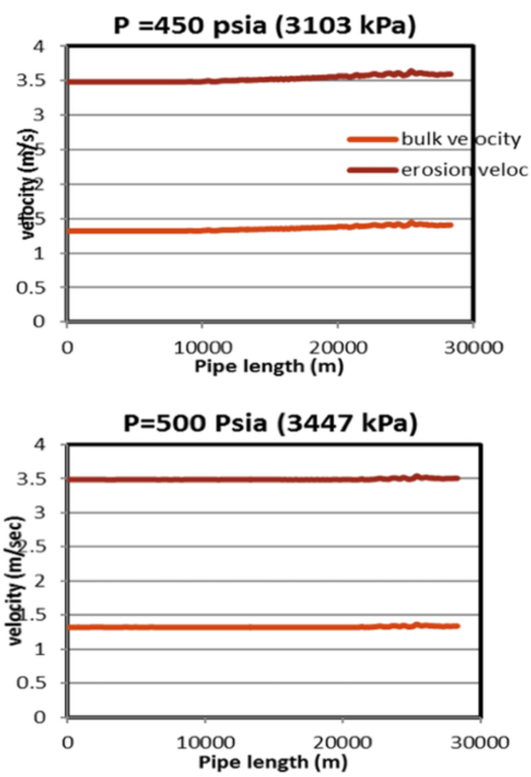

Figure 4.5: Bulk and erosion velocity at high inlet pressure of 450 and 500 psia

5. Conclusions

1. Akakus Oil Operations (AOO) have available capacity at the GOSP A-NC115 which could be utilized to process and treat the IR production.
2. An existing 18" pipeline between IR EPF and GOSP A NC-115 could be utilized to transport the IR production provided no slug problems arise.
3. Our study has indicated that at 500 psia inlet pressure, the IR crude can be safely transported through the existing 18" pipeline. This can be achieved by installing a multiphase pump station.
4. The calculated flow bulk velocity is substantially lower than the erosion velocity at inlet pressures higher than 450 psia.
5. At inlet pressures less than 450 psia, there is a flow risk associated with the formation of slugs and it is not recommended to operate the pipeline at pressures lower than this value.

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