A Technical Report of an Assignment on

GAS FLOW AND NETWORK ANALYSIS

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Submitted to

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ABSTRACT

This report presents an analysis of three natural gas pipeline transmission scenarios through 342km, from Escravos to Lagos, given conditions of 70barg Maximum Allowable Operating Pressure (MAOP) at Escravos terminal and minimum delivery pressure of 45barg at Lagos.

To begin, the maximum pipeline capacity at the given operating constraints was estimated from a simple model built with a single pipeline network, process stream properties and other necessary model input parameters. Afterwards, a technical analysis was carried out for the requirements and feasibility of expanding the gas network by an extra 300mmscfd and 600mmscfd with two expansion options: using compressor stations to provide the additional pressure that will be required for the expansion and using pipeline looping to reduce pressure drop along the original pipe such that the 70barg MAOP and 45barg delivery pressure were adhered to. Finally, an economic comparison was made between the two pipeline expansions options mentioned above.

Results showed that a maximum pipeline capacity of 625mmscfd will be required for the first task. Furthermore, the 300mmscfd expansion will require one compressor station of 2818.94hp rating or a 243km length of reinforcement while the 600mmscfd expansion will require two compressor stations of a total rating of 4523hp or a reinforcement pipe length of 335km for the use of compressor stations or pipeline looping respectively.

The economic analysis revealed that gas network capacity expansion was found to be significantly more expensive if pipe looping is used relative to the use of compressor stations as the overall cost, for both 300mmscfd and 600mscfd extra gas network expansion by looping exceeds the cost of using compressor stations by £187.62 million.

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1. INTRODUCTION

Natural gas transmission is currently done with pipelines or as Liquefied Natural Gas (LNG) because the locations of production are mostly not where they are needed. In this project, there was a need to expand a natural gas pipeline transmission network due to increased gas demand. Technical feasibility was done and economic analysis/comparison of the two options was carried out.

2. AIMS AND OBJECTIVES

2.0 The aim of the Assignment

This assignment aims to familiarize the author with the process of planning, designing and analysing natural gas transmission using pipeline networks.

2.1 The objective of the Assignment

Specifically, the objectives of the assignment are:

i. To estimate the maximum pipeline capacity value given operating constraints and required output condition.
ii. To identify the factors that affect gas pipeline capacity.
iii. To conduct compressor design for pipeline expansion and perform the cost analysis involved.
iv. To investigate pipeline looping option for gas network expansion.
v. To compare the economic feasibility of compression versus pipeline looping as options for natural gas pipeline expansion.

3. LITERATURE REVIEW

Natural gas pipe network expansion will create additional pressure requirements. To account for this, compressors can be installed to re-pressurise the stream or pipe looping can be used to reduce the pressure in the original pipe network. While both the rating of the compressor station or the length of the loop pipe to be used depends on the capacity of the pipe network, length of the reinforcement pipe can also be estimated using Campbell’s approach. In which case, both the original pipes and the reinforcement pipes must be assumed to be horizontal, isothermal and under steady-state flow and gas compressibility factor must be assumed to be constant across all pipes (Fanaei & Niknam, 2010).

4. ESCRAVOS NATURAL GAS NETWORK ANALYSIS

The natural gas stream used throughout this work has the properties specified in Table 4.1. The gas network analysis tool used is Promax®.

Table 4.1: Properties of the Escravos Natural Gas

Component	Mole fraction (%)
Methane	93.76
Ethane	3.14
Propane	0.62
Butane	0.2
Pentane	0.07
Nitrogen	2.03
Carbon Dioxide	0.18

4.1 TASK 1: Maximum Pipeline Capacity Estimation, Factors Affecting Pipeline Capacity, Compressor Design for Expansion and Cost Analysis

4.1.1 (1a) Estimation of Maximum Pipeline Capacity Given MAOP of 70barg and 45barg Minimum Delivery Pressure

In this section, the pipeline capacity required to deliver gas, from Escravos to Lagos, through 342km, such that the minimum arrival pressure is 45barg is estimated, given a maximum allowable operating pressure of 70barg at the inlet. Table 4.2 shows the input variables used in building the model and conducting the simulation, along with justifications for any input variable specified by the author. Sensitivity analysis was carried out on the flow rate required and an optimum arrival pressure of **45.799barg** was obtained as shown in Figure 4.1.

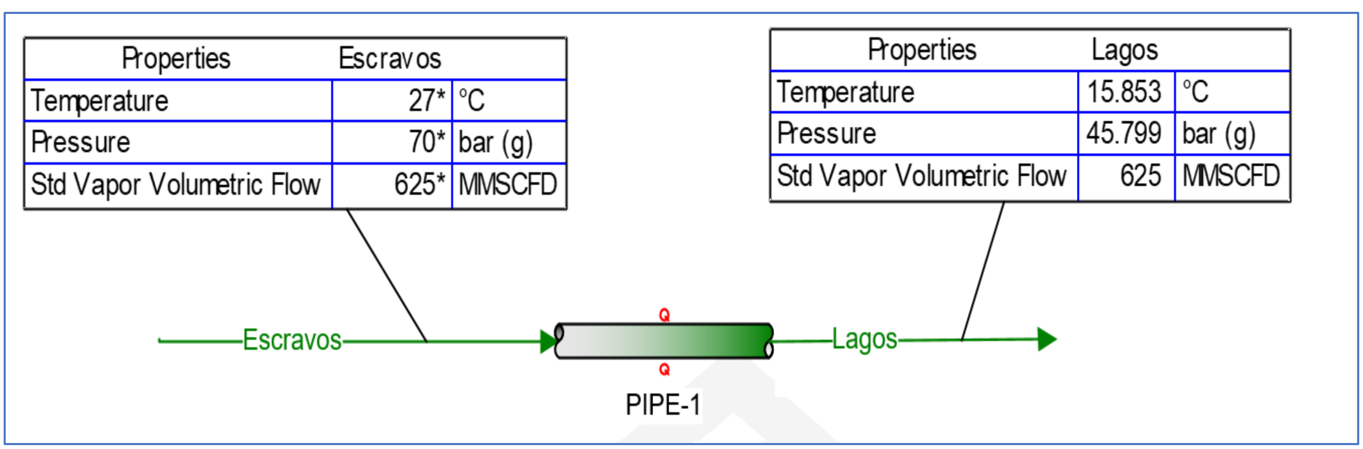

Figure 4.1: Model and Stream Conditions for Task 1

4.1.2 (1b) Factors Affecting Gas Pipeline Capacity

Based on sensitivity analysis conducted on model parameters, the following factors have been found to affect natural gas pipeline capacity.

i. Pipeline roughness
ii. Pipeline Internal Diameter
iii. Fluid properties
iv. Operating conditions (Temperature and Pressure)

4.1.3 Analysis of Compressor Stations Usage for Pipeline Capacity Expansion

In this section, simulations were carried out to determine the optimum number of compressor stations that will be required to increase the pipeline capacity by 300mmscfd and 600mmscfd, maintaining the MAOP of 70barg and gas delivery pressure of 45barg at Lagos terminal. This will be later compared, technically and economically, with the use of pipeline looping to achieve the same task.

4.1.3.1 (1C.i) Increasing the pipeline capacity by 300MMSCFD with Compressor Stations

From Section 4.1.1, the pipeline capacity required to deliver gas at a minimum of 45barg pressure without exceeding the MAOP of 70barg was obtained as 625MMSCFD. To expand it by 300MMSCFD, the pipe capacity was specified in the model to be 925MMSCFD and operating conditions were optimised to achieve the required delivery pressure of 45.061barg shown in Figure 4.2 shows along with the model and stream conditions for this task. Table 4.3 shows the changes made to the model in Section 4.1.1 to obtain the model used in this section. Inlet conditions and pipe make were not altered.

In addition to the modifications in Table 4.3, a fan was introduced to cool the stream after compression because huge compressor horsepower requirements and extremely high process stream temperatures resulted when Stream 2 (Figure 4.2) was compressed without a fan.

Again, the temperature profile in the pipelines was monitored to ensure that the limit, as specified in Section 4.1.1 is not exceeded. Figure A-2 and Figure A-3 show the temperature profiles for PIPE-2A and PIPE-2B respectively.

4.1.3.2 (1C. ii) Increasing the Pipeline Capacity by 600MMSCFD with Compressor Stations

To design for an additional 600MMSCFD expansion network with the use of separators, the model in Figure 4.3 was used. Table 4.4 shows the input variables that were used to develop it. Inlet conditions and pipe make were not altered.

Table 4.2: Input Variables and Solution of Task 1 simulation.

INPUT VARIABLE	VALUE	UNIT	REMARK	JUSTIFICATION
Pipe length	342	km	Given	N/A
Nominal Pipe Size, NPS	36	inch	Given	N/A
Pipe wall thickness	0.25	inch	Given	N/A
Maximum Allowable Operating Pressure, MAOP (inlet)	70	barg	Given	N/A
Outlet pressure	45	barg	Given	N/A
Gas temperature (Inlet)	27	ºC	Given	N/A
Gas specific gravity	0.6		Given	N/A
Gas specific heat ratio	1.4		Given	N/A
Standard temperature	15.5	ºC	Given	N/A
Compressor isentropic efficiency	80	%	Given	N/A
Compressor mechanical efficiency	95	%	Given	N/A
Atmospheric pressure	1.01325	bara	Given	N/A
Gas compressibility factor	0.85		Given	N/A
Number of Length of Pipe Increment	200		Specified	To obtain 200 increments of pipe segments
The material of Pipe construction	Carbon Steel		Specified	Typical of the project setting, Nigeria
Inclination Angle	0	Degrees	Specified	Changes in elevation were negligible
Inlet Pressure	70	bar(g)	Specified	Given Operating constraint
Std Vapor Volumetric Flow	**625**	**MMSCFD**	Computed & solution	Required maximum flow rate for given constraints

Table 4.3: Specific Input Variables for additional 300MMSCFD Expansion with Compressors Design.

INPUT VARIABLE/VESSEL		VALUE	UNIT	REMARK	JUSTIFICATION
Pipe length	PIPE-2A	176	km	Specified	A part of the total of 342km
	PIPE-2B	166	km	Specified	A part of the total of 342km
Number of Length of Pipe Increment		100	Per pipe	Specified	To obtain 100 increments of pipe segments for both
Separator Outlet Pressure		70	barg	Specified	To continue flow
Std Vapor Volumetric Flow		925	MMSCFD	Computed	625mmscfd + 300mmscfd

Velocity profiles for the three pipes in Figure 4.6 (PIPE-2C, PIPE-2D and PIPE-2E) are shown in Figures A.4, A.5 and A.6, of Appendix A, respectively.

4.1.4 Cost Analysis and Summary of Expansion by the Use of Compressor Stations Design

Table 4.5 summarises the results of the foregoing analysis and gives the cost estimates of using the compressors for the two cases of pipeline capacity expansion being considered.

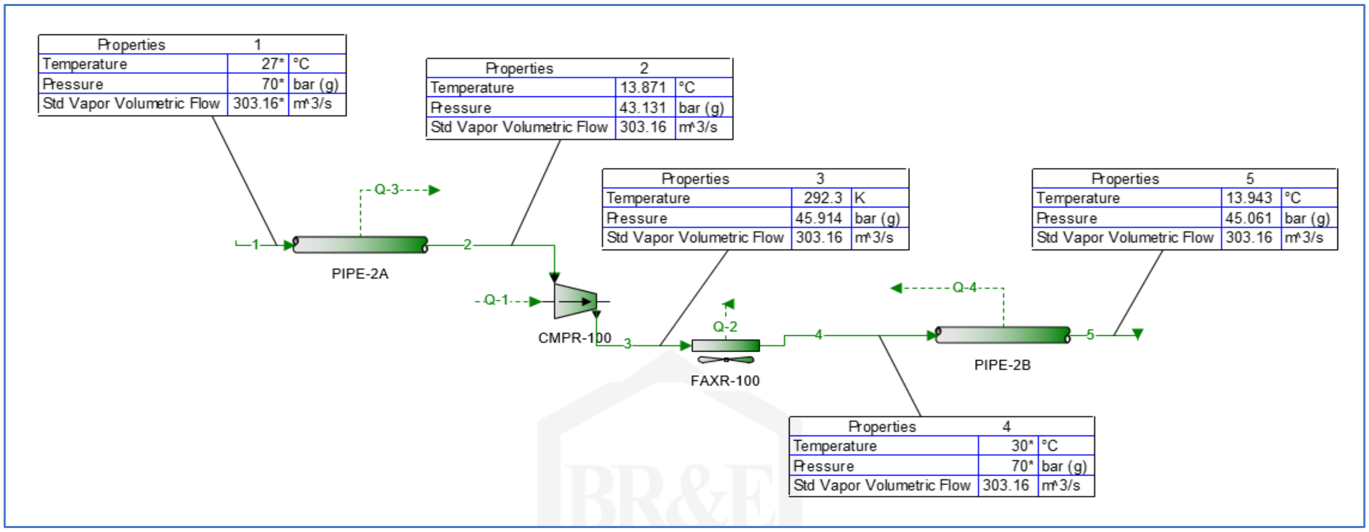

Figure 4.2: Model and Stream Properties for 300MMSCFD Expansion Design with Compressors

Table 4.4: Specific Input Variables for additional 600MMSCFD Expansion with Compressors Design.

INPUT VARIABLE/VESSEL		VALUE	UNIT	REMARK	JUSTIFICATION
Pipe length	**PIPE-2C**	121	km	Specified	A part of the total of 342km
	PIPE-2D	121	km	Specified	A part of the total of 342km
	PIPE-2E	80	km	Specified	A part of the total of 342km
Number of Length of Pipe Increment		100	Per pipe	Specified	To obtain 100 increments of pipe segments
		50		Specified	To obtain 50 increments of pipe segments
		20		Specified	To obtain 20 increments of pipe segments
Std Vapor Volumetric Flow		**1225**	**MMSCFD**	Computed	625mmscfd + 600mmscfd

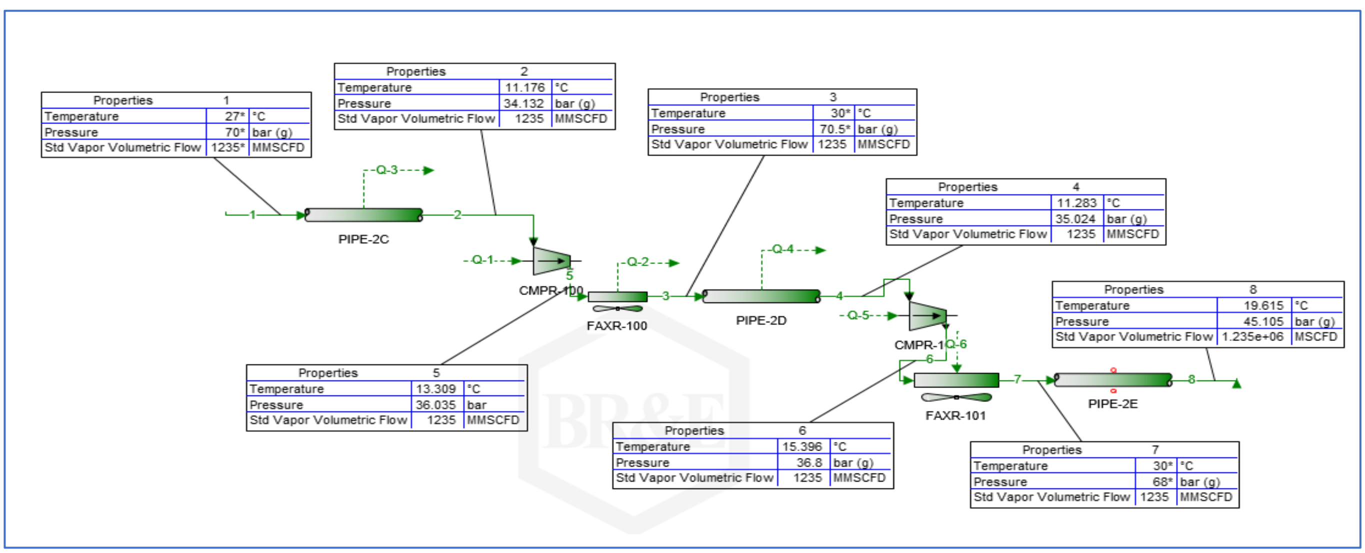

Figure 4.3: Model and Stream Properties for 600MMSCFD Expansion Design with Compressors

Table 4.5: Cost Analysis and Summary of Results of Compressor Requirements for Pipeline Capacity Expansion

<table>
<tr><th>S/N</th><th>EXPANSION CAPACITY (MMSCFD)</th><th>REQUIRED NUMBER OF COMPRESSOR STATIONS</th><th colspan="2">COMPRESSOR RATING (hp)</th><th>TOTAL HORSEPOWER REQUIREMENT (hp)</th><th>COST @ £2000/hp (£)</th><th>DELIVERY PRESSURE (bar)</th></tr>
<tr><td>1</td><td>300</td><td>1</td><td colspan="2">2818.94</td><td>2818.94</td><td>5637880</td><td>45.061</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">600</td><td rowspan="2">2</td><td>Station 1</td><td>Station 2</td><td rowspan="2">4523</td><td rowspan="2">9, 046, 000</td><td rowspan="2">45.105</td></tr>
<tr><td>1546</td><td>2977</td></tr>
</table>

4.2 TASK 2: Analysis of Pipeline Looping Usage for Pipeline Capacity Expansion

In Section 4.1.3, the optimum number of compressor stations that will be required to increase the pipeline capacity by 300mmscfd and 600mmscfd, maintaining the MAOP of 70barg and gas delivery pressure of 45barg at Lagos terminal, was estimated. In this section, pipeline looping will be used to achieve the same task such that pressure drop is reduced along the original pipeline.

In each case, the length of the reinforcement pipe was estimated using sensitivity analysis on its effect on the arrival pressure and varying it until the desired arrival pressure was reached.

4.2.1 (2a) Scenario 1: Increasing Pipe Capacity by 300MMSCFD with Pipeline Looping.

From Section 4.1.1, the pipeline capacity required to deliver gas at a minimum of 45barg pressure without exceeding the MAOP of 70barg was obtained as 625MMSCFD. Table 4.5 shows the input variables used for generating the expansion loop model, for an additional 300mmscfd capacity, as shown in Figure 4.4. Inlet conditions and pipe make were not altered from the previous models.

The simulation result (Row 3, Table 4.6) shows that the optimum length of reinforcement pipe needed to achieve a delivery pressure of 45barg at an MAOP of 70barg is 243km of the total 342km transmission distance for an additional 300mmscfd pipeline capacity increase.

4.2.2 (2b) Scenario 2: Increasing Pipe Capacity by 600MMSCFD with Pipeline Looping

To design for an additional 600MMSCFD expansion network using pipeline looping option, the model in Figure 4.5 was used. Table 4.7 shows the input variables that were used to develop it. Inlet conditions and pipe make were not altered from the previous models.

Table 4.6: Specific Input Variables for additional 300MMSCFD Expansion with Pipeline Looping.

INPUT VARIABLE/VESSEL		VALUE	UNIT	REMARK	JUSTIFICATION
Pipe length	Original pipe 1 (PIPE-O1)	243	Km	Specified	Parallel & forms loop with PIPE-R
	Reinforcement pipe (PIPE-R)	**243**	**km**	**Computed**	**Optimum to achieve desired delivery pressure**
	Original Pipe 2 (PIPE-O2)	99	Km	Specified	342km-243km
Pipe Increment	Original pipe 1 (PIPE-O1)	50		Specified	To achieve stepwise computing
	Reinforcement pipe (PIPE-R)	50		Specified	To achieve stepwise computing
	Original Pipe 2 (PIPE-O2)	20		Specified	To achieve stepwise computing
Splitter	The fraction of output Stream to both pipes	50	%	Specified	Halved since Loop pipe size the same as original pipe size
Std Vapour Volumetric Flow		925	MMSCFD	Computed	625mmscfd + 300mmscfd

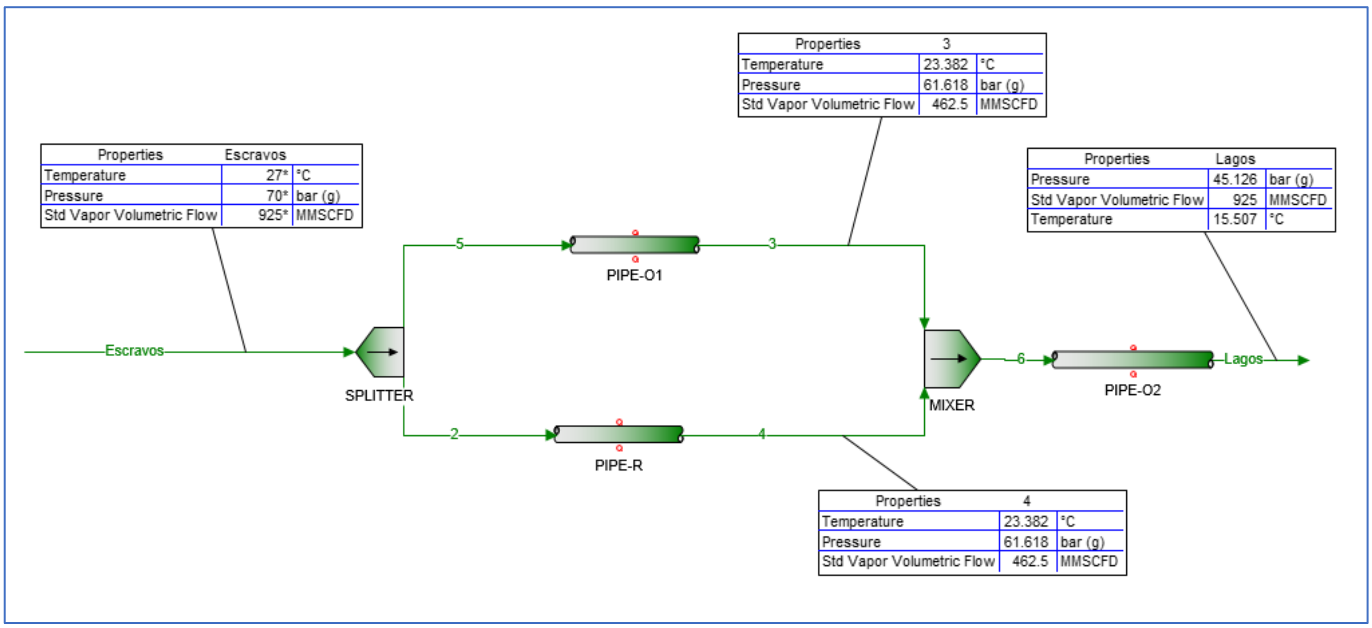

Figure 4.4: Model and Stream Properties for 300MMSCFD Expansion Design using pipeline looping

The velocity profiles for the three pipes in Figure 4.4 are shown in Figures A-7, A-8 and A-9 of Appendix A.

The simulation result (Row 3, Table 4.7) shows that the optimum length of reinforcement pipe needed to achieve a delivery pressure of 45barg at an MAOP of 70barg is 335Km of the total 342Km transmission distance for an additional 600mmscfd pipeline capacity increase.

The velocity profiles for the three pipes in Figure 4.5 are shown in Figures A-10, A-11 and A-12 of Appendix A.

Table 4.7: Specific Input Variables for additional 600MMSCFD Expansion with Pipeline Looping.

INPUT VARIABLE/VESSEL		VALUE	UNIT	REMARK	JUSTIFICATION
Pipe length	Original pipe 1 (PIPE-O1)	335	Km	Specified	Parallel & forms loop with PIPE-R
	Reinforcement pipe (PIPE-R)	**335**	**Km**	**Computed**	**Optimum to achieve desired delivery pressure**
	Original Pipe 2 (PIPE-O2)	7	Km	Specified	342km-335km
Pipe Increment	Original pipe 1 (PIPE-O1)	50		Specified	To achieve stepwise computing
	Reinforcement pipe (PIPE-R)	50		Specified	To achieve stepwise computing
	Original Pipe 2 (PIPE-O2)	20		Specified	To achieve stepwise computing
Splitter	The fraction of output Stream to both pipes	50	%	Specified	Halved since Loop pipe size the same as original pipe size
Std Vapour Volumetric Flow		1225	MMSCFD	Computed	625mmscfd + 600mmscfd

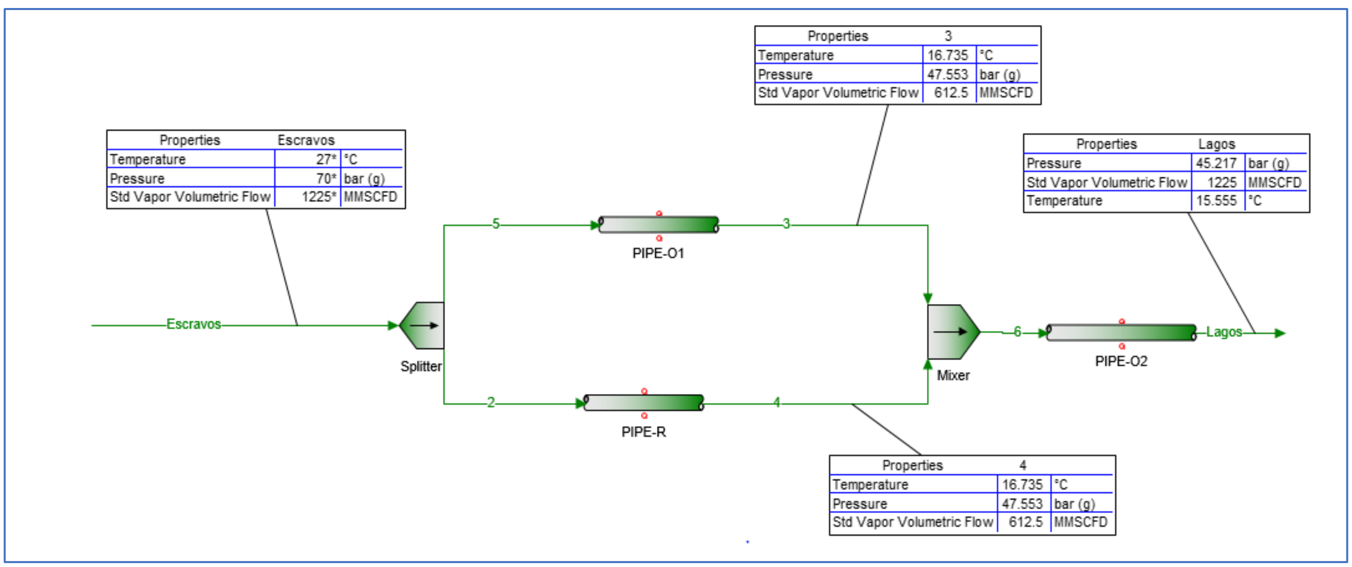

Figure 4.5: Model and Stream Properties for 600MMSCFD Expansion Design using pipeline looping

4.3 TASK 3: Comparison of Economic and Technical Feasibility of Compression versus Reinforcement Design

Economic and technical comparisons are made, in this section, between pipeline expansion with the use of separator stations and the use of pipeline looping (reinforcement) for 300mmscfd and 600mmscfd increment – the two scenarios considered above.

4.3.1 Economic Comparison of Pipeline Expansion with Pipe Looping Versus Expansion with Compressor Stations

Based on £350, 000 per km pipe expansion loop cost and £2000 per horsepower for compressor stations, the cost of the gas network expansions options designed in the previous options are analysed in Table 4.8 and compared in Figure 4.6.

Table 4.8: Economic Analysis of Pipeline Expansion Options

EXPANSION OPTION	NETWORK CAPACITY INCREMENT CASE	REQUIRED LOGISTICS		UNIT COST OF LOGISTIC		COST OF OPERATION
		Loop Pipe (Km)	Compressors (hp)	Looping (£/km)	Compressor station (£/hp)	
Loping	300mmscf	243	N/A	£350,000	N/A	£85,050,000
	600mmscf	335	N/A	£350,000	N/A	£117,250,000
Compression	300mmscf	N/A	2818.94	N/A	£2,000	£5,637,880
	600mmscf	N/A	4523	N/A	£2,000	£9,046,000

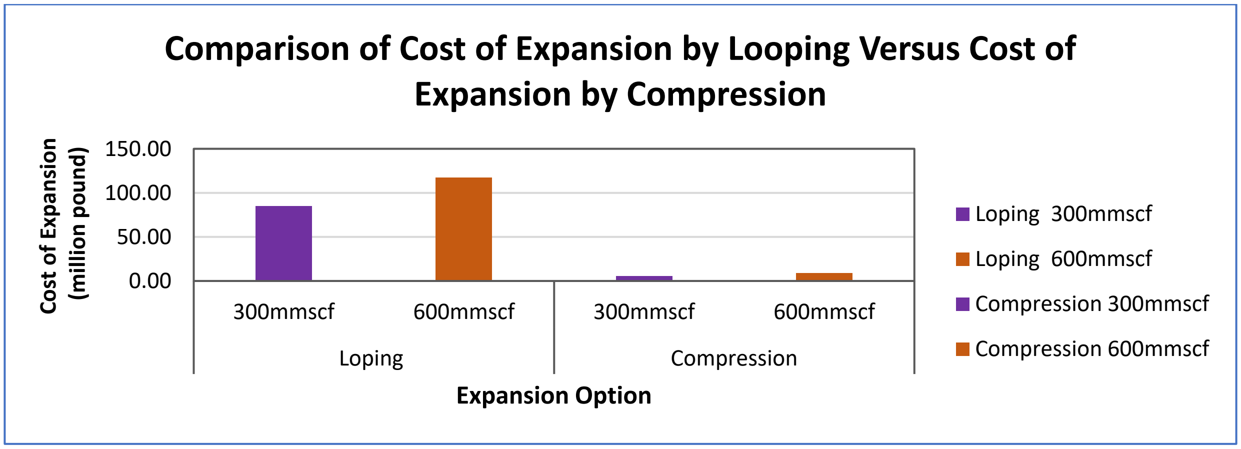

Figure 4.6: Comparison of Cost of Expansion by Looping Versus Cost of Expansion by Compression

5. DISCUSSION OF RESULTS

Pipe sizes were kept constant throughout the analysis because parameters for economic analysis were only provided for 36inch NPS pipes.

In the task of Section 4.1.1 – regarding maximum pipeline capacity estimation, Figure A-1, in Appendix A, shows that the maximum velocity profile across the pipeline is 20.73 ft/s or 6.32 m/s. This is less than the maximum erosional velocity constraint of $20m/s$ set by (AMERICAN PETROLEUM INSTITUTE, 2012)and advised by (Nojoomi & Moghadasi, 2015). Also, the excessive temperature rise was prevented since this can lead to increased gas velocity and consequent pipe erosion and pipe failure.

In the same vein, fans were introduced to cool the gas streams, after compressions, in the subsequent tasks involving compression stations, because huge compressor horsepower requirements and extremely high temperatures resulted when streams were compressed without a fan.

The high-temperature rise can be attributed to the energy released, in terms of heat, in the intermolecular bonding or compaction of the gas atoms that happens during compression – the opposite of Joule Thompson's effect.

The length of the reinforcement pipe needed for the 600mmscf expansion with pipe looping was 92km more than the length needed for the 300mscf case. This is because increasing flow rate will result in increased pressure drop which is directly proportional to the length of the pipe.

Enormous differences exist among the cost of network expansion using compressor stations versus using pipeline looping. The cost of the pipeline looping option was found to exceed the cost of using compressor stations by 79.41million pound for an extra 300mmscfd increase and 108million pound for a 600mmscfd.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The following conclusions have been deduced from this project,

1. A maximum pipeline capacity of 625MMSCFD is required to deliver gas from Escravos to Lagos, a distance of 342km, given a maximum inlet pressure of 70barg and a minimum arrival pressure of 45barg.
2. Gas compression causes an increase in temperature. Maintaining the minimum allowable and safe process temperature conditions, based on API standards, were, therefore, factored into each design.
3. When considering pipeline capacity expansion with pipe looping, the length of the reinforcement pipe needed increases with an increase in the desired amount of the gas flow rate increase.
4. The 300mmscf network expansion will require one compressor station of 2818.94hp rating or a 243km length of reinforcement while the 600mmscfd expansion will require two compressor stations of a total rating of 4523hp or a reinforcement pipe length of 335kKm for the use of compressor stations or pipeline looping respectively.
5. Gas network capacity expansion was found to be significantly more expensive if pipe looping is used (to reduce the pressure along the original pipe) relative to the use of compressor

stations. The huge difference is as a result of the high cost of the expansion pipelines compared with the logistics required for compression.

6. The overall cost, for both 300mmscfd and 600mscfd extra gas network expansion by looping, exceeds the cost of using compressor station by £187.62 million.

6.2 Recommendations

- Implementation of the findings of this study should be premised on further comprehensive economic analysis. This is because the cost of compressor stations was assumed to include the cost of the fans used but the horsepower requirements used for the economic analysis were only those obtained from the compressor rating.
- Also, energy stream was not modelled in some of the pipelines as heat loss was assumed to be negligible along the pipeline. This should not be the case in highly temperate regions and for long distant pipeline transmission.

7. REFERENCES

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8. Appendix A

VELOCITY PROFILES ALONG PIPELINES

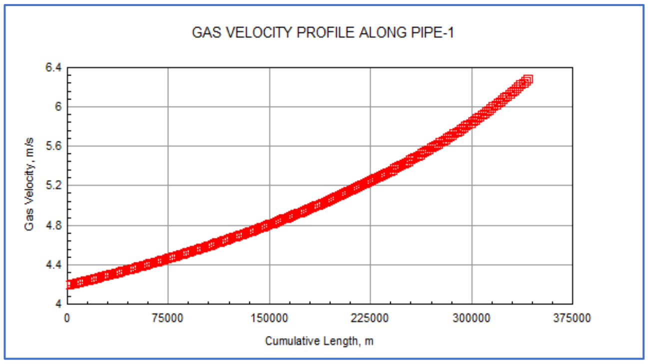

Figure A- 14: Gas Velocity Profile along Pipeline for Gas Transmission from Escravos to Lagos

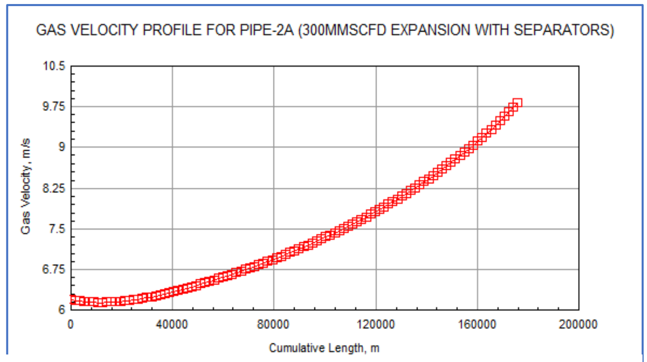

Figure A- 13: Gas Velocity Profile along PIPE-2A (300mmscfd Expansion with Separators)

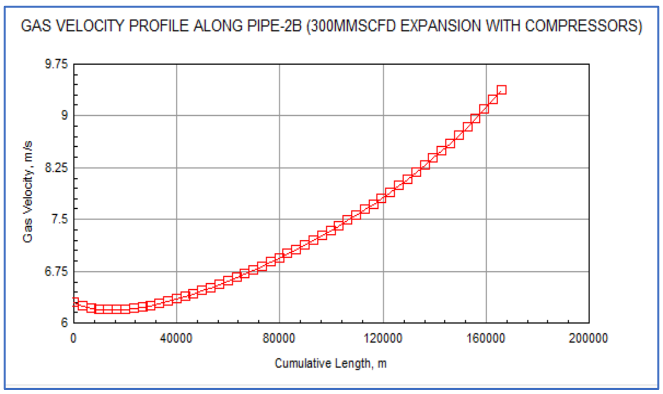

Figure A- 16: Gas Velocity Profile along PIPE-2B (300mmscfd Expansion with Separators)

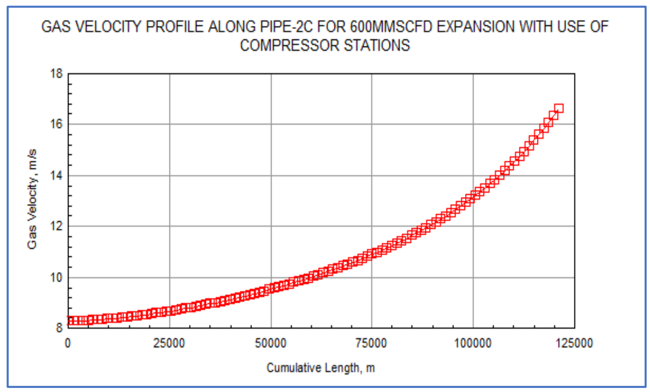

Figure A- 15: Gas Velocity Profile along PIPE-2C for 600mmscf Expansion with Compressor Stations

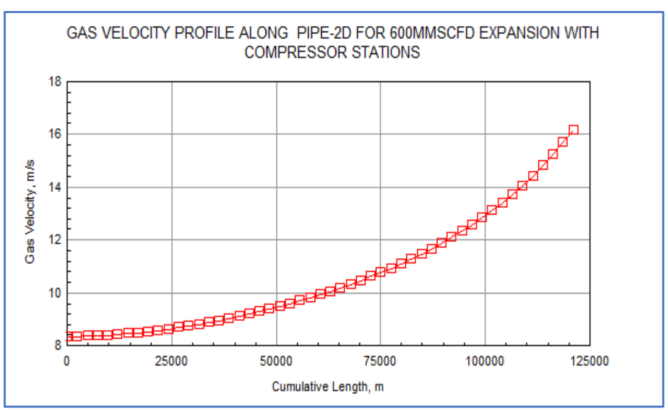

Figure A- 17: Gas Velocity Profile along PIPE-2D for 600mmscfd Expansion with Compressor

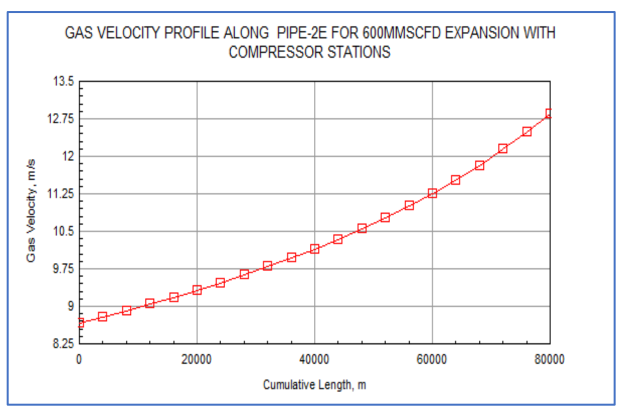

Figure A- 18: Gas Velocity Profile along PIPE-2E for 600mmscfd Expansion with Compressor Stations

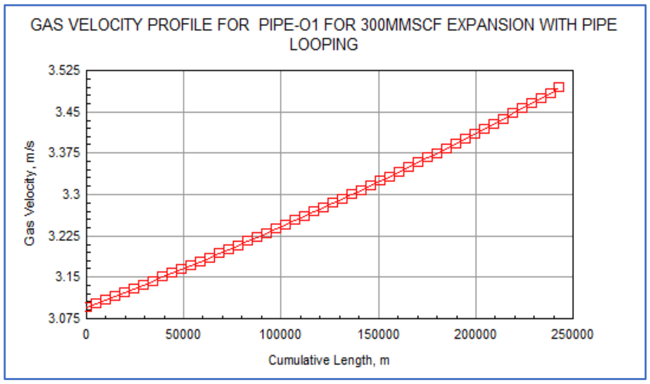

Figure A- 19: Gas Velocity Profile along PIPE-O1 for 300mmscfd Expansion with Pipeline Looping

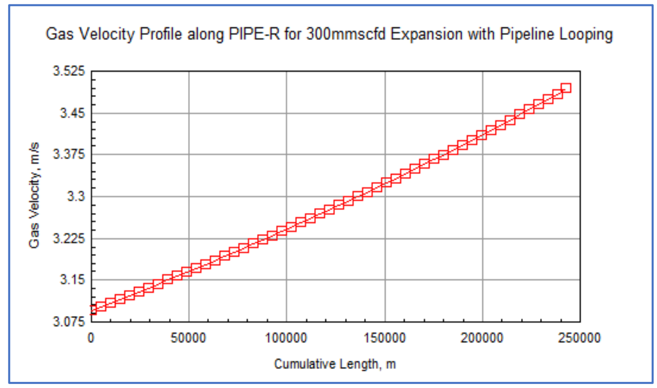

Figure A- 20: Gas Velocity Profile along PIPE-R for 300mmscfd Expansion with Pipeline Looping

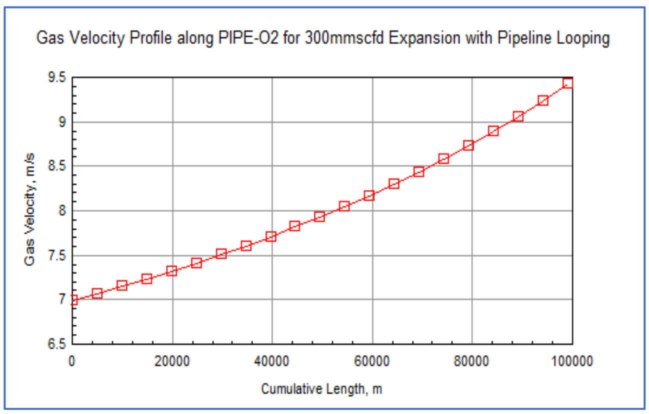

Figure A- 21: Gas Velocity Profile along PIPE-O2 for 300mmscfd Expansion with Pipeline Looping

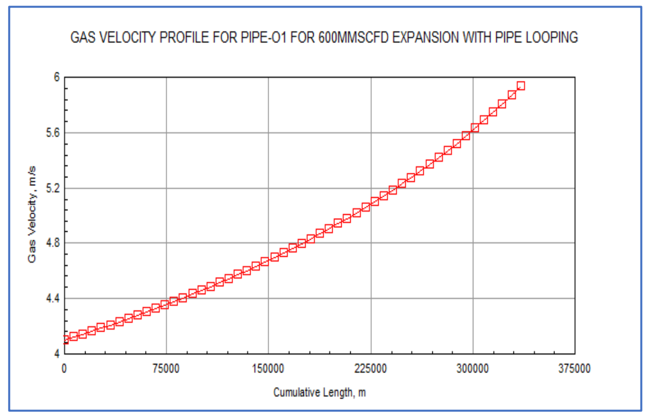

Figure A- 22: Gas Velocity Profile along PIPE-O1 for 600mmscfd Expansion with Pipeline Looping

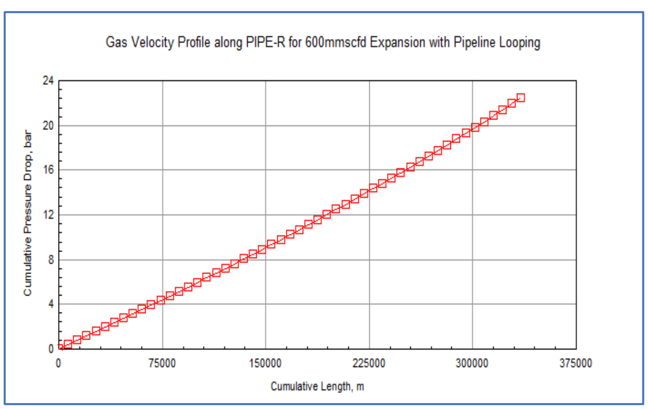

Figure A- 23: Gas Velocity Profile for PIPE-R for 600mmscfd Expansion with Pipeline Looping

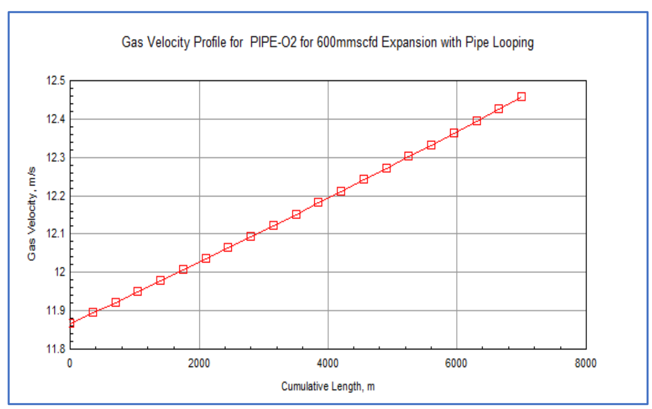

Figure A- 24: Gas Velocity Profile for PIPE-O2 for 600mmscfd Expansion with Pipeline Looping