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		4031	2.7
0.3	10840	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.

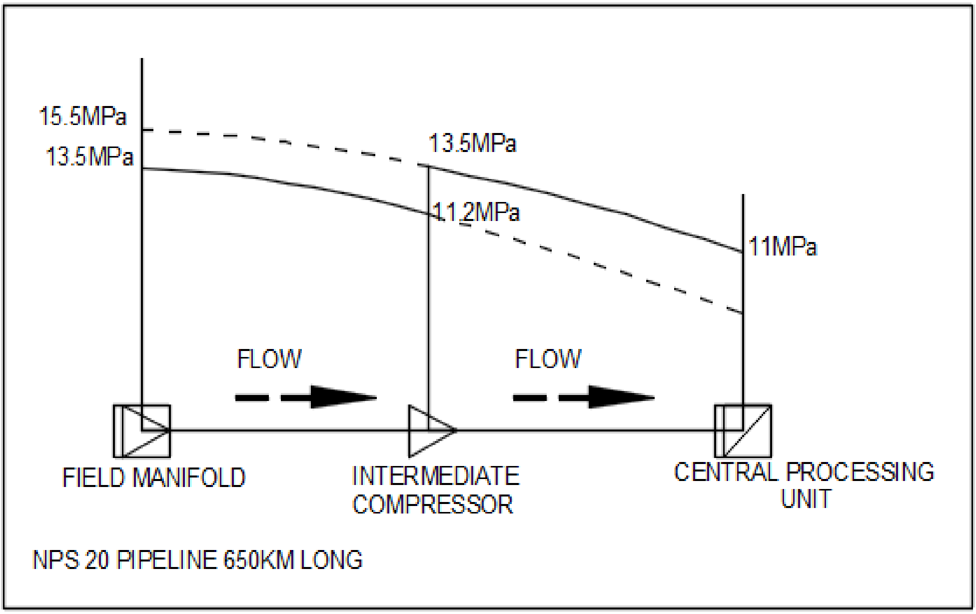

Figure 4: Optimum compressor stations required

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.

REFERENCES

[1] Krishnaswami, P., Chapman, K. S., and Abbaspour, M. (2004) Compressor Station Optimization for Line-Pack Maintenance, In Proceedings of the 36th PSIG Annual Meeting, Palm Springs.

[2] Carter, R. G., and Rachford, H. H. (2003) Optimizing Line-Pack Management to Hedge Against Future Load Uncertainty, In Proceedings of the 35th PSIG Annual Meeting, Bern, Switzerland.

[3] DeWolf, D., and Smeers, Y. (2000) The Gas Transmission Problem Solved by Extension of the Simplex Algorithm, Journal of Management Science, 46, PP.1454-1465.

[4] Chung, T. L., Li, K. K., Chen, C. J., Xie, J. D. and Tang, G. O. (2003) Mult-Objective Transmission Network Planning by a Hybrid Genetic Algorithm Approach with Fuzzy Decision Analysis, International Journal of Electrical Power & Energy Systems, 25, pp.187-192.

[5] Uraikul, V., Chan, C.W., and Tontiwachwuthikul, P. (2003) MILP Model for Compressor Selection in Natural Gas Pipeline Operations, International Society for Environmental Information Sciences, Environmental Informatics Archives, 1, pp.138-145.

[6] Belyaev, B. M., and Patrikeev, V. G. (2003) Influence of Variations of the Composition of Natural Gas from Different Fields on the Results of Mass and Volumetric Flow Rate Measurement under Standard Conditions in Gas Distribution Organizations, Measurement Techniques Journal, 46(5), PP.462–465.

[7] Menon, E. S. (2005) Gas Pipeline Hydraulics, CRC Press, Taylor & Francis Group, 6000 Broken Sound Parkway NW, Suite 300, Boca Raton.

[8] Babu, B.V., Rakesh, A., Pallavi, G., and Syed, J.H. (2005) Optimal Design of Gas Transmission Network Using Differential Evolution, Journal of Multidisciplinary Modelling in Materials and Structures, 1, PP.315-328.

[9] Rios-Mercado, R., Kim, S., and Boyd, E. (2006) Ancient Operation of Natural Gas Transmission Systems: A Network-Based Heuristic for Cyclic Structures, Computers and Operations Research Journal, 33, pp.2323-2351.

[10] Borraz-S´anchez, C. (2010) Optimization Methods for Pipeline Transportation of Natural Gas, PhD Thesis, University of Bergen, Bergen, Norway.

[11] Chebouba, A., Yalaoui, F., Smati, A., Amodeo, L., Younsi, K., and Tairi, A. (2009) Optimization of Natural Gas Pipeline Transportation Using Ant Colony Optimization, Journal Computers and Operations Research, 36, PP.1916-1923.

[12] Hamedi, M., Farahani, R.Z., Husseini, M.M., and Esmaeilian, G.R., (2009) A Distribution Planning Model for Natural Gas Supply Chain: a Case Study, Energy Policy, 37, PP.799-812.

[13] Adeyanju and Oyekunle (2013) Optimization of Natural Gas Transportation in Pipeline, Department of Chemical Engineering, University of Lagos, Nigeria, Available in: http://www.unilag.edu.ng/opendoc.php?sno=16333&doctype=pdf, Retrieved 7 February 2020.

[14] Frimannslund, L. and Haugland, D. (2008) Line Pack Management for Improved Regularity in Pipeline Gas Transportation Networks, In Martorell, S., Guedes-Soares, C., and Barnett, J. (editors), Safety, Reliability and Risk Analysis: Theory, Methods and Applications, volume 4, pp. 2963–2969. CRC Press, London.

[15] Zavala, V.M. (2014) Stochastic Optimal Control Model for Natural Gas Networks, Computers and Chemical Engineering Journal, 64, PP.103–113.

[16] Chaczykowski, M. (2010) Transient Flow in Natural Gas Pipeline: The Effect of Pipeline Thermal Model, Journal of Applied Mathematical Modelling, 34(4), PP.1051–1067.

[17] Borraz-S´anchez, C., and Haugland, D. (2013) Optimization Methods for Pipeline Transportation of Natural Gas with Variable Specific Gravity and Compressibility, TOP, 21(3), PP.524–541.

[18] Cod-energyservices (2020), Pipeline Mechanical Design, Available in: https://www.cod-energyservices.com/Pipeline Mechanical Design/, Retrieved 21 March 2020.

[19] ASME (2018) Gas Transmission and Distribution Piping System, American Society of Mechanical Engineering Code for Pressure Piping, Two Park Avenue, New York.

[20] Zhu, G. and Kwong, S. (2010) Gbest-Guided Artificial Bee Colony Algorithm for Numerical Function Optimization, Journal of Applied Mathematics and Computation, 217(7), pp. 3166–3173

GSJ: Volume 8, Issue 5, May 2020
ISSN 2320-9186

APPENDIX A

FLOW ASSURANCE FLOW CHART INCORPORATING LINE SIZING PROCESS