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Optimal Design of Gas Pipeline Transmission Network

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Abstract

This work is on the optimal design of gas flowline system. The study involves designing of an optimal configuration of a pipeline system with optimum pipeline size and optimum number of compressors. The pipeline system used as a case study consists of three pipelines (pipeline A, 1,6km, pipeline B, 2 km, and pipeline C, 2.4 km) to a field manifold and eventually to a central processing facility (CPF) via a bulk line which is 75 km to the CPF. The optimization techniques employed in this study were iterative estimation method and Artificial Bee Colony (ABC) algorithm method. Upheaval buckling analysis, on-bottom stability analysis and pipeline end expansion analysis were further performed on the flowline system to ensure that it is strong enough to contain and transport the Non-Associated Gas (NAG) the CPF while satisfying the life span requirement and at minimum cost of investment and operation. The results shows that the optimal pipe diameter for the three hook-up pipelines and the bulkline considered are 6”, 6”, 8”, and 20” respectively. The upheaval buckling analysis results show that the flowlines are not at risk from upheaval buckling at a burial depth of 1.2m with safety factors greater than1.5 for all imperfection heights. The on-bottom stability analysis results show that the flowlines are stable and the wall thicknesses are sufficient for the attainment of a negative buoyancy effect at the swamp sections and shall not require concrete coating. The optimal number of compressor stations analysis shows that 1 intermediate compressor is needed to effectively move the gas via the bulkline from the field manifold to the CPF. The analysis could be applied to other pipeline systems.

Keywords: Artificial bee colony, End expansion analysis, On-bottom stability, Optimal number of compressors, Upheaval buckling.

1. INTRODUCTION

A pipeline is a facility through which liquids, gases or (to some extent) solids (like slurries) are transported. Although other forms of transportation are available, pipelines are the safest and most efficient and economic means of transporting crude oil and natural gas (NG) from producing fields to processing plants, refineries, and to the consumers. As gas travels through the pipeline, gas pressure decreases due to friction with the pipe wall. Hence, it is necessary to increase the pressure at a number of points along the pipeline to keep the gas flowing. Compressor stations are installed along pipelines to provide necessary energy to maintain the required pressure throughout the pipeline.

Numerous works have been done from the scientific programming point of view, albeit few have been made toward numerical models for the line-packing difficulties, for example, Krishnaswami et al. [1] simulated good pressure points in compressor locations to match a particular line packing in a flowline system that was non-isothermal. Carter and Rachford [2] talked about a few control procedures to work pipeline frameworks through times of fluctuating burdens. The analysis was to look out for a good arrangement for the line-pack within varying presumptions. De Wolf and Smeers [3] used linear and nonlinear impediments to model the NG pipeline framework to reduce cost. Chung et al. [4] proposed a multi-objective numerical programming strategy. Venture costs, unwavering quality and ecological effect form the three distinct destinations of the model. Uraikul et al. [5] proposed a Mixed Integer Linear Programming (MILP) model to improve the activities of choosing and controlling the compressor. The target of the examination is to limit the working expenses of the system and satisfy client needs in the framework. Belyaev and Patrikeev [6] carried out an investigation on the effect of varieties of gases, by utilizing remedy factors that rely upon the pipe thickness under standard conditions. Menon [7] built up that the pipeline opposition, additionally alluded to as the most extreme flow capability in a pipeline, is firmly reliant on the physical properties of pipelines and the type of the gas. Babu et al. [8] introduced a model to structure the ideal gas transmission network.

Rios-Mercado et al. [9] proposed a heuristic arrangement calculation for gas transmission issues having the structure of a round tree. The system is made out of two phases. At the primary stage, dynamic computer program is utilized to discover ideal qualities for weight factors while the stream factors are fixed. Borraz-Sanchez and Rios-Mercado [10] considered the ideal for compressor station tasks in the cyclic gaseous petrol pipeline framework while limiting the fuel utilization of the stations. In different investigations, heuristic methodologies were proposed so as to limit blower station costs. The subterranean insect state improvement calculation is utilized out of the blue for considering gas stream tasks in the investigation of Chebouba et al.[11]. Hamedi et al. [12] proposed progressive calculation to take care of dispersion arrange issue by utilizing a solitary target, multi-period blended number nonlinear programming (MINLP) display.

Adeyanju and Oyekunle [13] displayed a streamlining methodology of petroleum gas transmission organized by utilizing the Reduced Gradient calculation, which is a numerical enhancement procedure. Frimannslund and Haugland [14] pursued the thoughts exhibited and crafted by Carter and Rachford [2] and proposed a scientific definition to adapt to line-pressing dimensions for a pipeline arrange framework in unfaltering state conditions. Zavala [15] exhibited a stochastic model to take care of the line-pressing issue. The model likewise catches the system elements by discretizing the overseeing incomplete differential conditions in reality. Chaczykowski [16] examined one-dimensional, non-isothermal gas stream model to mimic moderate and quick liquid homeless people. Their work depends on precarious warmth move term in the vitality condition. Borraz-S'anchez and Haugland [17] examined the impact brought about by the changeability of the particular gravity and compressibility of the gas on stream evaluations in transmission pipeline frameworks. They broadened recently recommended models by fusing the variety in pipeline stream limits with gas explicit gravity and compressibility.

This study involves optimal design of a pipeline system using iterative estimation method and artificial bee colony algorithm method. The pipeline system comprises hook-up flowlines consisting of three pipelines (pipeline A, 1,6km, pipeline B, 2 km, and pipeline C, 2.4 km) to a field manifold and eventually to a central processing facility via a bulk line which is 75 km length. Aside determining the pipeline diameters, this work also involves upheaval buckling analysis, on-bottom stability analysis and pipeline end expansion analysis on the flowline system.

2. MATERIALS AND METHODS

2.1 Gas Pipeline Design Criteria

The basic assumptions made in gas pipeline design used in this work include negligible elevation (horizontal pipe), isothermal flow, negligible change in kinetic energy; no mechanical work is done on the gas and steady-state flow. In addition, the arrival pressure of 135 bar was used while pipeline life cycle of 30years was considered. The optimal gas pipeline design criteria include pipeline routing, pipeline sizing (pipeline diameter determination) using different methods, wall thickness of pipeline, upheaval buckling analysis, on-bottom stability design analysis, and end expansion pipeline analysis.

General Sizing Philosophy

The general sizing philosophy was applied for the flowline [18]. The general sizing philosophy is represented with a simple flow chart in Appendix A.

2.1.1 Gas Pipeline Diameter Estimation

The optimum pipeline size is hinged on a 'lifetime' study of the pipeline system, considering the capital cost for installing the compressors, the pipeline itself, receiving facilities, as well the operational cost for the system [7]. Pipeline diameter sizes for gas lines could be estimated from the American Gas Association (AGA) Equation [18],

$$V = \frac{P_{in}^2 - P_{out}^2}{L} = CfzT\rho \frac{q^2}{d^5} \quad (1)$$

where P_{in} is inlet pressure (MPa), P_{out} is outlet pressure (MPa), L is pipe length (m), C is constant $= 5.7 \times 10^{-10} \left(\frac{MPa}{K}\right)$, F is friction factor, z is gas compressibility factor, T is temperature (K), ρ is gas density $\left(\frac{kg}{m^3}\right)$, q is flow rate at standard conditions $\left(\frac{m^3}{s}\right)$, and d is pipe internal diameter (m). An approximation of Equation (1) can be done, when the change in pressure is under 10% of inlet pressure:

$$P_{in}^2 - P_{out}^2 \cong 2P_{in}(P_{in} - P_{out}) \quad (2)$$

Substituting Equation (2) in Equation (1) and rearranging, we have,

$$\Delta P = (P_{in} - P_{out}) = CfzTL\rho \frac{q^2}{2P_{in}d^5} \quad (3)$$

The gas density formula is given as;

$$\rho = \frac{PM}{zRT} \quad (4)$$

where M is molecular mass (kg/Kmole) and R is gas constant (R = 8314 J/kmole.K). The compressibility factor can be obtained from z-factor charts or from Equation (5),

$$z = \frac{PV}{RT} \quad (5)$$

2.1.2 Estimation of the Flowline Diameter by Iteration

The primary consideration in pipeline diameter sizing is based on the flow rate of the gas via the line for an acceptable pressure drop and gas velocity. The process may follow the sequence below:

i. Start with an educated guess as the pipe size (diameter). Estimate the flow velocity that meets the criteria recommended.
ii. Estimate the pressure drop using the AGA equation for gas line. Determine the upstream pressure that should give the required downstream pressure. If the upstream pressure so obtained exceeds the available downstream pressure for the desired flow rate, then the selected pipeline size is not adequate, hence we go for the next larger pipe size. Conversely, If the upstream pressure so obtained is lower than the available pressure for the desired flow rate, then the pipe may have been over sized and the next smaller pipe diameter should be considered.
iii. The above steps should be repeated until an optimum size (i.e. the size that gives an upstream pressure requirement, lower than the available source pressure without exceeding the pressure limit of the pipe material or its associated fittings) is obtained.
iv. Thereafter, other secondary conditions (e.g. low flow conditions, flow regime, temperature, erosional velocity and liquid holdup should be investigated.

2.1.3 Velocity Criteria for Pipeline Sizing

For gas flow lines, the following sizing criteria apply:

i. Recommended velocity is 5 – 10 m/s
ii. Continuous operation above 20 m/s should be avoided.

Generally, the velocity of gas at any point in a flowline is given by Equation (6) [7],

$$u = 14.7349\left[\frac{Q_b}{d^2}\right]\left[\frac{P_b}{T_b}\right]\left[\frac{ZT}{P}\right] \qquad \text{(SI units)} \tag{6}$$

where u is gas upstream velocity (m/s), Q_b is standard condition gas flow rate (m^3/day), d is inside diameter of pipe (mm), P_b is base pressure (MPa), T_b is base temperature (K), Z is upstream gas compressibility factor, T is gas temperature at upstream (K) and P is upstream pressure (MPa).

2.1.4 Erosional Velocity Criteria for Pipeline Sizing

Erosional velocity is another primary basis for sizing production manifolds, process headers, flowlines and other lines transmitting gas and liquid in multi-phase flow. The erosional velocity is defined as follows [7]:

$$V_e = \frac{C}{\sqrt{\rho}} \tag{7}$$

where V_e is erosional velocity, C is a constant $(75 < C < 150)$ and ρ is gas density. Substituting for ρ from Equation (4) into Equation (7) and rearranging it, we obtain,

$$V_e = C\sqrt{\frac{zRT}{PM}} \tag{8}$$

Substituting $M = 29G$ into Equation (8), we obtain,

$$V_e = C\sqrt{\frac{zRT}{29GP}} \tag{9}$$

where G is gas gravity (dimensionless).

Another criterion for pipeline sizing is liquid holdup, although this was not considered in this research.

2.2 Nominal Wall Thickness

The wall thickness is obtained on the basis of the principle of thin-walled stresses, modified with a safety factor to limit the allowable stresses and it is by Equation (10) [19],

$$t_{min} = \frac{PD}{2\sigma_Y FET} + C_A + t_{tol} \tag{10}$$

where t_{min}, P, D, σ_y, E, F, T, C_A, and t_{tol} are pipe wall minimum thickness (mm), pipe internal design pressure (N/mm^2), outside pipe diameter (mm), pipe specified minimum yield strength (N/mm^2), seam pipe factor, design factor, temperature deration factor (1.00, for temperature $< 250^oC$), corrosion allowance (3mm) and manufacturing tolerance (0.5mm) respectively.

2.3 Artificial Bee Colony (ABC) Algorithm

The artificial bee colony algorithm is an optimization technique which mimics the astute hunting actions of bees. Unconstrained optimization issues are usually resolved by the ABC Algorithm [20]. The optimization code has two functions: the start and the objective functions. The start function sets the minimum and maximum permissible values for the variables, which also sets the maximum cycle number (MCN). In the objective function, the constants are declared. The objective is to get the minimum pressure drop ($p_1 - p_2$) which is assigned to the variable z. p_1 is the pressure at inlet and it is an input data. The ABC algorithm selects a pipe diameter, computes the value of p_2, the pressure drop and the number of iterations or maximum cycle number. Pipe diameter is provided as an input parameter, but the optimizer changes the value in each cycle. Other parameters (u_1, u_2 and V_e) are equally calculated. The pipe diameter at the minimum pressure drop is chosen as the optimized pipe diameter.

2.4 Upheaval Buckling Analysis (Design for Buckling)

Upheaval buckling occurs in buried flowlines that runs at high temperatures and pressures. The steps for assessing the risk of upheaval buckling are:

i. Driving force estimation;
ii. Determination of the total downward force needed for the pipeline to stay in position without upheaval buckling;
iii. Estimation of the available downward force (sum of pipeline weight and uplift resistance)
iv. Comparison between the required downward force and available downward force (expressed as a Safety Factor);
v. Calculation of equivalent stresses in the flowline.

An 'initial imperfection' is assumed in the trench outline for the assessment of upheaval buckling. For this work, an initial imperfection of 0.2 m to 0.4 m is assumed.

2.4.1 Calculation of Axial Driving Force

The axial force P is given as [18],

$$P = P_{Total} = P_1 + P_2 + P_3 + P_4 \tag{11}$$

where P_1 , P_2 P_3 and P_4 are the residual effective lay tension, change in axial force induced by hydro-testing, pressure component induced by operating conditions and temperature component induced by the conditions of operation respectively. P_1 and P_2 components are assumed negligible in this work.

The pressure component, P_3 is estimated by Equation (12),

$$P_3 = \frac{\pi D_i^2}{4}(1 - 2v)(P_i - P_e) \tag{12}$$

whereP_i $is\ the$ design maximum internal pressure, P_e $is\ the$ maximum external design pressure, v is Poisson ratio and $D_i is\ the$ internal diameter.

The temperature component, P_4, is estimated as,

$$P_4 = EA\alpha(T_m - T_i) \tag{13}$$

where T_m $is\ the$ operation maximum temperature, T_i is the installation temperature, α is the linear thermal expansion coefficient, E is Young's modulus and A is the pipe internal area. The pipe internal area is given as,

$$A = {}^{\pi}/_{4}\left(D_o^2 - D_i^2\right) \tag{14}$$

where D_i and D_o are the pipe internal diameter and external diameter respectively.

2.4.2 Calculation of Available Uplift Resistance

For buried pipelines, for non-cohesive cover (eg. sand, gravel or crushed rock) the upward resistance force, F is calculated by Equation (15) [18],

$$F = W_{sub} + q_{nc} \tag{15}$$

where W_{sub} is the pipeline operating submerged weight and q_{nc} is the uplift resistance of the over-burden. W_{sub} is equal to the installation submerged weight (W_{Inst}).

$$\mathrm{W}_{Inst.} = W_{Mat.} + W_{Con.} - \text{Bouyancy} \tag{16}$$

$$W_{Mat} = Weight\ of\ material\ in\ air = {}^{\left[\pi(D^2 - (D - 2t)^2) \times \rho_{Mat.} \times g\right]}/_{4} \tag{17}$$

$$W_{Con} = Weight\ of\ concrete\ in\ air = {}^{\left[\pi((D - 2t_{con})^2 - D^2) \times \rho_{con} \times g\right]}/_{4} \tag{18}$$

$$\text{Bouyancy} = {[\pi((D - 2t_{con})^2) \times \rho_{Water} \times g]}/{4} \tag{19}$$

The uplift resistance of the over-burden is given as,

$$q_{nc} = \gamma D_{eff} H \left[1 + f\, {H}/{D_{eff}}\right] \tag{20}$$

where γ *is the* over submerged weight, H (m) is the cover (from top to surface of pipe), f is uplift coefficient (f = 0.5 for dense sand, rock cover; f = 0.1 for loose sand), and D_{eff} is the effective diameter (including coating etc.).

For cohesive cover (e.g. clay, silt and mud) the resistance force F is given by:

$$F = W_{sub} + q_c \tag{21}$$

where q_c *is t*he uplift resistance of the over − burden.

$$q_c = cD_{eff\times} min\left[3,\ {H}/{D_{eff}}\right] \tag{22}$$

where D_{eff} *is the o*utside diameter of pipe and c is the cover shear strenght.

2.4.3 Estimation of Required Uplift Resistance

For buried pipelines, the required downward force, W_{req} is given by Equation (23) [18],

$$W_{req} = \left[1.16 - \left(\frac{4.76}{P_{Total}}\right) \times \sqrt{\frac{EIW_{inst}}{\Delta h}}\right] \times \left[P_{Total} \times \sqrt{\frac{\Delta h W_{inst}}{EI}}\right] \tag{23}$$

where EI is the pipeline flexural rigidity and Δh *is* Imperfection height

.

$$I = \frac{\pi}{64}(D^4 - (D - 2t)^4) \tag{24}$$

A comparison between the required and actual uplift resistance is expressed as a safety factor, SF:

$$SF = {F}/{W_{req}} \tag{25}$$

A conservative design factor of 1.5 was used in this work. It is assumed that the pressure and temperature profiles remain constant, pipeline is straight and no residual installation axial tension.

2.5 On-Bottom Stability Design Analysis

On-bottom stability analysis was carried out to ascertain the stability demands of the flowline to prevent possible sinking or floatation [18]. The mainline section wall thickness was applied in the analysis because it gives the results for the worst case scenario of stability that could be encountered during the entire life span of the pipe.

2.5.1 Concrete Coating Calculation

River Sections

The flowline weight is dependent on the buoyancy of the line, which is the volume of water weight supplanted by pipe, the liquid load weight carried by the pipe and the backfill weight (if trenched) [18]. Figure 1 shows a pipe buried in backfilled trench.

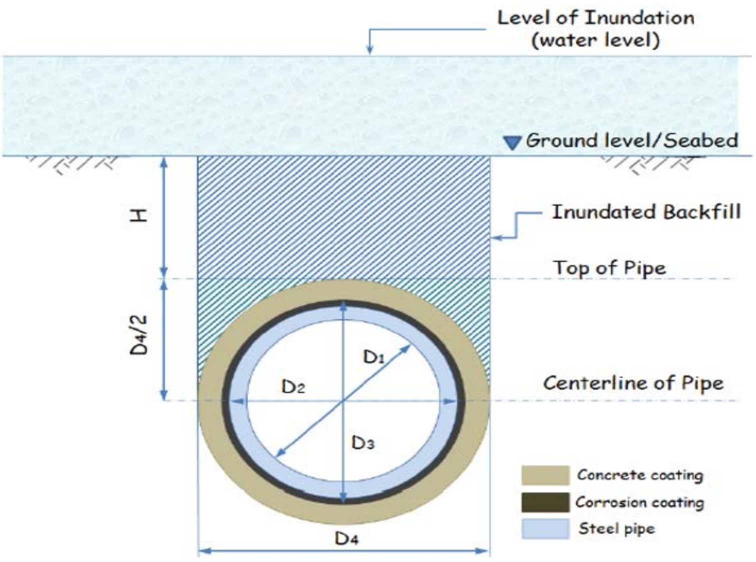

Figure 1: Pipe buried in backfilled trench [18]

H = Depth from top of pipe to backfill surface (m)
D_1 = Internal steel pipe diameter (m)
D_2 = Outside steel pipe diameter (m)
D_3 = Outside pipe diameter with corrosion protection (m)
D_4 = Outside pipe diameter with concrete coating (m)

The description of the forces due to the buoyancy of the river water is as follows:

$$W_p = g\frac{\pi}{4}\left[\rho_{st}\left(D_p^2-\left(D_P-2t_p\right)^2\right)+\rho_{cp}\left(\left(D_p+2t_{cp}\right)^2-D_p^2\right)\right] \tag{26}$$

where W_p is the weight of pipe with corrosion protection in air (N/m), D_p is the pipe outside diameter (m), t_p is pipe wall thickness (m), ρ_{cp} is the density of corrosion protection coating (kg/m^3) and t_{cp} is the thickness of corrosion protection coating (m).

$$W_{con} = g\frac{\pi}{4}\left[\rho_{cc}\left(\left(D_P+2t_{cp}+2t_{cc}\right)^2-\left(D_P+2t_{cp}\right)^2\right)\right] \tag{27}$$

where W_{con} is the concrete weight in air (N/m) and t_{cc} is the thickness of concrete coating (m), ρ_{cc} is the is the density of concrete coating (kg/m^3).

$$W_{lf} = g\frac{\pi}{4}\left[\rho_{lf}\left(\left(D_P-2t_p\right)^2\right)\right] \tag{28}$$

where W_{lf} is the weight of line-fill (N/m) and ρ_{lf} is the density of line-fill (kg/m^3).

$$W_{dw} = g\frac{\pi}{4}\left[\rho_w\left(\left(D_P+2t_{cp}+2t_{cc}\right)^2\right)\right] \tag{29}$$

where W_{dw} is the weight of water supplanted by the concrete and corrosion coated pipe (N/m) and ρ_w is the density of river / swamp water (kg/m^3).

$$W_{bf} = g\left(1.073D_p^2+HD_p\right)\left(1-\frac{1}{s_{bf}}\right)\rho_{bf} \tag{30}$$

where D_p is the outside pipe diameter (m), H is the soil cover over pipe (m), s_{bf} is the specific gravity of backfill particles and ρ_{bf} is the bulk unit weight of dry backfill, lb/ft^3.

The correlation of the lift and drag forces to the effective transverse is generalized by the Equation (31)which is suitable for steady state currents found in rivers,

$$W_c = \rho_w V^2 d \left[\frac{f}{\mu} C_d + C_L\right] \tag{31}$$

where W_C, V, d, f, μ, C_d and C_L are weight per unit length of pipe, perpendicular velocity,, outside diameter of line, safety factor, soil to pipe friction factor, coefficient of drag and coefficient of lift respectively. A summation of these vectors therefore gives,

$$W_p + W_{con} + W_{lf} + W_{bf} \geq W_{dw} + W_c + 0.25W_p \tag{32}$$

In order to avoid floatation in water, the total downward forces acting on the flowline (Submerged weight) shall be over the peak upward force on the line.

2.6 Pipeline End Expansion Analysis

The method of analysis applied in calculating the flowline end expansion is on the basis of stress-strain relation. Pipeline end expansion as analysed from the flowlines end expansion is [18],

$$\Delta L = \Delta L_P - \Delta L_f + \Delta L_T \tag{33}$$

where ΔL_P is the end expansion due to pressure effect, ΔL_T is the end expansion due to temperature effect and ΔL_f is the end expansion due to soil friction (resistance to end expansion). These parameters are given by relations in Equations (34) to (36),

$$\Delta L_P = \frac{[(0.5 - \upsilon).\delta_{Ho}.L]}{E} \tag{34}$$

$$\Delta L_T = \alpha(T_{max} - T_{inst})L \tag{35}$$

$$\Delta L_f = \frac{fL^2}{2\pi t_n DE} \tag{36}$$

where L is the pipeline active length. It is given as,

$$L = \frac{F_A - Q}{f} \tag{37}$$

where F_A is the axial expansion force. It is given by Equation (38),

$$F_A = (A_{st} + A_{cc})[(0.5 - \upsilon).\delta_{Ho} + E.\alpha.(T_{max} - T_{inst})] \tag{38}$$

where A_{st}, A_{cc}, υ, δ_{Ho}, E, D, α, t_n, T_{max}, T_{inst}, f, and Q are the cross-sectional area of steel pipeline, cross-sectional area of the steel pipeline coating, Poisson ratio, hoop stress, Young's modulus, total outer diameter of pipeline, thermal expansion coefficient, pipeline nominal wall thickness, maximum operating temperature, installation temperature, soil axial friction force and end resistance force from end facility respectively.

2.7 General Criteria for Pipeline Diameter Selection

Three criteria are used for pipeline diameter selection in this work. They are highlighted here:

i. Pressure drop – Small pressure drop is desirable.
ii. Gas velocity –Gas velocity in the range 5 – 10 m/s is required.
iii. Erosional velocity – The erosional velocity should be 50% more than the gas velocity.

These three criteria are applied to each of the pipelines using the results from the AGA equation and the ABC algorithm to select the optimum diameter for each pipeline.

2.8 Optimal Number of Compressor Stations

Between the three pipelines and the field manifold, pressure drop is small due to the short distances and hence no intermediate compressor station is necessary. The Maximum Allowable Operating Pressure (MAOP) which is the flowline design pressure at the field manifold is limited to 13.5MPa. The distance between the field manifold and the central processing unit is much and as such there will be considerable pressure drop along the line. The pressure need to be boosted at an in-between. One method is to fix a compressor in-between the manifold and the CPU, and afterward estimate the distance between the intermediate compressor and the CPU, so that beginning at 13.5MPa at intermediate compressor, the gas suction pressure at CPU is exactly 11MPa. This is achieved by applying the AGA Equation to the length of flowline with upstream and downstream pressure of $13.5MPa$ and $11MPa$ respectively.

2.9 Input Data for the Analysis

The input data for this work are presented in Tables 1 to 3.

Table 1: Design and operating parameters

S/NO.	Parameter	Unit	Value
1	Flowline Material	-	2205 Duplex Stainless Steel
2	CITHP (Closed-In Tubing Head Pressure)	bar	202
3	FTHP (Flowing Tubing Head Pressures)	bar	143/193
4	Design Pressure	bar	353
5	Design Temperature	(°C)	-50/80
6	Design Flow rate	(MMscfd)	31
7	Pipe Wall Roughness (mm)	Mm	0.01-0.03
8	Manifold Arrival Pressure (bar)	bar	135
9	Mean Minimum Ambient Temperature	°C	23
10	Minimum Ambient Temperature	°C	18
11	Mean Maximum Ambient Temperature	°C	31
12	Maximum Ambient Temperature	°C	35

Table 2: Thermal conductivity of materials (W/m-K)

S/NO.	Parameter	Value
1	Duplex Stainless Steel	23
2	Carbon Steel	45
3	Wet Soil/Sand	2.1
4	Polyethylene coating	0.4

Table 3: Flowline mechanical design data

S/NO.	Parameter	Unit	Value
1	Pipe Outside Diameter	mm	168.3
2	Wall Thickness	mm	13.2
3	Material Grade	-	API 5LC grade LC 65-2205
4	Flange Rating (ANSI CLASS)	-	2500#
5	Corrosion Allowance (2)	mm	0.3
6	Corrosion Coating Material	-	3LPP
7	Corrosion Coating Thickness	mm	2.0
8	Corrosion Coating Density	kg/m^3	890
9	Concrete Coating Density	kg/m^3	3040
10	Pipe material Density	kg/m^3	7850
11	Content Density	kg/m^3	184.77

Table 3: Continuation

S/NO.	Parameter	Unit	Value
12	Water Density	kg/m^3	1025
13	CITHP	bar	202
14	Design Pressure (1)	bar	353
15	Specified Minimum Yield Strength	MPa	448.0
16	Pipe material Density	kg/m^3	7850
17	Poisson's Ratio	-	0.3
18	Young Modulus	N/mm^2	1.9×10^5
19	Coefficient of thermal Expansion	per °C	13.7×10^{-6}
20	Design Temperature (min/max)	°C	-50/80
21	Ambient Temperature	°C	23
22	Design Life	Years	30

3. RESULTS AND DISCUSSION

Pipeline Iteration Results

Pipeline A was sized based on design flow rate of 28 MMscfd. Summary of iteration results for pipeline A are in Tables 4, 5 and 6.

Table 4: Summary of the iteration results of the pressure drop and suction pressures at a flow rate of 28 MMscfd

Guess Pipeline Sizes (in)	Inlet Pressure P_1 (MPa)	Pressure Drop (MPa)	Outlet Pressure P_2 (MPa)
4 (0.1016m)	14.2413	0.7413	13.5
6(0.1524m)	13.5999	0.0999	13.5
8(0.2032m)	13.5238	0.0238	13.5
10(0.254m)	13.5078	0.0078	13.5
12(0.3048m)	13.5031	0.0031	13.5
14(0.3556m)	13.5015	0.0015	13.5

Table 5: Summary of the iterative results of the inlet velocities and outlet velocities at a flow rate of 28 MMscfd

Guess Pipeline Sizes (in)	Inlet Pressure P_1 (MPa)	Outlet Pressure P_2 (MPa)	Inlet Velocity u_1 (m/s)	Inlet Velocity u_2 (m/s)
4 (0.1016m)	14.2413	13.5	8.7315	9.2110
6 (0.1524m)	13.5999	13.5	4.0637	4.0938
8 (0.2032m)	13.5238	13.5	2.2987	2.3028
10 (0.254m)	13.5078	13.5	1.4729	1.4738
12 (0.3048m)	13.5031	13.5	1.0232	1.0234
14 (0.3556m)	13.5015	13.5	0.7518	0.7519

Table 6: Summary of the iterative results of erosional velocities at a flow rate of 28MMscfd for

Inlet Pressure P_1 (MPa)	Outlet Pressure P_2 (MPa)	Inlet Velocity u_1 (m/s)	Inlet Velocity u_2 (m/s)	Erosional Velocity (m/s)
14.2413	13.5	8.7315	9.2110	18.1540
13.5999	13.5	4.0637	4.0938	18.5772
13.5238	13.5	2.2987	2.3028	18.6293
13.5078	13.5	1.4729	1.4738	18.6404
13.5031	13.5	1.0232	1.0234	18.6436
13.5015	13.5	0.7518	0.7519	18.6447

Pipeline B was sized based on design flow rate of 31 MMscfd. Summary of iteration results for pipeline C are shown in Tables 7, 8 and 9.

Table 7: Summary of the iterative results of pressure drop and outlet pressures at a flow rate of 31MMscfd

Guess Pipeline Sizes (in)	Inlet Pressure P_1 (MPa)	Pressure Drop (MPa)	Outlet Pressure P_2 (MPa)
4 (0.1016m)	14.6205	1.1205	13.5
6 (0.1524m)	13.6528	0.1528	13.5
8 (0.2032m)	13.5364	0.0364	13.5
10 (0.254m)	13.5120	0.0120	13.5
12 (0.3048m)	13.5048	0.0048	13.5
14 (0.3556m)	13.5022	0.00222	13.5

Table 8: Summary of the iterative results of inlet velocities and outlet velocities at a flow rate of 31MMscfd

Guess Pipeline Sizes (in)	Inlet Pressure P_1 (MPa)	Outlet Pressure P_2 (MPa)	Inlet Velocity u_1 (m/s)	Inlet Velocity u_2 (m/s)
4 (0.1016m)	14.6205	13.5	9.4163	10.1979
6 (0.1524m)	13.6528	13.5	4.4817	4.5324
8 (0.2032m)	13.5364	13.5	2.5426	2.5495
10 (0.254m)	13.5120	13.5	1.6302	1.6317
12 (0.3048m)	13.5048	13.5	1.1327	1.1331
14 (0.3556m)	13.5022	13.5	0.8324	0.8325

Table 9: Summary of the iterative calculation results of erosional velocities at a flowrate of 31MMscfd

Inlet Pressure P_1 (MPa)	Outlet Pressure P_2 (MPa)	Inlet Velocity u_1 (m/s)	Inlet Velocity u_2 (m/s)	Erosional Velocity (m/s)
14.6205	13.5	9.4163	10.1979	17.9170
13.6528	13.5	4.4817	4.5324	18.5411
13.5364	13.5	2.5426	2.5495	18.6207
13.5120	13.5	1.6302	1.6317	18.6375
13.5048	13.5	1.1327	1.1331	18.6425
13.5022	13.5	0.8324	0.8325	18.6442

Pipeline C was sized based on design flowrate of 65MMscfd. Summary of iteration results for pipeline C are shown in Tables 10, 11 and 12.

Table 10: Summary of the iterative calculation results of pressure drop and outlet pressures at a flow rate of 65MMscfd

Guess Pipeline Sizes (in)	Inlet Pressure P_1 (MPa)	Pressure Drop (MPa)	Outlet Pressure P_2 (MPa)
4 (0.1016m)	18.6679	5.1679	13.5
6 (0.1524m)	14.2878	0.7878	13.5
8 (0.2032m)	13.6911	0.1911	13.5
10 (0.254m)	13.5629	0.0629	13.5
12(0.3048m)	13.5253	0.0253	13.5
14(0.3556m)	13.5117	0.0117	13.5

Table 11: Summary of the iterative results of inlet velocities and outlet velocities at a flow rate of 65MMscfd

Guess Pipeline Sizes (in)	Inlet Pressure P_1 (MPa)	Outlet Pressure P_2 (MPa)	Inlet Velocity u_1 (m/s)	Inlet Velocity u_2 (m/s)
4 (0.1016m)	18.6679	13.5	15.4632	21.3827
6 (0.1524m)	14.2878	13.5	8.9794	9.5034
8 (0.2032m)	13.6911	13.5	5.2711	5.3457
10 (0.254m)	13.5629	13.5	3.4054	3.4212
12 (0.3048m)	13.5253	13.5	2.3714	2.3759
14 (0.3556m)	13.5117	13.5	1.7440	1.7455

Table 12: Summary of the iterative calculation results of erosional velocities at a flow rate of 65MMscfd

Inlet Pressure (P_1) (MPa)	Outlet Pressure P_2 (MPa)	Inlet Velocity u_1 (m/s)	Inlet Velocity u_2 (m/s)	Erosional Velocity (m/s)
18.6679	13.5	15.4632	21.3827	15.8562
14.2878	13.5	8.9794	9.5034	18.1244
13.6911	13.5	5.2711	5.3457	18.5152
13.5629	13.5	3.4054	3.4212	18.6025
13.5253	13.5	2.3714	2.3759	18.6283
13.5117	13.5	1.7440	1.7455	18.6377

The bulkline was sized based on design flowrate of 100MMscfd. Summary of calculation results is shown in Tables 13, 14 and 15.

Table 13: Summary of the iterative calculation results of pressure drop and outlet pressures at a flowrate of 100MMscfd

Guess Pipeline Sizes (in)	Inlet Pressure P_1 (MPa)	Pressure Drop (MPa)	Outlet Pressure P_2 (MPa)
10 (0.254m)	13.5	4.929	8.5710
14 (0.3556m)	13.5	0.7712	12.7288
18 (0.4572m)	13.5	0.2149	13.2851
22 (0.5588m)	13.5	0.0784	13.4216
26 (0.6604m)	13.5	0.034	13.4660
30 (0.762m)	13.5	0.0166	13.4834
34 (0.8636m)	13.5	0.0089	13.4911
38 (0.9652m)	13.5	0.0051	13.4949
42 (1.0668m)	13.5	0.0031	13.4969

Table 14: Summary of the iterative calculation results of inlet velocities and outlet velocities at a flowrate of 100MMscfd

Guess Pipeline Sizes (in)	Inlet Pressure P_1 (MPa)	Outlet Pressure P_2 (MPa)	Inlet Velocity u_1 (m/s)	Inlet Velocity u_2 (m/s)
10 (0.254m)	13.5	8.5710	4.5477	7.1630
14 (0.3556m)	13.5	12.7288	2.3203	2.4609
18 (0.4572m)	13.5	13.2851	1.4036	1.4263
22 (0.5588m)	13.5	13.4216	0.9396	0.9451
26 (0.6604m)	13.5	13.4660	0.6727	0.6744
30 (0.762m)	13.5	13.4834	0.5053	0.5059
34 (0.8636m)	13.5	13.4911	0.3934	0.3937
38 (0.9652m)	13.5	13.4949	0.3149	0.3151
42 (1.0668m)	13.5	13.4969	0.2578	0.2579

Table 15: Summary of the iterative results of erosional velocities at a flowrate of 100MMscfd

Inlet Pressure P_1 (MPa)	Outlet Pressure P_2 (MPa)	Inlet Velocity u_1 (m/s)	Inlet Velocity u_2 (m/s)	Erosional Velocity (m/s)
13.5	8.5710	4.5477	7.1630	14.5017
13.5	12.7288	2.3203	2.4609	11.8998
13.5	13.2851	1.4036	1.4263	11.6480
13.5	13.4216	0.9396	0.9451	11.5886
13.5	13.4660	0.6727	0.6744	11.5695
13.5	13.4834	0.5053	0.5059	11.5620
13.5	13.4911	0.3934	0.3937	11.5587
13.5	13.4949	0.3149	0.3151	11.5571
13.5	13.4969	0.2578	0.2579	11.5562

Based on results presented above, 6”diameter pipeline is more adequate to evacuate 28 MMscfd and 31MMscfd from Pipeline A and Pipeline B respectively. A 4” flowline is not recommended due to the huge pressure drop of 0.7413 MPa over the 1.6 km pipeline and 1.1205MPa over the 2 km pipeline. For pipeline C, 8” pipeline is more adequate to evacuate 65MMscfd from Pipeline C. A 4” and 6” pipeline is not recommended due to the large pressure drop (5.1679MPa and 0.7878MPa respectively) and high gas velocities over the 2.4 km pipeline. For the bulk pipeline, a 20” pipeline is more adequate to evacuate 100 MMscfd to 200MMscfd (if flow rate is increased to 200MMscfd, same pipeline diameter applies) from the manifold. 10”, 12”, 14” and 16” pipelines are not recommended due to the huge pressure drop over the 75 km pipeline. The ABC algorithm also gave same pipe diameters as judged from the iteration results. The recommended pipeline diameters are presented in Table 17.

Table 17: Recommended pipeline sizes from iterative calculations and ABC algorithm

Hook-up Flowlines	Recommended Pipeline Sizes (inches)
PipelineA (28 MMscfd & 1.6 km) to Manifold	6
PipelineB (31 MMscfd & 2 km) to Manifold	6
PipelineC (65 MMscfd & 2.4 km) to Manifold	8
Bulkline (100 MMscfd & 75 km) from Manifold	20

Upheaval Buckling Analysis Results

The upheaval buckling analysis was done for Pipeline A flowline. The analysis assumed a minimum burial depth of 1.2 m and maximum imperfection height of 0.4 m. Table 18 presents the results for imperfection height range of 0.2m to 0.4m. From the results, the flowline is not at risk of upheaval buckling as the available uplift resistance is greater than the required uplift with the lowest safety factor greater than 1.5.

Table 18: Pipeline a upheaval buckling analysis result

Imperfection Height (m)	Available Uplift Resistance (N/m)	Required Uplift (N/m)	Safety Factor, $SF = {}^{F}/_{W_{req}}$
0.2	10840	4031	2.7
0.3		5466	2.0
0.4		6677	1.6

On-Bottom Stability Analysis Results

The results of stability analysis carried out for the 6” flowline in swamp with backfilled earth are presented in Table 19. The results indicate that the current wall thickness is sufficient for the attainment of a negative buoyancy effect for pipeline on-bottom stability at the swamp sections. The pipeline is stable and does not require concrete coating.

Table 19: Stability Result Summary

Pipeline	Steel Wall Thickness (mm)	Recommended Concrete Coating Thickness	Safety Factor (Installation)	Safety Factor (Operation)
6” Flowlines	13.2	0	8.65	8.73

End Expansion Analysis Results

Pipeline end expansion was calculated for the 6” flowline using operating conditions. The results are presented in Table 20. The end expansion value is negligible.

Table 20: Pipeline end expansion results

Pipeline	Pipeline Anchor Force (kN)	Net Pipeline End Expansion (mm)
6” Flowline	708.3	19

Optimal Number of Compressor Stations

The analysis showed that the gas pressure required at the manifold is 15.5MPa based on application of the AGA equation, which provides a delivery pressure of 11MPa at the CPU terminus. But, since the maximum allowable operating pressure (design pressure) of the flowline is limited to 13.5MPa, which is lower than 15.5MPa, an intermediate compressor station is installed between the manifold and the CPU. This is shown in the Figure 4.

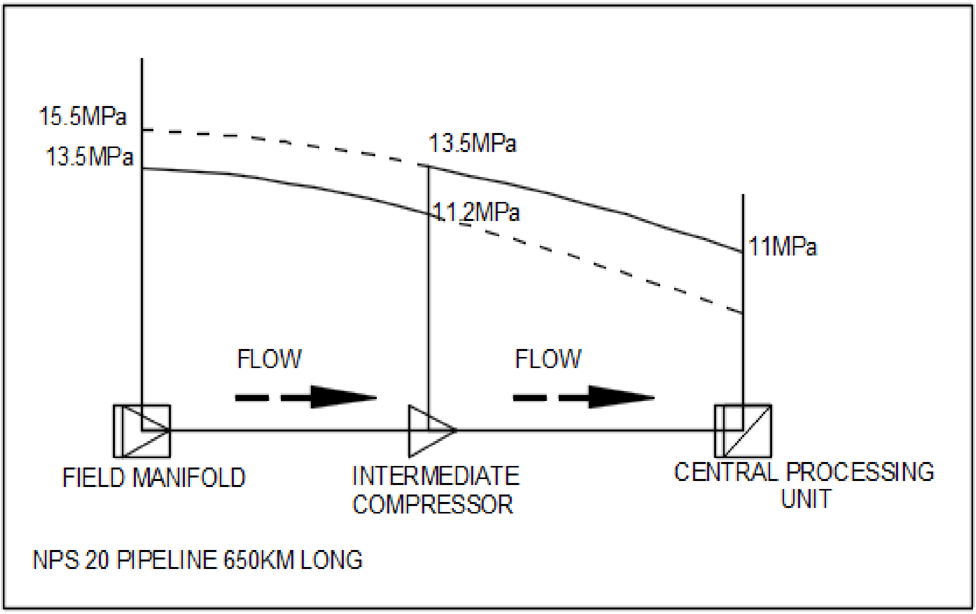

Figure 4: Optimum compressor stations required

4. CONCLUSIONS

Steady State hydraulic iterative calculations and ABC algorithm simulation were employed to determine optimal size (diameter) for a pipeline system consisting of Pipeline A, Pipeline B and Pipeline C which meet at a manifold and a bulk line from the manifold to a central processing unit. Pressure drop, gas velocity and erosional velocity were the three criteria used for pipeline diameter selection, using the AGA equation. The iterative calculations and the ABC algorithm gave the same pipeline diameter for the four different pipelines forming the network. A 6” pipeline size is recommended for the Pipeline A and PipelineB pipeline, while an 8” pipeline size is recommended for the Pipeline C. A 20” pipeline size is recommended for the bulk line. Upheaval buckling analysis, on-bottom stability analysis and pipeline end expansion analysis were further performed on the flowline A. On upheaval buckling, the pipeline is not at risk at a burial depth of 1.2m with safety factors greater than 1.5 for all imperfection heights. At the estimated pipeline thickness, the pipeline is stable with negative buoyancy and hence requires no concrete coating. Also, the end expansion of the pipeline is negligible.

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APPENDIX A

FLOW ASSURANCE FLOW CHART INCORPORATING LINE SIZING PROCESS