International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 10 Oct. 2022, pp: 1285-1294 www.ijaem.net ISSN: 2395-5252

Parametric Analysis of Subsea Multiphase Pipeline

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Date of Submission: 15-10-2022 Date of Acceptance: 31-10-2022

ABSTRACT:This research paper focused on the parametric analysis of subsea multiphase pipeline. This research shows how the size of a pipe tends to affect the design and what kind of Pipe can be used in the design of a pipeline in the Gulf of Guinea from the Wellhead to the Separator meeting certain design conditions such as the Discharge Temperature, Discharge Pressure, and Erosional Velocity Ratio. Conditions of design to meet up include Discharge Temperature of not less than 63.89°C, Discharge Pressure of not less than 7,860.02KN/m2, and the Erosional Velocity Ratio not greater than one (<1). A Subsea data was gotten from Schlumberger bearing input parameters. Input parameters considered are 202.74mm, 254.46mm and 304.74mm pipe were varied against different flowrates of 0.01472m^3/s, 0.02576m^3/s, and 0.02944m^3/s. A Pipesim Simulator was used for this research where different flowrates were used against each pipe size to determine the Discharge Temperature, Pressure, and Erosional Velocity Ratio under the given conditions. After the analysis, 254.46mm and 304.74mm pipe was considered at a flowrate of 0.02944m^3/s because they met the required design conditions such as a Discharge Temperature of 65.56°C, Discharge Pressure of 7,909KN/m^2, and Erosional Velocity Ratio <1 for the 254.46mm pipeline and Discharge Temperature of 64.61°C, Discharge Pressure of 7,986KN/m^2 and Erosional Velocity Ratio <1 for the 304.74mm pipeline.

KEYWORDS: Flowrate, Pipe size, Pipesim, Discharge Pressure, Discharge Temperature, Erosional Velocity Ratio.

I. INTRODUCTION

The Nigerian Petroleum Industry started in 1956 when Oil was first discovered in Oloibiri in Bayelsa State. This discovery has led to so many explorations in the industry, making Nigeria a major producer in the oil sector at six rankings. Recent studies have shown that onshore oil and gas are depleting as the day goes thereby forcing these multi-national oil giants to move in search of areas rich in oil for mining. This search has led them to the sea where they were able to discover oil at a depth of 20m-3000m below sea level and these areas have shown to be very productive in crude oil and gas in a larger quantity than onshore that is to say the deeper you go, the larger quantity you discover.

The industry consists of design, fabrication, installation, drilling, production, refining, exportation etc. Design of pipeline is very key as it deals with parametric conditions for flow and crude oil complex mixture which comprises of “waxes, aromatics, naphthenes, asphaltenes, hydrates and resins”. In typical reservoir conditions (temperatures and pressure), wax molecules remain in solution with the crude oil. As the produced oil flows via a subsea pipeline laid on the ocean floor, its temperature decreases below WAT (Wax Appearance Temperature) because of heat loss along the pipeline. [1], [2], [3].

The designer is also required to know the type of terrain the pipeline must pass through and the elevation profile along the path as it impacts pressure loss and power requirements. The designer must take into account, “the environmental conditions, ecological, historical, and archaeological sites” as they mightinfluence the pipeline routing, thereby increasing the length of the pipeline [4], [5], [6].

The primary types of flow in a flow line are laminar and turbulent flow. Laminar flow occurs at low flow rates. At low flow rates, fluid particles flow smoothly in onedirection and there are little or no interactions between themselves and the pipe walls. As the flow rate rises, a critical point is reached when the flow changes from laminar to turbulent. The flow becomes “chaotic” and fluid

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 10 Oct. 2022, pp: 1285-1294 www.ijaem.net ISSN: 2395-5252

particles collide with each other and with the walls of the pipe. This critical point is a function of the fluid density and viscosity, flow line size, and flow rate. [7]

Design pressures is critical as it tells the designer what pressure is required at the separator to be above certain range, so as to be able to deliver at expected pressure or to be below a parameter, to avoid blowing up the separator. This is the total pressure drop that is required to flow fluid in a pipe section. i.e., the pressure gradient between the inlet and the outlet points along the line section. In an inclined pipe, this pressure gradient also includes the pressure loss due to elevation. The flow potential should be equal to or greater than that required to transport a given quantity of fluid in a flow line of a specific size. Otherwise, a pump, compressor, or a larger diameter pipeline would be required. [8]

For discharge temperature, wax formation is mostly considered. Therefore, wax appearance temperature (WAT) is given for consideration. Wax is paraffin with high carbon numbers (C18 to C60) which are naturally resident in oil. Waxes in the oil form deposit on the inner pipe wall and then become thicker over time, which leads to severe problems related to flow assurance. In extreme cases, the entire flow process could be halted for the replacement of the plugged section of the line. The estimated cost could be up to over $30,000,000 per incident. [9], [10], [11], [12].

Finally, erosional velocity ratio (EVR) is important to check corrosion of the pipeline. It is given that at EVR of <1, corrosion will not occur while at EVR >1, corrosion of the pipeline will occur. Erosional velocity ratio is the ratio of fluid velocity per erosional velocity whereas the erosional velocity it’s process in a pipeline that is accelerated by high fluid velocities, presence of sand, corrosive contaminants such as CO_2 and H_2S, which disturb the flow paths such as elbow. Pressure law is essential in pipeline, because at higher pressure, temperature drop is low while at low pressure, temperature drop is high.

This paper presents the parametric analysis of subsea multiphase pipeline using Pipesimsoftware. Therefore, this study would use PIPESIM software to optimize the design of a subsea flowline system concerning the fluid and flow parameters, and line sizes. The design of the pipelines is critical both for maximizing the oil/gas production, as well as for minimizing the shut-in and start-up times. The design entails assessing and simulation of several possible oil/gas exploitation scenarios, to deliver the produced fluids to the separation facility at the recommended pressure and temperature conditions. Several factors should be included in the study, including fluid pressure, temperature, velocity, etc. This study was carried out using data from a Nigerian field. [13], [14].The objective of this work is to carry out a piping analysis using Pipesim Software, do sensitivity studies of the input parameters against the design output parameters.

At certain process conditions of Temperature and Pressure, there is potential for wax formation,this has been a major problem in pipeline analysis. Transportation of crude oil in a cold environment is mostly affected by low temperature, which brings about the wax formation and this is made possible when its temperature (inlet coolant temperature) drops below the wax appearance temperature (WAT). This wax formation can cause restriction in crude oil flow in the pipeline, pressure abnormalities, and artificial blockage leading to reduction or interruption in production, which in extreme cases may lead to shutting down of facility or abandoning of the affected line. It should be noted that wax deposits are not solid wax but a gel that consists of solid wax crystals and trapped liquid, which in course of time will become hardened (aging).

Also, above certain velocities, inadequate poor pipe sizing can lead to excessive corrosion of pipeline

As the oil and gas are extracted from the well, it is inevitably polluted by solidparticles such as sand, etc. that cause pipe erosion, and if this erosion is not monitored, predicted, and controlled, the entire production process can be affected even shut down. Estimating erosion in multiphase flow is difficult and some factors affect erosion damage such as impact angle, size of particles, the shape of particles, impact velocity, properties of particles, and properties of the target material.

II. MATERIALS AND METHODS

PIPESIM software is a steady state, multiphase flow simulator for the design and diagnostic analysis of oil and gas production systems. PIPESIM software tools model multiphase flow from the reservoir to the wellhead. PIPESIM software also analyzes flowline and surface facility performance to generate a comprehensive production system analysis. PIPESIM software performs simultaneous steady-state heat and pressure balances for each pipe or tubing segment (segment length determined automatically). The

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fluid properties used for these calculations are averaged for each segment. Calculations are always performed in the direction of flow. The consideration of this research paper focused from the wellhead to the first phase separator. [15]

Parametric Analysis with PIPESIM

The base inner piper inner diameter is resolved as far as the most extreme suitable bay pressure while the base insulation required is resolved as far as fluid landing temperature at the separator. The inner pipe diameter is measured to keep the flow line bay pressure under pre-decided cut off points and distinctive insulation thickness is tried to choose the best thickness that guarantee the fluid entry temperature is kept over the hydrate formation temperature for extended shutdown span of 48hours. In the parametric study, the flowrate of 0.01472m$_3$/s, 0.02576m^3/s, 0.02944m^3/s and inner pipe diameters of 202.74mm (8in), 254.46mm (10in), 304.74 (12in) are considered.

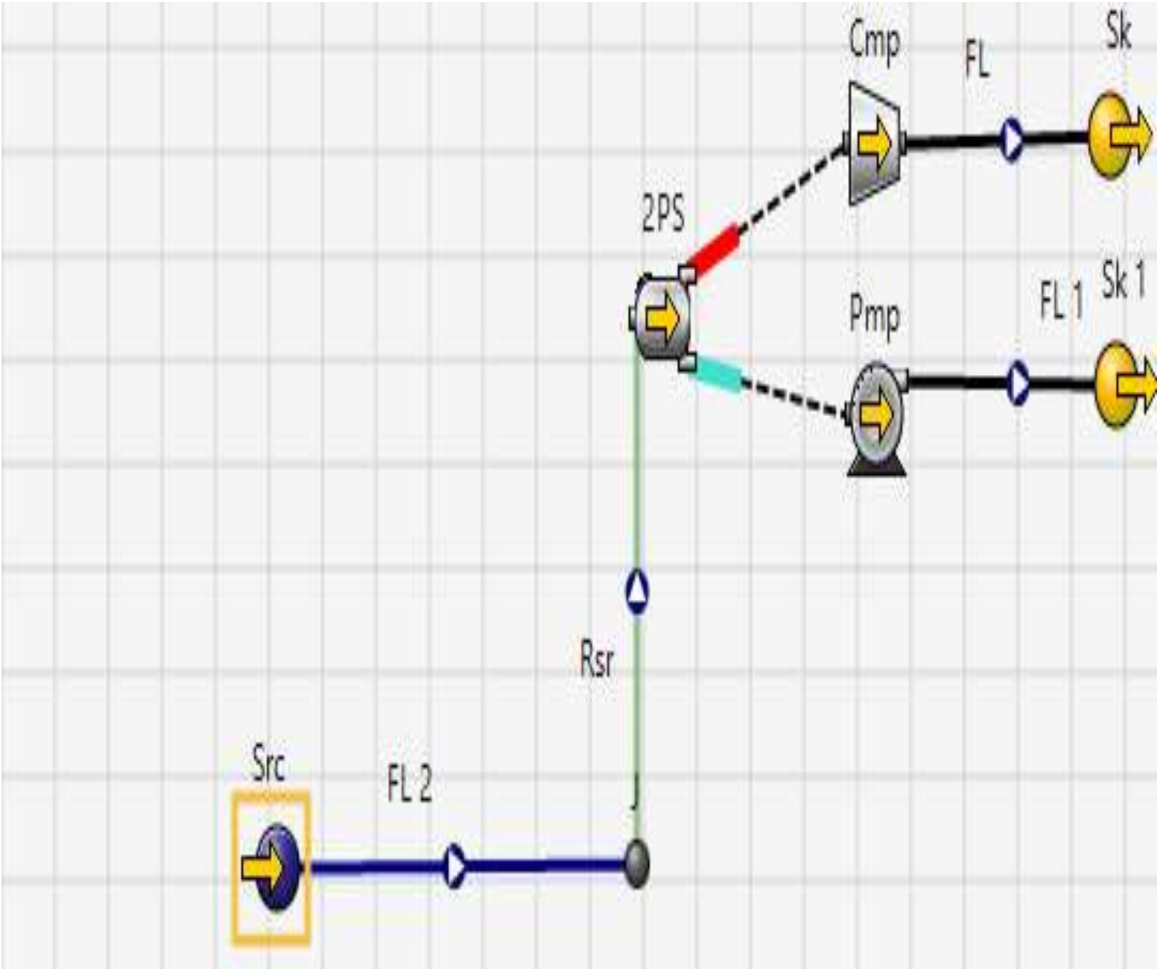

Figure 1: The PIPESIM Network Model.

Table 1: Base Data

S/N	Manifold/Source Data	Value
1.	Temperature	176°F (80^{o}C)
2.	Pressure	1500 psia (10,340KN/m^2)
	Subsea Tieback Data	

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3.	Rate of Undulations	0
4.	Horizontal Distance	6 miles (31,680 ft) (9,662.4m)
5.	Elevation Distance	0 ft
6.	Available Internal Diameters	8, 10, 12 inches. (202.74mm, 254.46mm, 304.74mm)
7.	Wall thickness	0.5 inches (12.7mm)
8.	Roughness	0.001 in (0.0254mm)
9.	Ambient temperature	38°F (3.33°C)
10.	Pipe thermal conductivity	35 Btu/hr/ft/°F
11.	Insulation thermal conductivity	0.15 Btu/hr/ft/°F
12.	Insulation thickness	0.5 inches (12.7mm)
13.	Ambient Fluid	Sea Water
14.	Ambient fluid velocity	1.5 ft/sec (0.4572m/s)
15.	Burial depth	Elevated above ground
16.	Ground conductivity	1.5 Btu/hr/ft/°F
17.	Wax Appearance Temperature	147°F (63.89°C)
	Riser Data	
18.	Horizontal Distance	0ft (Vertical pipe)
19.	Elevation Difference	+1600 ft (+457.5m)
20.	Available Internal Diameters	8, 10, 12 inches. (202.74mm, 254.46mm, 304.74mm)
	Aqueous Component	
21.	Water	10 (% bbl/bbl)

Source: Schlumberger, Port Harcourt

Table 2 Properties of Pipe materials for thermal analysis

S/N	**Material**	**Density (Kg/m^3)**	**Specific heat (J/kg/K)**	**Thermal conductivity (W/mK)**	**U-value (W/m^2K)**
1.	Stainless steel	7850	460	14.4	16

2.	Carbon steel	7850	460	45	--
3.	Polyurethane foam	800	1600	0.025	1.2
4.	Izoflex	250	800	0.007	0.131
5.	Aerogel	100	1000	0.013	0.65
6.	FBE	1300	1500	0.3	

Source: Schlumberger, Port Harcourt

Table 3: Environmental Data

S/N	Parameter	Unit	Value
1.	Water depth	M	2000
2.	Seawater density	Kg/m^3	1025
3.	Seabed temperature	^0C	4
4.	Sea surface temperature	^0C	27.5
5.	Air temperature	^0C	27
6.	Surface current velocity	m/s	2.57
7.	Seabed velocity	m/s	0.51

Source: Schlumberger, Port Harcourt

III. RESULTS AND DISCUSSION

Data Assessment

Base data including manifold/source data, properties of pipe material and environment material have been analyse in this chapter. Results obtained from running these data's through various design calculation method have also been discussed and their sensitivities.

Pipe Analysis

Tables 4 to 6 shows populated results for Discharge Pressure, Discharge Temperature and Erosional Velocity Ratio for different flowrates and pipe sizes from the analysis performed using PIPESIM. The analysis for each Pipe table shows the results obtained at different flowrates. The results shows that as the flowrate increase, the discharge pressure reduces whereas the discharge temperature and erosional velocity ratio increases.

Results from Table 4, shows that only $0.01472m^3/s$ flowrate could deliver above the design criteria of discharge pressure of $7,860.02KN/m^2$. For discharge temperature criteria above 63.89C, both discharge flowrates of $0.02576m^3/s$ and $0.02944m^3/s$ passed the temperature criteria. However, the erosional velocity criteria of < 1.0 were passed by all three cases for the 202.74mmpipeline.

From Table 5, all flowrates met the required discharge pressure criteria of above 7,860.02KN/m^2 and erosional velocity ratio of <1 whereas both 0.02576m^3/s and 0.02944m^3/s met the required temperature criteria of above 63.89°C.

From Table 6, all flowrates were able to deliver at the required discharge pressure above 7,860.02KN/m^2 and erosional velocity ratio <1 whereas only 0.02944m^3/s met the required discharge temperature above 63.89°C. Hence, the discharge flow at 02944m^3/s for the pipe of size 254.46mm and 304.74mm justified the design selection criteria. Further analysis was carried out using this pipe and the design conditions.

Table 4: Flowrates, Discharge Pressures, Temperatures and Erosional velocity ratios for Line ID of 202.74mm.

Flowrate (m^3/s)	Discharge Pressure (KN/m^2)	Discharge Temperature (°C)	Erosional Velocity Ratio
0.02944	7,763	66.51	0.27
0.02576	7,837	65.12	0.23
0.01472	7,974	57.35	0.13

Table 5: Flowrates, Discharge Pressures, Temperatures and Erosional velocity ratios for Line ID of 254.46mm

Flowrate (m^3/s)	Discharge Pressure (KN/m^2)	Discharge Temperature (°C)	Erosional Velocity Ratio
0.02944	7,909	65.56	0.22
0.02576	7,943	64.05	0.19
0.01472	8,005	55.68	0.11

Table 6: Flowrates, Discharge Pressures, Temperatures and Erosional velocity ratios for Line ID of 304.74mm

Flowrate (m^3/S)	Discharge Pressure (KN/m^2)	Discharge Temperature (°C)	Erosional Velocity Ratio
0.02944	7,986	64.61	0.18
0.02576	8,006	62.98	0.16
0.01472	8,063	54.05	0.09

IV. SENSITIVITY STUDIES

From Table 4 - 6, the result for 202.74mm pipeline shows that at a flowrate of 0.01472m^3/s, the discharge pressure is 7,974KN/m^2, discharge temperature is 57.35°C and erosional velocity ratio is 0.13 whereas for 0.02576m^3/s; discharge pressure is 7,837KN/m^2, discharge temperature is 65.12°C and erosional velocity ratio is 0.23 while with 0.02944m^3/s; discharge pressure is 7,763KN/m^2, discharge temperature 66.51°C and erosional velocity ratio is 0.27.

For 254.46mm Pipeline, at flowrate of 0.01472m^3/s; discharge pressure is 8,005KN/m^2, discharge temperature is 55.68°C and erosional velocity ratio is 0.11 whereas for 0.02576m^3/s; discharge pressure is 7,943KN/m^2, discharge temperature is 64.05°C and erosional velocity ratio is 0.19 while at 0.02944m^3/s; discharge pressure is 7,909KN/m^2, discharge temperature is 65.56°C and erosional velocity ratio is 0.22.

For 304.74mm Pipeline, at flowrate of 0.01472m^3/s; discharge pressure is 8,063KN/m^2, discharge temperature is 54.05°C and erosional velocity ratio is 0.09 whereas for 0.02576m^3/s; discharge pressure is 8,006m^3/s; discharge temperature is 62.98°C and erosional velocity ratio is 0.16 while with 0.02944m^3/s; discharge pressure

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is 7,986KN/m^2, discharge temperature is 64.61°C and erosional velocity ratio is 0.18.

Case of 202.74mm pipeline

For the 202.74mm pipeline, the variation trend for discharge pressure, discharge temperature and erosional velocity ratio against the pipeline distance are given in Figs2 – 4, Fig 2 captures discharge Pressure against Pipeline Distance.

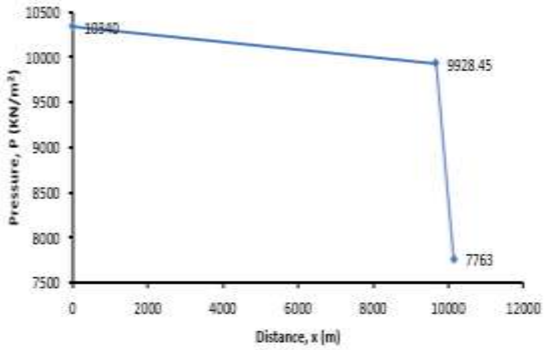

Figure 2: Plot of Pressure (KN/m^2) vs. Distance (m) at 0.02944m^3/s for 202.74mm Line ID.

From Fig 2 above (for line ID of 202.74mm and maximum flowrate of 0.02944m^3/s), pressure gradually dropped from the well at 10,340KN/m^2 to about 9,928.45KN/m^2 at a distance of about 9,662.4mdue to friction. At this point, a sharp/steep pressure decline was observed and continued to about 10,150.4m, at a pressure of 7,763KN/m^2.

The riser elevation caused a high-pressure drop because the fluid was flowing against gravity and without the aid of external energy like a pump or artificial lift. The result from this plot of System Outlet Pressure Vs. Total distance (Fig 2) indicates that the 202.74mm line size will not deliver the fluid to the separator at a pressure above 7,860.02KN/m^2 at a liquid flow rate of 0.02944m^3/s and therefore does not satisfy the delivery pressure criterion.For the pipe diameter 202.74mm, the variation of temperature to distance is shown in Fig 3.

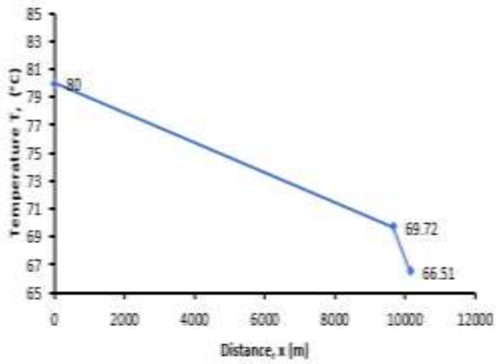

Figure 3: Plot of System Discharge Temperature (°C) vs. Distance (m) at 0.02944m^3/s for 202.74mm Line ID.

From Fig 3, the system temperature gradually dropped from the wellhead at 80°C to 69.72°C at 9,662.4m. Beyond this point, there was a sharp temperature drop, also indicating the start of the riser elevation. The fluid spent some time between the manifold and the topside (first stage separator) than it did between the wellhead and the manifold. However, the discharge temperature is 66.51°C upon arrival at the separator. The discharge temperature is greater than the WAT of 63.89°C. Temperature drop at the seabed is higher than the riser due to a temperature difference of 4°C at the seabed and 27.5°C at the surface, so temperature tends to be lost more by convention from the wellhead to the manifold than the manifold to the Separator. Therefore, the sea environment is the major reason for the temperature drop in the pipeline.Similarly, the corresponding erosional velocity ratio against distance is captured in Fig 4

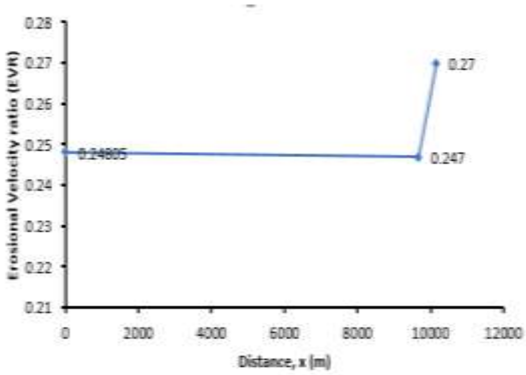

Figure 4: Plot of Erosional Velocity Ratio vs. Distance (m) at 0.02944m^3/s for 202.74 Line ID

Figure 4 shows that the erosional velocity ratio dropped from the wellhead at 0.24805 to

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about 0.247 at 9,662.4m. After this point, the erosional velocity ratio experienced a sharp increase and this can be attributed to the effects of geometry and flow constrictions due to the riser elevation. These flow constriction and geometric effects of the riser on the fluid flow continued from the riser base to the entrance of the first stage separator and the erosional velocity ratio value at the separator was 0.27. However, it is still within the permissible erosional velocity ratio value of <1. Compared to the erosional velocity ratio values at the other flow rates for line ID of 202.74mm (Table 4), the erosional velocity ratio value for a flowrate of 0.02944m3/s was highest because velocity is the dominant factor that influences erosion. To mitigate against erosion, velocity limits and therefore production limits can be imposed.

Case of 254.46mm Pipeline

For the 254.46mm pipeline, the variation trend for the parameters (discharge pressure, temperature and erosional velocity ratio) to pipeline distance is captured in Figs 5, 6 and 7 respectively.Fig 5 captures discharge pressure against pipeline distance as shown below

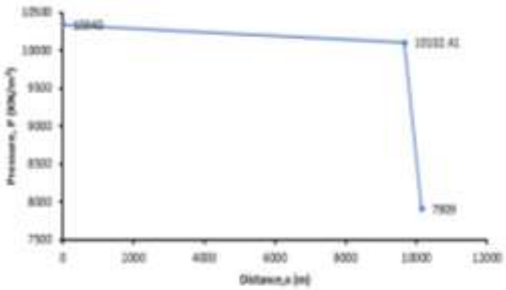

Figure 5: Plot of Pressure (KN/m^2) vs. Distance (m) att 0.02944m^3/s for 254.46mm Line ID

From Fig 5, pressure dropped from the wellhead at 10,340KN/m^2 to 10,102.41KN/m^2 at 9,662.4m. However, the discharge pressure is 7,909KN/m^2. In this case of line ID of 254.46mm, it is above the minimum pressure delivery requirement of 7,860.02KN/m^2.For the pipe diameter of 254.46mm, the variation of temperature to distance is shown in Fig 6

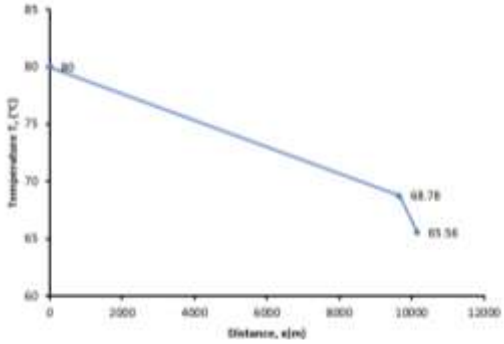

Figure 6: Plot of System Discharge Temperature (°C) vs. Distance (m) at 0.02944m^3/s for 254.46mm Line ID

From Fig 6, we observed a temperature drop from wellhead at 80°C to 68.78°C at 9,662.4m with a flow rate of 0.02944m^3/s. It also experiences a further reduction at the Riser elevation to the Separator to 65.56°C of 457.5m elevation. The discharge temperature at the Separator is greater than the expected temperature of 63.89°C thereby making the pipe suitable for consideration.Likewise, the corresponding erosional velocity ratio trend against distance is captured in Fig 7.

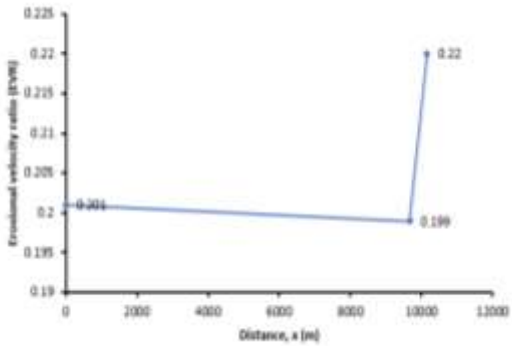

Figure 7: Plot of Erosional Velocity Ratio vs. Distance (m) at 0.02944m^3/s for 254.46mm Line ID.

From Fig 7, we observe that the EVR dropped from the wellhead at 0.201 to 0.199 at 9,662.4m. At this point, a sharp increase occurs signifying the Riser elevation of 457.5m, and the EVR received at the Separator is 0.22. This value shows that the pipe met the EVR of not greater than one (<1), which means pipeline erosion will not occur.

Case of 304.74mm Pipeline

To further study the effect of pipeline diameter in the system parameters been investigated, analysis was conducted using a

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pipeline of 304.74mm and the trend are reported in Figs 8, 9, 10 for discharge pressure, temperature and erosional velocity ratio respectively.Fig 8 captures discharge pressure against pipeline distance as shown below;

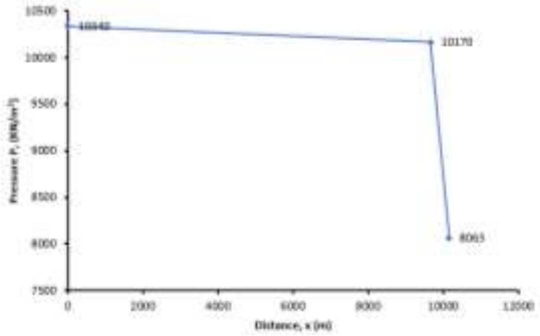

Figure 4.8: Plot of Pressure (KN/m^2) vs. Distance (m) at 0.02944m^3/s for 304.74mm Line ID

From Fig 8, at a flowrate of 0.02944m^3/s through a 304.74mm pipe, we observe a gradual pressure drop from the wellhead at 10,340KN/m^2 to 10,170KN/m^2 at 9,662.4m. At the point of the Riser elevation, there was a sudden drop of pressure again to the Separator at 7,986KN/m^2 of 457.5m elevation. In addition, the pressure drop of 304.74mm shows that it is higher than the expected, therefore it can be considered.For the pipe diameter 304.74mm, the variation of temperature to distance is shown in Fig 9.

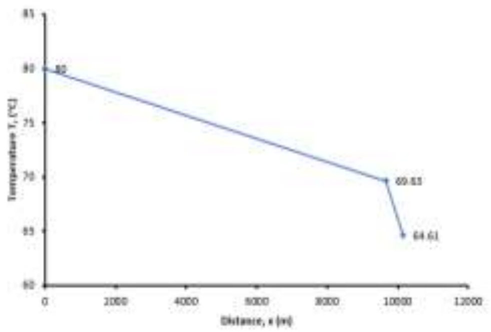

Figure 9: Plot of System Discharge Temperature (°C) vs. Distance (m) at 0.02944m^3/s for 304.74mm Line ID

From Fig 9 above, the 304.74mm diameter pipeline with a flow rate of 0.02944m^3/s had a temperature drop from the wellhead at 80°C to 69.63°C at 9,662.4m. At the point of the Riser elevation, it experiences a further drop to the Separator and the temperature received at the Separator was 64.61°C. It is also greater than the given temperature expected at the Separator of 63.89°C.Similarly, the corresponding erosional velocity ratio trend against distance is captured in Fig 10.

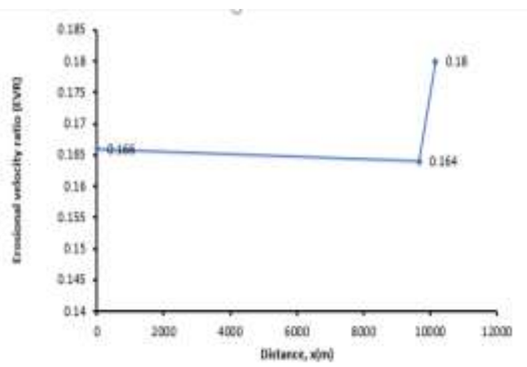

Figure 10: Plot of Erosional Velocity Ratio vs. Distance (m) at 0.02944m^3/s for 304.74mm Line ID

From Fig 10 above, the EVR at 0.02944m^3/s for 304.74mm diameter pipeline has a drop from the wellhead at 0.166 to 0.164 at 9,662.4m. Once again, there was a quick increase from the Riser to the Separator of 0.18. The EVR received at the Separator is less than one (<1), which shows that there will be no erosion in the pipeline.

V. CONCLUSION

The study carried out shows that the 254.46mm and 304.74mm pipes met the requirement

We can recall that our given Wax Temperature Appearance is 63.89°C, expected Pressure of 7,860.02KN/m^2, and Erosional Velocity ratio of less than one (<1).Therefore, with a 202.74mm pipeline, at a flowrate of 0.2944m^3/s and 0.02576m^3/s, only temperature drop and erosional velocity ratio met the requirement while at 0.01472m^3/s, only pressure drop and erosional velocity ratio met the requirement.

Whilst for 254.46mm pipeline, at a flowrate of 0.02944m^3/s and 0.02576m^3/s, all the values exceed the given requirement for pressure, temperature, and erosional velocity ratio whilst at 0.01472m^3/s, the temperature drop was not greater than the Wax Appearance Temperature, which only the first and second flowrate to meet up the standard for 254.46mm pipeline.Also for the 304.74mm pipeline, at a flowrate of 0.02944m^3/s, all the values met the required standard given while for flowrate of 0.02576m^3/s and 0.01472m^3/s, both temperature values failed to meet up the required standard for 304.74mm pipeline.From the above analysis, we conclude that only the 254.46mm and 304.74mm pipelines met the required standard given for the operation of the pipeline.

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