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Optimizing Natural Gas Pipeline Design to Prevent Hydrate Formation During Gas Transportation

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Abstract:

In this work, Natural Gas pipeline design was optimized to curb the anomalies with maintenance cost and enhancing successful delivery of gas to a plant. Secondary data on the Natural gas compositional streams and field data on the pipeline were obtained and four basic design protocols namely Hydraulic, Mechanical, Geo-technical and Operational Design concepts were applied. Design equations and applicable codes from ASME B31.8, B16.10 and API 5L specifications were used to estimate the Pipe sizing, Maximum Allowable Operating Pressures, Burst Pressure, Collapse Pressure, Hydrotest Pressure. The parameters were validated with ASME codes and PIPEFLEX. The Natural Gas compositional streams were inputted to ASPEN HYSYS and simulation of the natural gas flow was done along the optimized design pipeline. Results shows that the temperature at entry was 68^0F and 86^0F at the exit point with an average temperature of 94.03^0F along the pipeline and a pressure drop of zero as pressure at entry (NG1) was 1072psi and at exit (NG11) became 1072psi.The compression horse power required to transport the Natural Gas in the pipeline was predicted as 60HP. Flow were assured as there were no hydrate formation along the streams and pipe segments with a constant flow regime

Keywords **—Natural Gas, Pipeline, Hydrate Formation, Design, Pressure drop.**

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I. INTRODUCTION

The transportation of Natural gas from field to various points of utilization and market is important because of difficulty in its storage and require a comprehensive infrastructure.Several means of transportation such as Pipeline Natural Gas (PNG), Compressed Natural Gas (CNG), Liquefied Natural Gas (LNG) and Gas To Solid (GTS) are available[1]. Transportation by pipeline regarded as the most safe method of conveying and distributing natural gas to so many points at a large volume requires adequate design of the system for optimum delivery without failure[2]. The design of a natural gas pipeline is the most important aspects of natural gas transmission and distribution through pipeline due to the dangerous nature. This design entails a plan and program that consider all factors not limited to majors (hydraulic components, mechanical components, geothermal parameters and operating/maintenance parameters)for safe and effective distribution and delivery of gas [3].For successful transportation of Natural gas with flow assured in pipelines, optimum design that will consider the length and diameter of the pipeline, flow rate of gas and its composition, suction and discharge pressure of the pipe and number of compressor stations is vital. Optimum design of Natural gas pipeline as the most suitable means of gas transportation is important because of the rise in its demand for residential, commercial, industry and power generation(EIA). In order to optimize the design of Natural gas transmission network,[4] presented a model to optimize the length, diameter and number of compressors of a transmission line. Bolkan et al [5] developed an algorithm for optimizing gas pipeline network design with the operating condition of the system for successful delivery of gas. Adeyanju and Oyekunle[6] applied the reduced gradient algorithm in addressing procedure of natural gas transmission network optimization. Their model was derived from the first source model developed by Edgar et al.[7]. Ainouche[8]developed linear programming model considering taking line pack for the optimal planning of a gas pipeline operating system. Bhaduri and Talachi [9] optimized the Qinghai gas pipeline by predicting the optimum pipe size, compression facilities, pipeline route, operating pressure, and storage facilities, if required. The design, constructions and operation of natural gas pipeline have been guided by developed codes and standards (ASME and API) for personnel safety and reducing the risk of pipeline failure for successful delivery[10]. This work will optimize Natural gas pipeline with codes and standard with all components and parameters of the gas stream for optimal delivery of gas.

II. METHODOLOGY

Hydraulic,Mechanical, Geo-technical and Operational design of the pipeline was done with field data and composition of the gas and inputted in to Aspen Hysys for simulation.

A. Hydraulic Design Parameters

The properties of the Natural gas flowing through the system are presented in Table 1.

Table 1 .Computation of Natural gas Physical Properties

Gas Comp	Mole %	MW	(MF x MW)	(TCi)	(MF x TCi)	(PCi)	(MFx PCi)
CH_4	87.02	16.04	13.958	343	298.479	668	581.294
C_2H_6	4.96	30.07	1.491	550	27.280	708	35.117
C_3H8	2.43	44.10	1.072	666	16.184	616	14.969
i-C_4H_{10}	1.72	58.12	0.581	735	7.350	529	5.290
n-C_4H_{10}	1.68	58.12	0.976	765	12.852	515	8.652
i-C_5H_{12}	0.46	70.14	0.323	829	3.813	490	2.254
n-C_5H_{12}	0.15	72.15	0.108	845	1.268	489	0.734
C_6H_{14}	0.08	86.18	0.069	913	0.730	437	0.350
CO_2	1.43	44.01	0.629	548	7.836	1071	15.315
H_2S	0.07	34.08	0.024	672	0.470	1306	0.914
	100		**19.232**		376.263		664.888

B. Mechanical Design Parameters

The mechanical design parameters was done with equation (1),(2),(3),(4),(5),(6) and (7).

$$D = \sqrt{\frac{3.5 \; x \; Qg \; x \; Ti}{Pi}} \qquad (1)$$

The pipe thickness was computed using Barlow's equation as shown in equation(2)

$$t_{NOM} = \frac{Pd.D}{2.£w.ή.\delta y.Ft} + Ca \qquad (2)$$

Reynold's Number was determined with the equation (3);

$$N_{Re} = \frac{20.Qh.\gamma g}{\mu D} (3)$$

Hydro test Pressure (Ph) was determine with equation(4);

$$Ph = 1.25xMAOP \qquad (4)$$

Pipeline burst and collapse pressure equation used are presented in equation(5) and (6) and the Maximum Allowable Pipeline operating pressure in equation(7)

$$Pb = 0.9(SMYS + SMTS) \frac{t}{(D-t)} (5)$$

$$PC = \frac{2xSMTSxt}{D} (6)$$

$$MAOP = \frac{2xfxSMTSxt}{D} (7)$$

C. Geo-Technical Design Parameter

- ***Pipeline Heat Transfer Coefficient***

HTC for Steel Pipe = $\alpha_1 = \frac{2\pi\lambda 1}{Dln(D1/D2)}$ Where D = 10, $\lambda 1$ = 45w/mk = 12285 w/^{o}C

HTC for Pipe Surrounding = $\alpha_n = \frac{2\pi\lambda n}{Dln(4h/D)}$ = Where D = Pipe Coat = 0.1969inch = 0.005m
λ_n = 0.21w/mk=57.33w/m^{0}C, h= 1m

D. Operational Condition of the Gas Pipeline

The basic pipe and operating condition parameters that were inputted during the simulation are presented as follows;

- Inlet Processing Pressure: 1072 psi
- Gas Volumetric Flow Rate: 65MSCF/D
- Inlet Processing Temperature: 68 ^{o}F
- Nominal Pipe Size: 8 inch
- Outside Diameter : 8.625 inch
- Wall Thickness : 0.322 inch
- Pipe Grade: X-46

E. Process/Component Description for Gas Pipeline for Turbine Feed

Pipeline are composed of several pieces of operational equipment that operate together to move the natural gas from production/processing base to the delivery points.

The natural gas stream NG1 from the processing facility with pressure and temperature of 1072 psi and 68F respectively, enters the compressor (Comp1) at the injection station and leaves at stream NG2 and enters the first control system (PCV1) and exits at stream NG3. Stream NG3 enters the first segment of the designed pipeline, 2.8KM long. Same operating condition is maintained as the natural gas stream NG4 passes through a 90^0 elbow to the second segment of the pipeline, 0.6KM long. Similarly, the natural gas NG5 goes through the second 90^0 elbow which enters the 3.6Km pipeline to deliver stream NG6 to the booster station which is 7KM from the injection base, the natural gas flows through the second compressor (Comp2) with the pressure boosted in stream NG7 and controlled by a PCV2 and entering the 6.95Km pipeline at streams NG8 and NG9 respectively. Again NG9 is controlled by PCV3 to deliver appropriate flow conditions, hence, the natural gas stream (NG10) flows through the last pipe segment, 0.05KM, producing the natural gas stream (NG11) delivered to the client at 1072 psi and 86.0 F pressure and temperature respectively. Figure 1 shows the simulated Natural gas pipeline with Aspen Hysys.

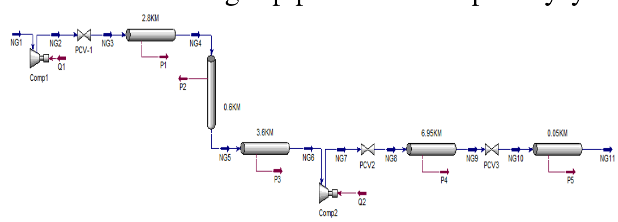

Fig. 1. Hysys Simulated 14KM Pipeline

III. RESULTS AND DISCUSSION

A. Pressure and Temperature on Streams (NG1 to NG11)

The pressure profile along the flow line shows that the natural gas started with a pressure of 1072 psi from the treatment plant and subsequently scaled up to 1104 psi with the aid of the first compressor along the flow line. The pressure is further scale up with the aid of the second compressor to 1090 psi at a distance of 7km along the pipeline after pressure dropped to 958 Psi before entering the second compressor. The said natural gas exited at a pressure of 1072 Psi by implication pressure drop along the line is zero as presented in Figure 2.

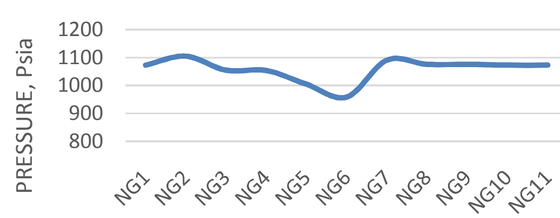

Fig.2.Pressure Profile along Stream NG1-NG11

Similarly, the temperature profile depicts that the natural gas started with a temperature of 68^{o}F, climaxed between 10 to 11 kilometers along the pipeline to a temperature of 105^{o}F, and exited at a temperature of 86^{o}F as shown in Figure 3.

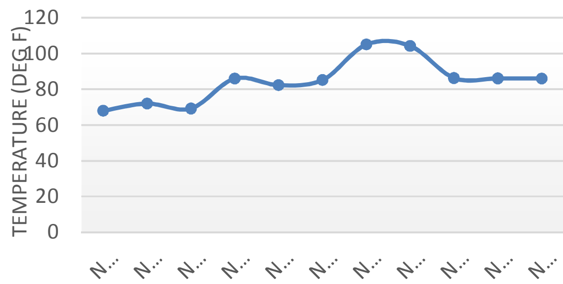

Fig. 3.Temperature Profile along Stream NG1-NG11

B. Flow Assurance on Streams (NG1 TO NG11)

The flow assurance analysis on streams NG1 to NG11 as performed on Hysys showed that flow is assured as condition for hydrate is not met. Figures 4 and Figure 5 show the envelop for NG1 and NG2 with its critical and hydrate curve

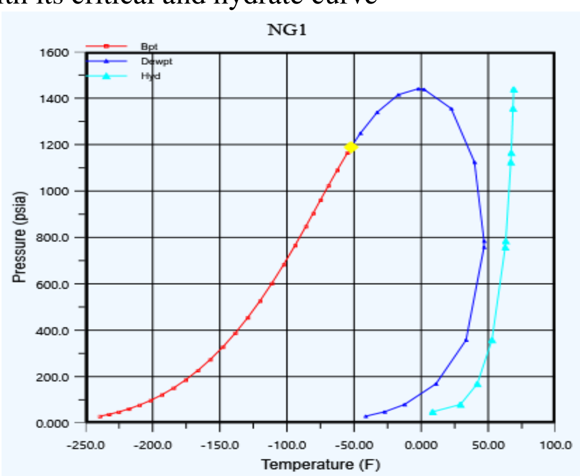

Fig.4. NG1 Critical path/hydrate formation status

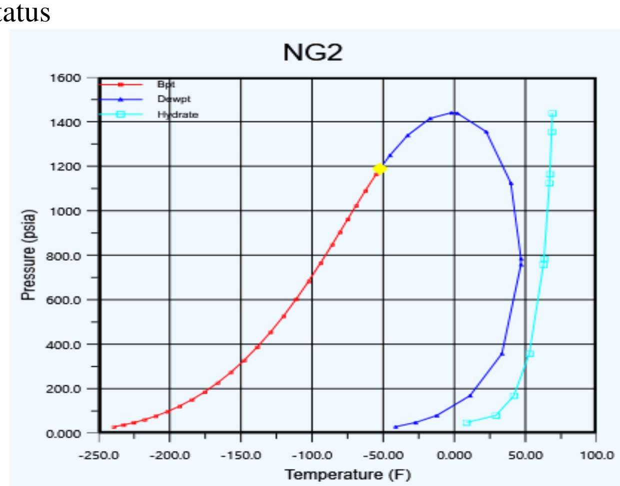

Fig. 5. NG2 Critical path/hydrate formation status

Besides the hydrate status shown, the critical path also shows that the fluid will remain a vapour (gas) all through the pipeline. Therefore, change of phase will not occur. Table 2 shows the stream and hydrate formation conditions.

Table 2. Stream Properties and Hydrate Formation Properties

SN	Stream	Temp. (^{O}F)	Pressure (PSIA)	REMARKS
1	NG1	68.00	1072	NO
	HYD1	66.31	1292	FORMATION
2	NG2	72.00	1104	NO
	HYD2	66.58	2271	FORMATION
3	NG3	69.25	1054	NO
	HYD3	66.14	1506	FORMATION
4	NG4	86.00	1053	NO
	HYD4	66.13	8112	FORMATION
5	NG5	82.32	1004	NO
	HYD5	65.66	6204	FORMATION
6	NG6	85.18	958	NO
	HYD6	65.17	7667	FORMATION
7	NG7	105.00	1090	NO
	HYD7	66.46	20960	FORMATION
8	NG8	104.20	1075	NO
	HYD8	67.33	20340	FORMATION
9	NG9	86.27	1075	NO
	HYD9	66.33	8262	FORMATION
10	NG10	86.06	1072	NO
	HYD10	66.30	8150	FORMATION
11	NG11	86.04	1072	NO
	HYD11	66.30	8135	FORMATION

C. Flow Assurance on Pipe Segments

- ***Pipe Length- 2.8KM***

The temperature profile from figure 6 generated shows a rise in temperature from 69.25^{o}F to 85.79 ^{o}F at 0.58km in a linear relationship and remained relatively constant from 0.58km to 2.8km at 86 ^{o}F. For hydrate to form, the temperature along the length of the pipe was 66.14 ^{o}F.

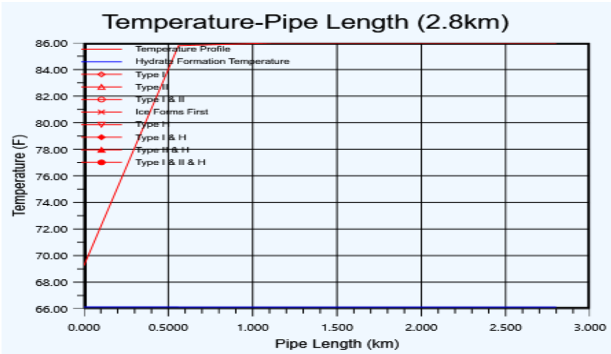

Fig. 6.Hydrate condition vesus Temperature profile for 2.8km pipe segment.

On the pressure profile as depicted in figure 7, the pressure from NG3 into the pipeline reduced slightly from 1054 Psi to 1053 Psi. Hydrate formation along the pipelength varies from 8002 Psi to 8112 Psi.

From the above conditions on both the temperature and pressure profile, hydrate will not be formed as hydrate formation condition are not met.

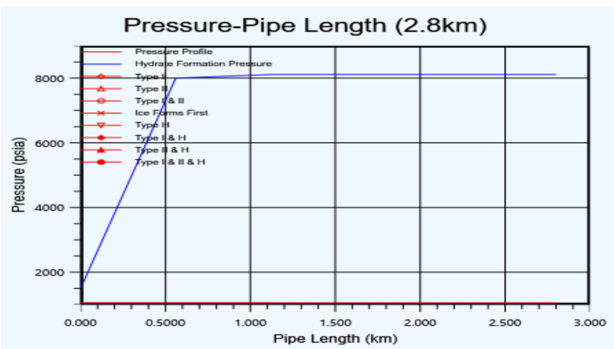

Fig.7.Hydrate condition vesus Pressure profile for 2.8km pipe segment

- ***Pipe Length- 0.6KM***

The figure 8 shows that NG4 enters the pipe at 86 ^{o}F and reduced to 82.32 ^{o}F. Hydrate formation temperature ranges from 66.13 ^{o}F to 65.66 ^{o}F along the pipe length.

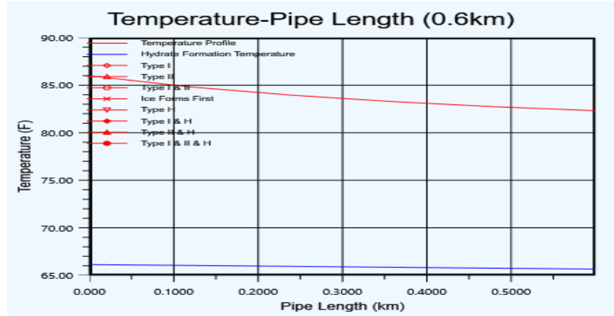

Fig. 8. Hydrate condition vesus Temperature profile for 0.6km pipe segment

The pressure reduced from 1053 Psi to 1004 Psi along the pipe length whereas the hydrate formation pressure varied from 8112 Psi to 6204 Psi as seen in Figure 9. Hence, hydrate will not form along the pipe length.

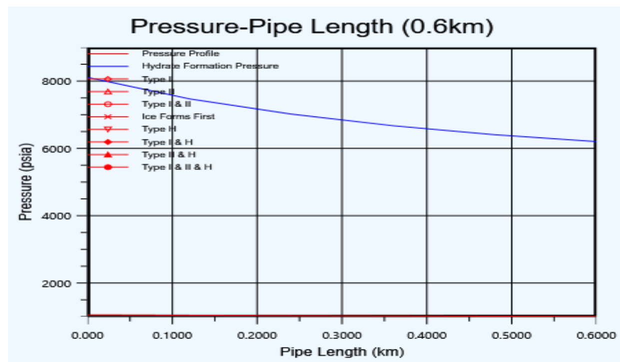

Fig. 9. Hydrate condition vesus Pressure profile for 0.6km pipe segment

- ***Pipe Length- 3.6KM***

It was observed from figure 10 that the temperature increased from 82.32 ^{o}F to 85.06 ^{o}F at 1.440km and increased linearly to 85.18 ^{o}F. Hydrate formation temperature reduced slightly form 65.66 ^{o}F to65.17 ^{o}F.

Figure 11 shows the reduced pressure from 1004 Psi to 958 Psi along the pipe length whereas the hydrate formation pressure increased from 6204 Psi to 7667 Psi.

The condition for hydrate formation on the line is not reached, hence, no hydration formation.

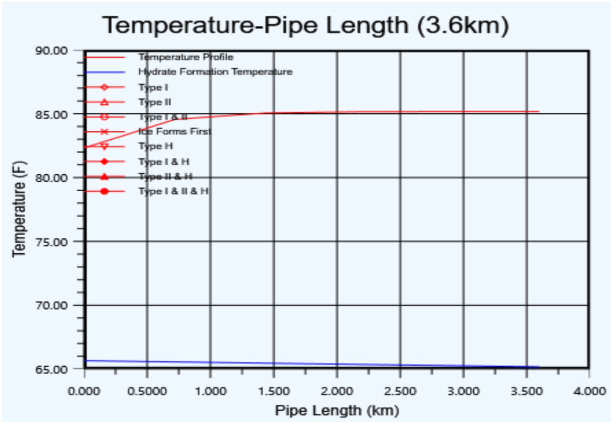

Fig. 10. Hydrate condition vesus Temperature profile for 3.6km pipe segment.

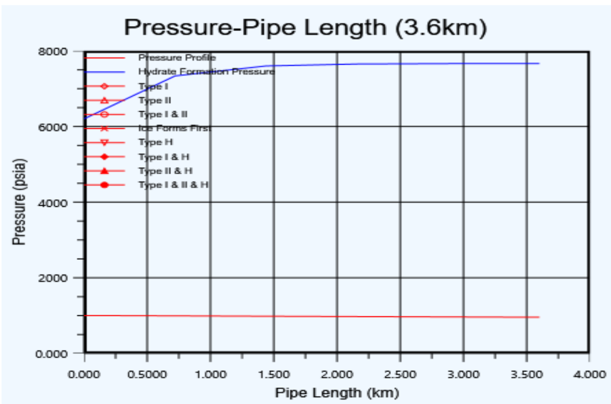

Fig.11. Hydrate condition vesus Pressure profile for 3.6km pipe segment.

- ***Pipe Length – 6.95KM***

Temperature in figure 12 decreased linearly from 104.2 ^{o}F to 86.27 ^{o}F. The hydrate formation temperature remains at 66.33 ^{o}F along the pipe length. The Pressure in the pipe remain constant at 1075 Psi and hydrate formation pressure reduced from 2024 Psi to 10330 Psi as seen figure 13.

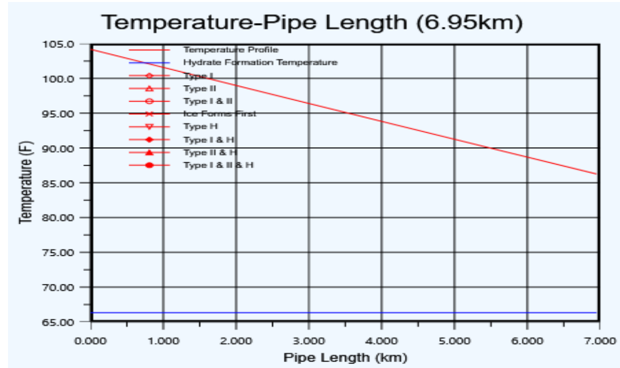

Fig.12. Hydrate condition vesus Temperature profile for 6.95km pipe segment.

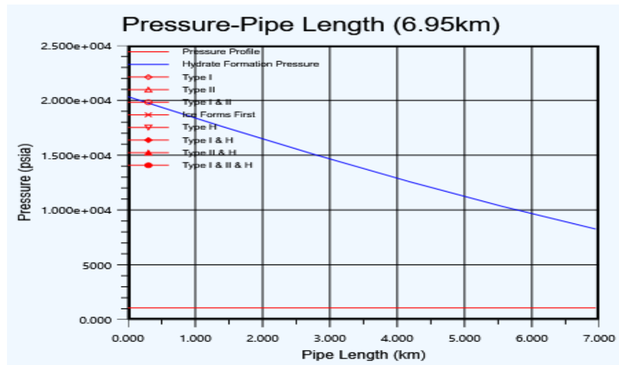

Fig.13. Hydrate condition vesus Pressure profile for 6.95km pipe segment

- ***Pipe Length – 0.05KM***

Figures 14 and 15 show that temperature and pressure remain almost the same along pipe length with only temperature reducing from 86.06 ^{o}F to 86.04 ^{o}F. Hydrate formation condition 8150 Psi to 8155 Psi and 66.30 ^{o}F for pressure and temperature respectively.

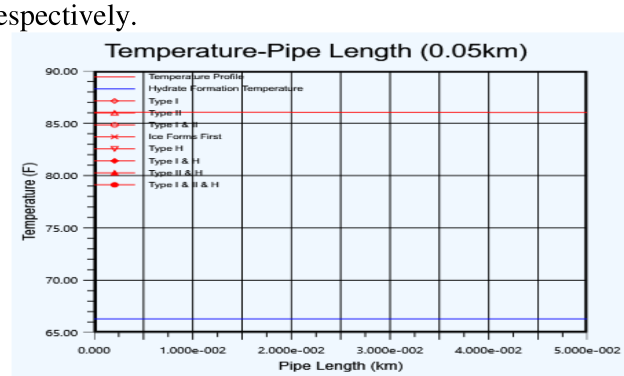

Fig. 14. Hydrate condition vesus Temperature profile for 0.05km pipe segment.

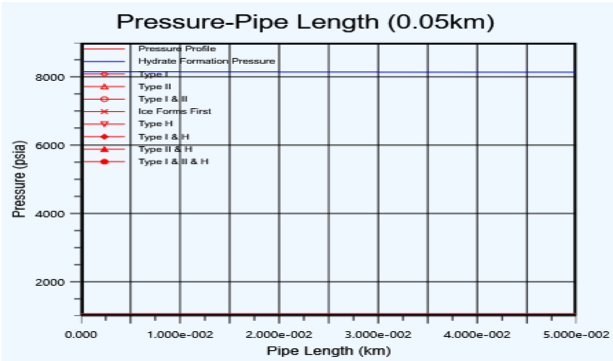

Fig.15.Hydrate condition vesus Pressure profile for 0.05km pipe segment.

IV. CONCLUSIONS

The following conclusions were drawn from the study:

- Compression horsepower (60HP) was required to transport the natural gas in the pipeline alongside some other parameters.
- The Natural Gas pipeline was simulated, and it all converged. Also the pressure loss till the delivery point was zero (0). The pressure from the inlet / injection station and that of the Outlet/delivery station was the same as 1072 Psi respectively.
- There were minor increases in temperature from 68 ^{o}F to 86 ^{o}F at the inlet to the outlet sections respectively and an average temperature of 94.03 ^{o}F along the pipeline.
- Flow were assured as there were no hydrate formed along the streams and pipe segments, no slug formed, no CO_2 freeze out, no liquid holdup and flow regime remain constant throughout the l4km pipeline.

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