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Thermal Insulation for Hydrate Prevention in Pipeline Design

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THE PETROLEUM industry spends millions of dollars every year to combat the formation of gas hydrates. Produced natural gas stream from the reservoir always saturates with water and one of the problems associated with its transmission pipeline is the formation of hydrates. Gas hydrates cause problems by plugging transmission lines and damaging equipment. Hydrate formation in pipeline arises due to temperature drop and other thermodynamic changes during production. To prevent hydrate formation, it is important to make accurate prediction of temperature and pressure under which gas hydrate will form. Formation of gas hydrate can be eliminated or decreased by several methods, thermal insulation, heating or chemical injection. The present study focused on hydrate prevention using thermal insulation technique done by HYSYS simulation software. Experimental work was carried out using PVT cell (mercury free system) to detect the hydrate formation temperature.

Keywords: Hydrates, Gas pipeline and HYSYS.

Gas hydrates are crystalline solids formed at low temperature and high pressure conditions when water molecules are brought into contact with suitable size gas molecules. The gas molecules are trapped in a cage-like structure produced as a result of a network of hydrogen-bonded water molecules. Depending on the size of the gas molecule, different crystals of gas hydrates can be formed. There are three forms of hydrate structures, the first structure (type I) due to the presence of small gas molecules such as methane and ethane, the second structure (type II) due to large gas molecules such as propane and isobutene, and the third structure (type H) in case of presence of large molecules such as methylcyclopentane with small gas molecules like methane. Most of Type H formers are not commonly found in natural gas. Gas hydrates can form at any location in the pipeline where water and gas coexist at the right temperature and pressure conditions(1-4).

During the transportation and processing of gas under cold weather conditions, gas hydrate will plug the pipeline, valve and equipment. Hydrate formation is the major flow assurance problem in the oil and gas industry since they can form inside the pipeline and obstruct flow. In the worst case scenario, the pipeline can explode and cause enormous economic and environmental damage. Hydrates will not form if the gas/water system is kept at a temperature higher than the hydrate formation temperature(5-7).

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During the journey of natural gas from reservoir to well head, natural gas flows cool slightly because of the insulation provided by the warm rock. On the contrary, temperature drop increases which enters in pipeline. In steady state operation, the temperature of gas decreases as it flows along the flow line due to transfer or loss of heat to the surrounding environment through pipe wall(8). Several methods have been used to inhibit and prevent the hydrate formation such as;

1) Chemical-based technologies have been developed to cope with hydrate formation. One of the most used methods is the application of thermodynamic inhibitors, such as methanol or glycol. Recent development in chemical technologies for hydrate control is the low dosage hydrate inhibitors (LDHI) including the kinetic inhibitors and anti-agglomeration additives.

2) Insulation is the best option to preserve heat, thus keeping operating temperature outside the hydrate region (minimizing heat loss).

3) Recently, electrical heating system for pipeline has been developed, in which pipeline can be directly heated due to resistive heating, which is commonly termed as direct electrical heating (DEH) method.

4) Cold flow technology (9-14).

The main objective of the present work is to prevent hydrate formation in natural gas pipelines using thermal insulation technique for lean and rich gas. The analyzed result was applied to a pipeline of the selected insulation material and thickness needed to prevent hydrate using HYSYS simulation package .The predicted conditions from HYSYS simulation compared with that results obtained from the experimental work using PVT cell.

Methodology

the thermodynamic environment suit for the transportation of natural gas stream thorough pipeline from platform to processing plant has been studied . Table 1 illustrates the specification and operating conditions of the pipeline.

TABLE 1. Specification and operation condition for pipeline.

Parameters	Description	Units
Horizontal length of pipeline , L	8000	m
Inner diameter of pipe , ID	0.2032	m
Wall thickness , WT	0.00635	m
Average external temperature, T_{ext}	10	˚c
Gas inlet pressure , P_{in}	1800	Psia
Minimum arrival pressure	1200	Psia
Gas inlet temperature, T_{in}	28	˚c
Design Gas flow rate , Q	8605.44	m^3/day
Maximum turn down	4302	m^3/day
Roughness	0.001	"
Average fluid velocity , V	3.228	m/s
Inner cross sectional area , A	0.032429	m^2
Pipe orientation angle , Ө	0	
Insulation radius , R	0.1016	m

The effects of different variables on natural gas hydrate formation are studied as shown below;

1) Natural gas composition in which two different compositions' are examined, one rich gas (A) and the other lean gas (B) as shown in Tables 2 and 3.

TABLE 2. Natural gas compositional for lean gas .

Component A	Mole fraction
C_1	75.42
C_2	7.65
C_3	4.27
n-C_4	8.42
n-C_5	2.67
N_2	0.16
Co_2	1.02
H_2o	0.39
Sum	100

TABLE 3. Natural gas compositional for rich gas .

Component B	Mole fraction
C_1	97.07
C_2	0.24
C_3	0.12
i-C_4	0.05
n-C_4	0.1
i-C_5	0.12
n-C_5	0.16
n-C_6	0.58
$C7^+$	0.66
N_2	0.12
Co_2	0.08
H_2o	0.7
Sum	100

2) Insulation type, in which two different types of insulation were examined; polystyrene foam (PSF) and polyurethane foam (PUF).
3) Insulation thickness, four different thicknesses are used for each insulator and composition.
4) The pipeline heat losses for the different insulation material and thickness were analyzed for composition A and B. HYSYS simulation package was used to simulate the thermodynamic environment of the gas stream which leads to determination of hydrate formation conditions (pressure and temperature) (15, 16).

A full automated mercury free system (PVT cell) was used to simulate the formation of hydrates in gas sample (lean gas). The test is conducted under different high pressures and low temperatures. The procedure is outlined in the following steps:

1. A gas sample whose compositional analysis is given in Table 2 was obtained from an actually existed gas field owned to Rashid Oil Company. It is transferred to the PVT cell by using hydraulic pump at pressure 36197Kpa and temperature 110 ˚c.

2) The cell was adjusted to pressure 1800 Pisa and temperature 28˚c (the operating conditions of the pipeline). The system was left for 24 hr to stabilize the gas composition and ensuring the absence of hydrate formation.

3) The pressure was maintained at) 1800 Pisa (and temperature allowed to decrease gradually below 28˚c to detect the starting point of hydrate formation, the hydrate can be detected by Interface detection system in PVT cell.

4) The temperature was raised again to 28˚c to ensure the absence of hydrate, and then the pressure adjusted to another lower pressure, temperature decreased gradually below 28˚ c until hydrate detected. Repeat the above step with different selected pressures in ranges (800 – 2200 Pisa) and record the hydrate formation temperature values.

5) The obtained results from PVT cell were compared with the simulated ones by HYSYS.

Results and Discussion

Several factors affecting hydrate are studied using HYSYS simulation software.

Effect of natural gas composition

The hydrate formation pressures and temperatures in pipeline are simulated by HYSYS for lean and rich gas to give hydrate formation profile of two different compositions to describe the degree of pressures and temperatures at which hydrate formed in pipeline as shown in Fig. 1 indicated that the hydrate profile of lean gas with gravity (0.6) is above rich gas with gravity (0.8), so hydrate formation temperature (HFT) of lean gas will be below HFT of rich gas at the same pressure. Methane percentage has an effective role on HFT of natural gas, methane + water system does not fall into the classification of Scott and Van Konynenburg(17) Because the critical point of methane is at such a low temperature. The existence of (C2 +, Co2 and N2) components in natural gas as shown in Tables 1 and 2 leads to higher HFT even at low fractions.

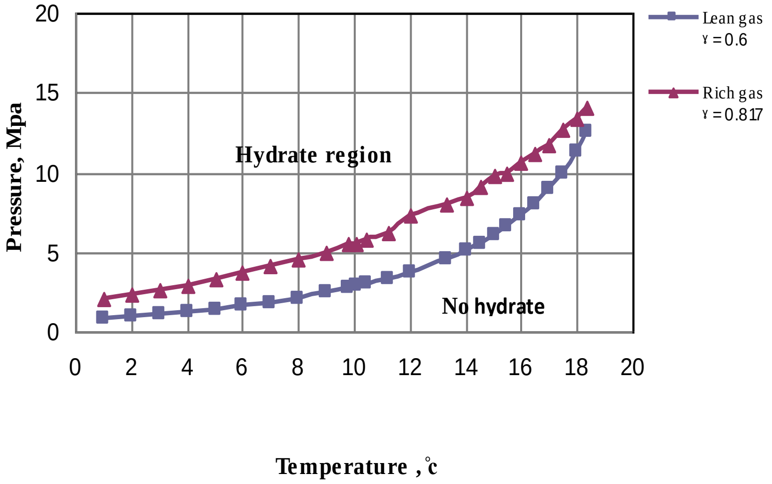

Fig. 1. Hydrate profile curves of lean and rich gas.

By HYSYS simulation, the pressure and temperature values along the pipeline were simulated, and then the hydrate formation temperature values at simulated pressure of each pipeline section were calculated for rich ($ɤ$ = 0.817) and lean gas ($ɤ$ = 0.6) as shown in Fig. 2 and 3, respectively. The temperature of producing fluid decreases as it flows along the pipeline because of low temperature of sea water.

For rich gas as shown in Fig. 2 at inlet gas pressure (P_{in} = 12.4 Mpa) and inlet temperature (T_{in} = 28 ˚c) the hydrate did not form because the HFT is 18.34 ˚c lower than the gas flowing temperature (T_f). Once gas flows, the hydrate started to form early in the pipeline and still founded to the end of transmission due to the existence of suitable pressure and temperature conditions for hydrate formation. For, *i.e.* at length 1 km the gas flowing pressure ($P_{f)}$ is 12.2 Mpa, T_f is 10.11 ˚c, and HFT is 18.28 ˚c.

For lean gas as shown in Fig. 3, the hydrate also formed at early section of pipeline. The intersection point between HFT curve and simulated gas temperature curve represents the starting point of hydrate in pipeline approximately at distance 250 m. To avoid line blockage, the flowing temperature for rich and lean gas must kept above HFT at any section of pipeline. It was observed from Fig. 2 and 3 difference in HFT values for two gases along the pipeline due to the lower gas gravity has a HFT than the higher gas gravity at the same operating pressure. At inlet pressure (12.4 Mpa), HFT for rich gas is 18.34 ˚c and for lean gas is 17.34 ˚c and the hydrate formation temperatures for lean gas along the pipeline will be lower than HFT_s for rich gas.

The next part illustrates the performance of pipeline operating conditions in case of using thermal insulation to increase gas flowing temperature to avoid hydrate formation. A comparison was done between two insulation materials (PSF and PUF) to choose the best choice of them in case of rich and lean gas.

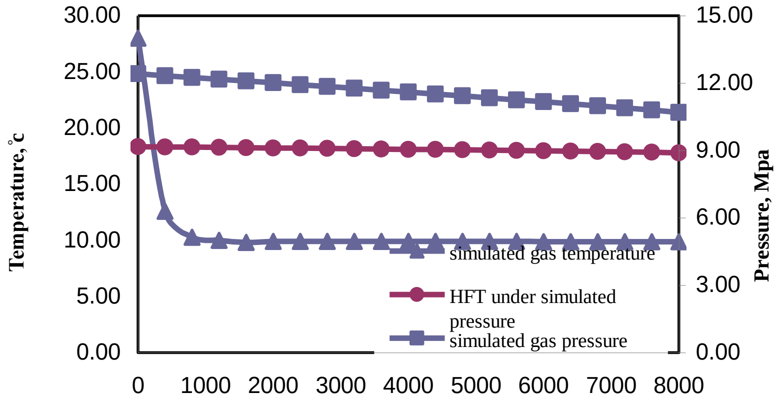

Fig. 2. Prediction for the hydrate formation region in pipeline for rich gas.

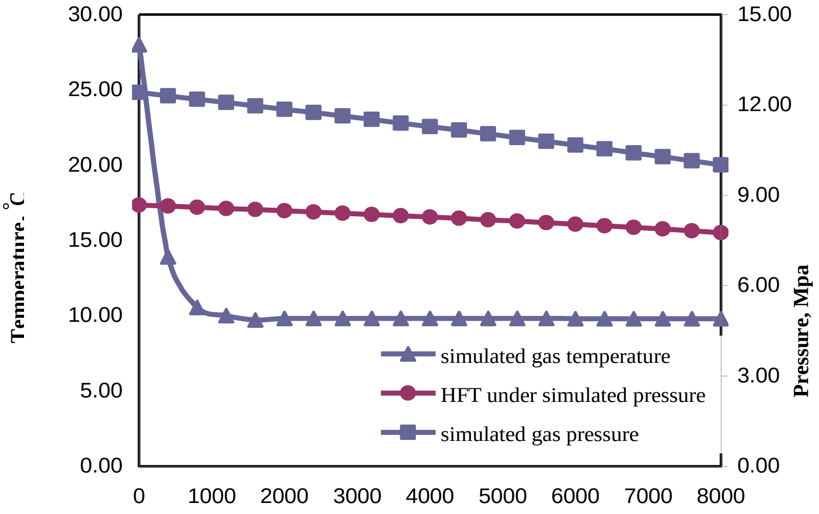

Fig. 3. Prediction for the hydrate formation region in pipeline for lean gas.

Effect of insulation material for rich gas

On using PSF layer of thicknesses 1 mm, 2 mm, and 3 mm as shown in Fig. 4, it was observed that by using PSF with 1 mm thickness, the flowing temperature dropped from 28 ˚C at fluid entry to 11.24 ˚C at fluid arrival. Hydrate started to form at distance 3.3 km where (Pf is 11.6 Mpa, T_f is 18 ˚C, and HFT is 18.2 ˚c). By increasing PSF thickness to 2 mm, the flowing temperature became 14.82 ˚C at fluid arrival and hydrate started to form at distance 5.5 km. On using PSF with 3 mm thickness, the minimum (T_f) became 16.8 ˚c at the end of transmission and hydrate formation appeared at distance 7 km. It was noticed that a PSF with 3 mm thickness is the best one for controlling temperature drop (Δ T) and moving hydrate to longer distance but hydrate still existed in the pipeline. So there are another two suggested solutions; the first one is using higher PSF thickness than 3 mm and the second is using another type of insulation having lower thermal conductivity than PSF.

The performance of PUF with thicknesses (1 mm, 2 mm, and 3 mm) were analyzed as shown in Fig 5. By using PUF with thicknesses 1 mm and 2 mm, the gas flowing temperature adjusted to higher values and hydrate moved to longer distance (4.6 km and 7.2 km), respectively, the two thicknesses aren't sufficient to avoid hydrate formation. With increasing insulation thickness to 3 mm, T_f dropped to 18.5 at fluid arrival, there were not any suitable conditions for hydrate at any section of pipeline. PUF with thickness 3 mm is the best choice for avoiding hydrate.

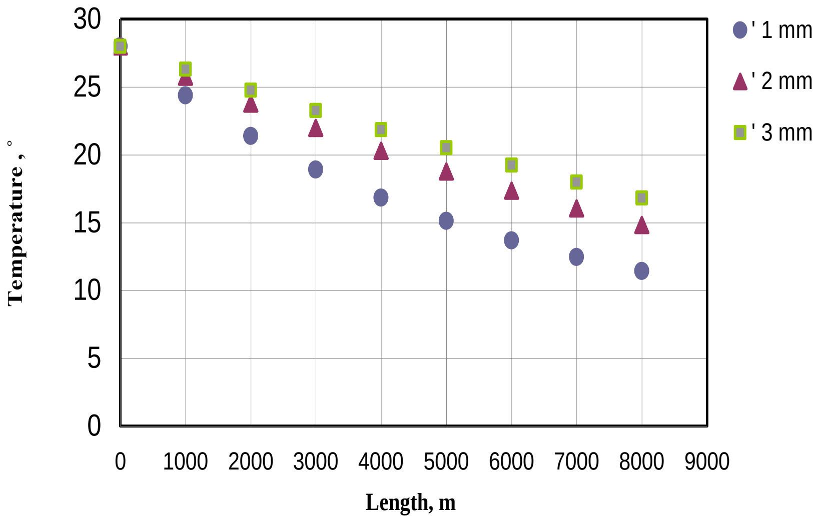

Fig.4. Temperature profiles with polystyrene layers of various thicknesses for rich gas.

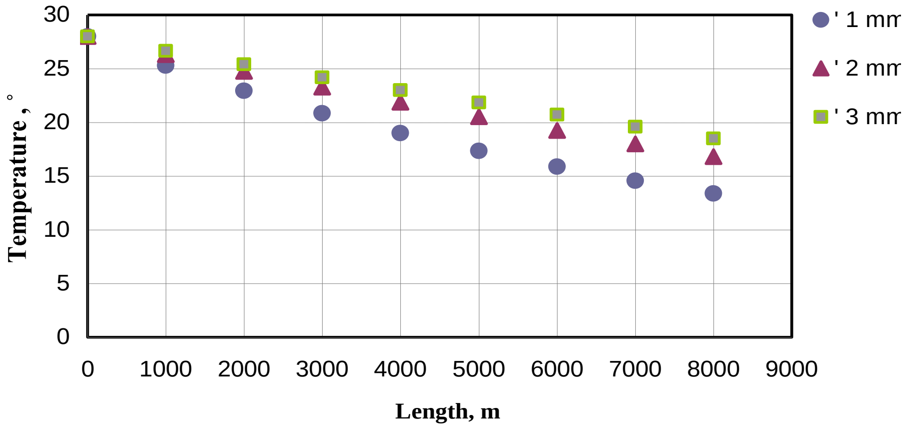

Fig. 5. Temperature profiles with Polyurethane Layers of various thicknesses for rich gas.

Effect of insulation thickness on heat loss for rich gas

A heat loss in the pipeline is affected by changing insulation thickness and material. Figure 6 indicated comparison between the influence of PSF and PUF on heat loss when using them at thicknesses (1 mm, 2 mm, 3 mm). Form this comparison it was observed that, larger insulation thickness leads to lower heat losses compared to lower thickness, PUF with thickness 3 mm gives lower heat loss than PUF with thickness 1 mm and 2 mm. For PSF with 3 mm thickness, heat loss became 213000 kj/h. In case of PUF with the same thickness, heat loss became 156000 kj/h. Therefore, PUF is the best choice for preserving heat and lowering heat losses of pipeline.

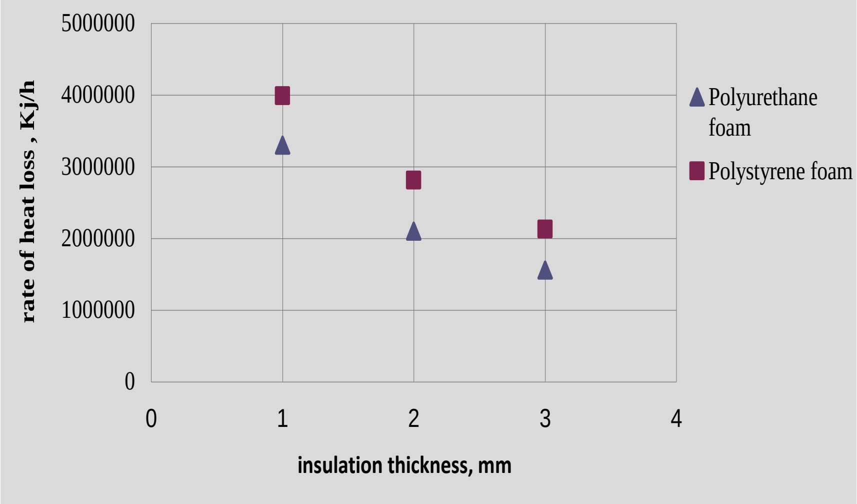

Fig. 6. Polyurethane and polystystyrene heat loss for rich gas.

Effect of insulation material for lean gas

A comparison between the effect of PSF and PUF with different thicknesses on gas flowing temperature is indicated in Fig. 7 and 8. Higher insulation thicknesses are needed to prevent hydrate formation compared to rich gas illustrated in the previous section. The performance of PSF with thicknesses (1 mm, 2 mm, 3 mm, and 4 mm) is showed in Fig 7. On using PSF at thickness 1 mm, the flowing temperature did not increase enough to resist hydrate formation. Hydrate appeared at distance 2.3 km with increasing PSF thickness to 2 mm, fluid arrival became 11.3 ˚c and hydrate moved to distance 4.8 km where (Pf is 10.9 Mpa, Tf is 16.27 ˚c, and HFT is 16.29 ˚c). By using PSF with thicknesses 3 mm and 4 mm, the gas flowing temperature adjusted to higher values as shown in Fig. 7 and hydrate moved to distance 6.2 km and 7.3 km, respectively. PSF with thickness 4 mm has the best performance among other lower thicknesses but not enough to prevent hydrate in all sections of pipeline.

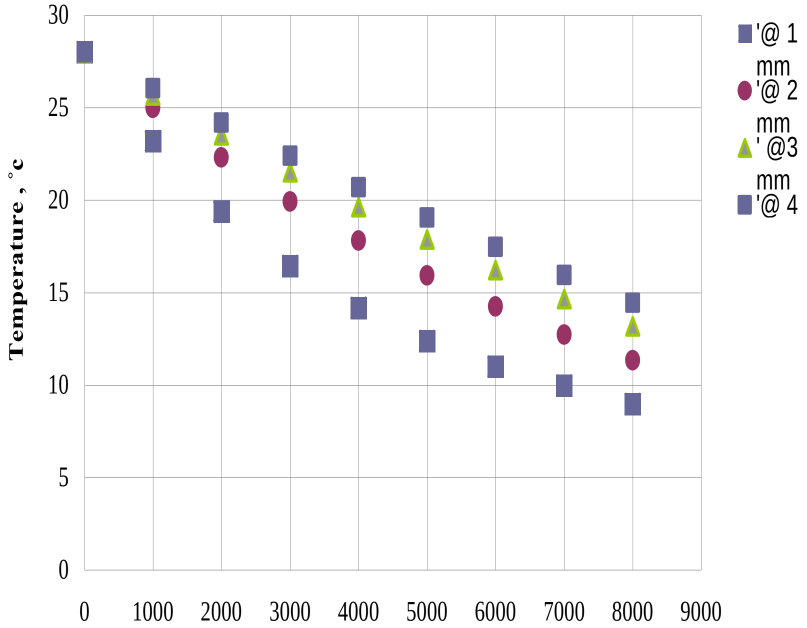

Fig.7. Temperature profiles with Polystyrene layers of various thicknesses for lean gas.

Figure 8 indicates gas flowing temperature profile when using PUF at different thicknesses. By using PUF layer with thicknesses 1 mm, 2 mm, and 3 mm, it was noticed that Tf increased to higher values and fluid arrival temperature became (10.2 ˚c, 13.2 ˚c, and 15 ˚c), respectively but not enough to prevent hydrate completely along transmission. The only PUF thickness that is capable of avoiding hydrate and making the gas flowing temperature higher than HFT at any section of pipeline is 4 mm thickness. At the end of transmission at distance 8 km, Tf became 16.1 ˚c and HFT is 15.31 ˚c.

Effect of insulation thickness on heat loss for rich gas

Figure 9 describes the heat losses in pipeline in case of using PSF and PUF with various thicknesses. By using PSF with thickness 4 mm, heat loss along the pipeline became 145000 kj/h; also this thickness is not enough to prevent hydrate as we mentioned before. Heat loss in case of using PUF with thickness 4 mm would be 107000 kj/h and hydrate not formed in any section in flow line. PUF gives lower heat loss compared to PSF at any thickness.

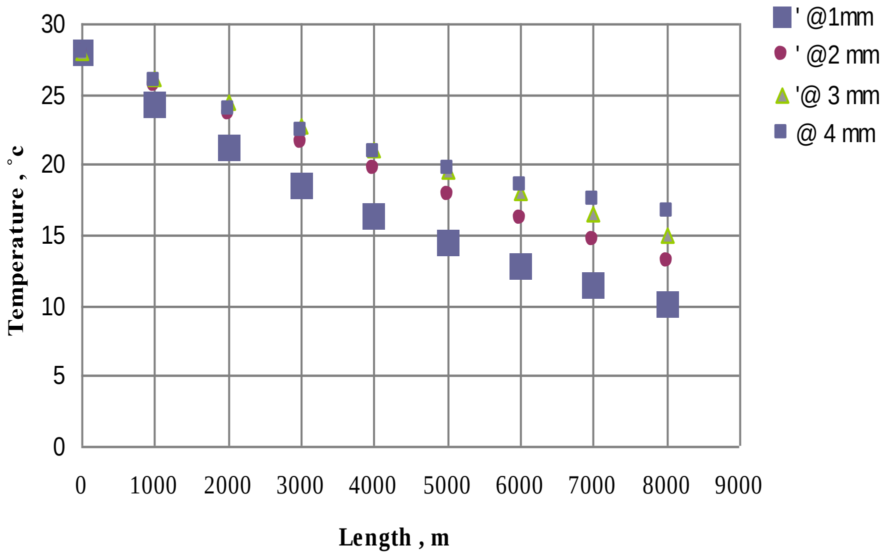

Fig. 8. Temperature profiles with Polyurethane layers of various thicknesses for lean gas.

The effect of gas gravity on thermal insulation design

For lean gas, the HFT will be lower than HFT for rich gas at any section of pipeline because the lower gravity leads to lower HFT compared to the higher gas gravity at the same operating pressure. The effect of gas gravity on insulation thickness for lean and rich gas indicated in Fig. 9 showed that the required insulation thickness in case of lean gas (polyurethane layer with 4 mm thickness) to prevent the hydrate formation is larger than the rich one (polyurethane layer with 3 mm thickness). PUF have best thermal characteristics than PSF for preventing hydrate formation during transmission.

Comparing the HYSYS simulation results with the PVT cell results

Experimental work was carried out using PVT cell (mercury free system) to detect the hydrate formation temperatures for lean gas at different pressure ranges. Figure 10 shows a comparison between HYSYS and PVT cell results for predicting HFT. The evaluation ensures the compatibility of simulated and experimental data.

Conclusion

The produced natural gas is always combined with water that leads to formation of hydrates in transmission lines. The operating temperature must be maintained above HFT to avoid blockage of pipeline. By HYSYS simulation, the HFT was detected in the pipeline, also a comparison among different insulation materials, thicknesses, and heat losses were calculated to choose the optimum insulation thickness at which hydrate not formed. Experimental study was done by using PVT cell to detect HFT of a sample of lean gas at different ranges of pressures and compared with HYSYS simulation results. From this study results, it is observed that:

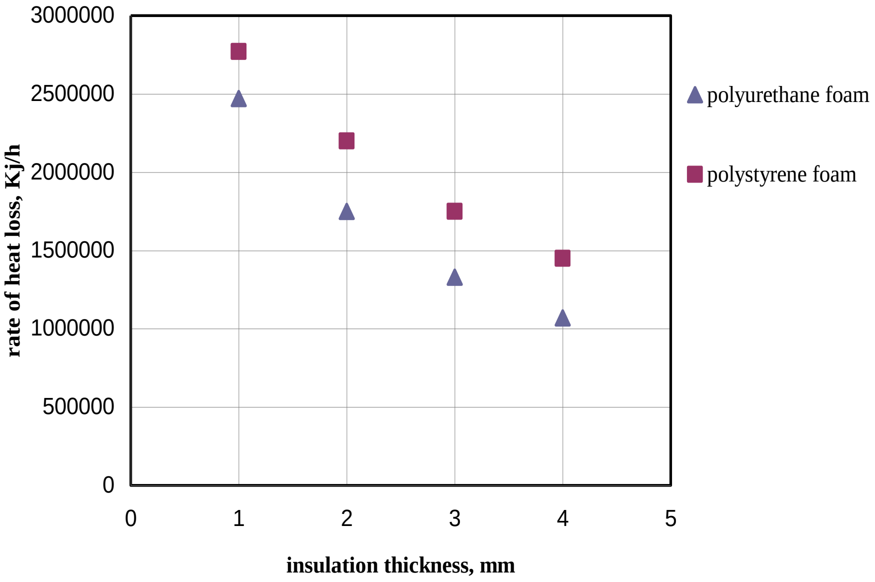

Fig. 9. Polyurethane and Polystyrene heat losses for lean gas.

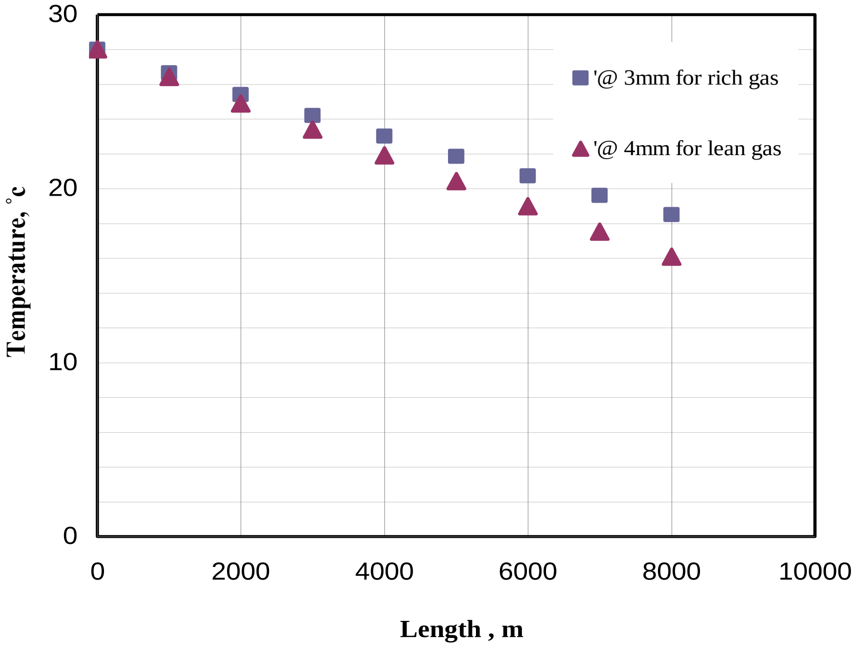

Fig. 10. The required insulation thickness for lean and rich gas.

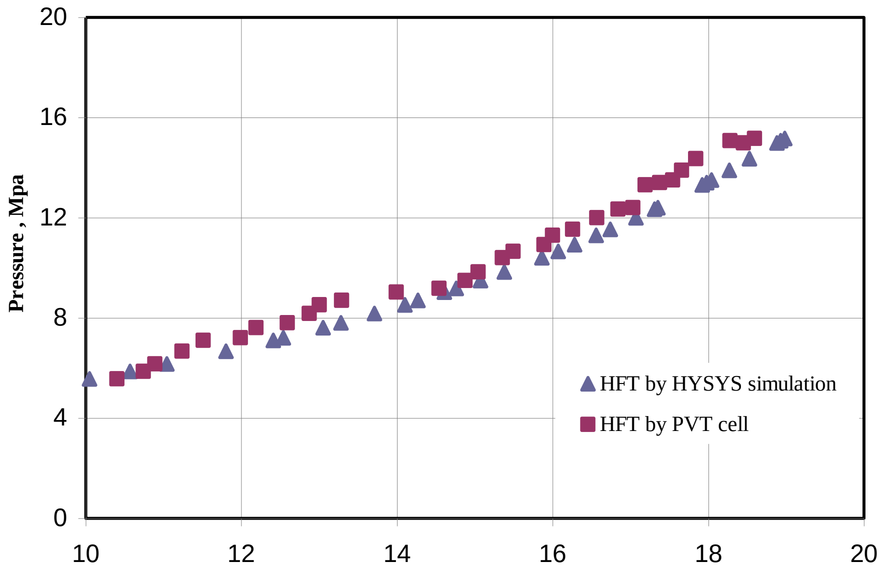

Fig. 11. Comparing between HYSYS and PVT cell results for hydrate formation prediction.

1- Thermal insulation is a very important element in hydrate formation prevention of pipelines to maintain the operating temperature out of the hydrate region. For subsea pipeline, insulation is the best choice because of the difficulty of heating the whole pipeline. Polyurethane foam is usually used because of good thermal characteristics.

2- Lower thermal conductivity (K) of insulation type is better than higher thermal conductivity in terms of preserving heat and lowering temperature drop along the pipeline. (K of polyurethane foam is 0.018 w/m-k and K of polystyrene foam is 0.027 w/m-k).

3- At the same insulation type, higher insulation thickness leads to lower temperature drop compared to lower thickness. For PUF (4 mm insulation thickness is better than 3 mm thickness for increasing gas flowing temperature during transmission as we mentioned in this paper).

4- The larger insulation thickness, the lower will be heat losses and vice versa.

5- The lower thermal conductivity of a certain type of insulation leads to lower heat losses compared to another one having higher thermal conductivity when used at the same thickness.

6- Gas gravity is a toughing parameter in hydrate formation criteria; the lower gravities lead to lower values of hydrate formation temperatures. On the other hand, the higher gas gravities increase HFT to higher values at a maintain pressure.

7- PVT cell is an experimentally way to detect HFT of natural gas.

References

1. **Tavasoli, H., Feyzi, F., Dehghani, M.R. and Alavi, F.,** Prediction of gas hydrate formation condition in the presence of thermodynamic inhibitors with the Elliott-Suresh-Donohue equation of state. *J. Petroleum Science and Engineering*, **77**, 93-103 (2011).

2. **Zhang, C.S., Fan, S.S., Liang, D.Q. and Guo, K.H.,** Effect of additives on formation of natural gas hydrate. *J. Fuel*, **8**, 5-2121 (2004).

3. **Ghiasi, M.M.,** Initial estimation of hydrate formation temperature of sweet natural gases based on new empirical correlation. *J. Natural Gas Chemistry*, **l**, 508-512 (2012).

4. **Saw, V.K., Ahmad, I., Mandal, A., Udayabhanu, G. and Laik, S.,** Methane hydrate formation and dissociation in synthetic seawater. *J. Natural Gas Chemistry*, **21**, 625-632 (2012).

5. **Wu, M., Wang, S. and Liu, H.,** A study on inhibitors for the prevention of hydrate formation in gas transmission pipeline. *J. Natural Gas Chemistry*, **6**, 8 -85 (2007).

6. **Daraboina, N., Malmos, C. and Solms, N.V.,** Synergistic kinetic inhibition of natural gas hydrate formation. *J. Fuel*, **108**, 749-757 (2013).

7. **Yao, H., Malmos, C., Li, Q., Chen, G. and Gong, G.,** A preliminary study on hydrate anti-agglomerant applied in multiphase flow pipeline. *J. Energy and Power Engineering*, **7,**271-266 (2013)

8. **Sadafule, S. and Patil, K.D.,** Study on effect of insulation design on thermal – hydraulic- analysis: an important aspect in subsea pipeline designing. *J. Petroleum Engineering and Technology*, **4**, PP 33-45 (2014).

9. **Heidaryan, E., Salarabadi, A., Moghadasi, J. and Dourbash, A.** A new high performance gas hydrate inhibitor. *J Natural Gas Chemistry*. **9**, 323–326 (2010).

10. **Gong, J. shi, B. and Zhao, J.,** Natural gas hydrate shell model in gas-slurry pipeline flow. *J. Natural Gas Chemistry*, **21**, 261–266 (2010).

11. **Lee, J.D. and Englezos, P.,** Enhancement of the performance of gas hydrate kinetic inhibitors with polyethylene oxide. *J. Chemical Engineering Science*, **60**, 5323 - 5330 (2005).

12. **Wilfred, O. and Appah, D.,** Analyzing thermal insulation for effective hydrate prevention in conceptual subsea pipeline design. *J. Current Engineering and Technology*, **5**, (4), 2492 - 2499 (2015).

13. **Park, J.M., Oh, D.W. and Lee**, **J.,** Numerical analysis of thermal mixing in a swirler-embedded line-heater for flow assurance in subsea pipelines *Advances. in Mechanical Engineering*, Article ID 739089 (2014).

14. **Akpabio, M.G.** *Master Thesis*, Cold Flow in Long-Distance Subsea Pipelines. Norwegian University of Science and Technology (2013).

15. **Ameripour, S.,** *D. Ph. Thesis*, Prediction of gas-hydrate formation conditions in production and surface facilities Office of Graduate Studies of Texas A&M University, (2005).

16. **Salam, K.K., Arinkoola, A.O., Araromi, D.O. and Ayansola, Y.E.,** Prediction of hydrate formation conditions in gas ipelines. *International Journal of Engineering* Sciences, **2**, (8), 327-331 (2013).

17. **Carroll, J.,** *Natural Gas Hydrates*” 2nd edition, chapter three, pp. 51-92, ISBN: 978-0-7506-8490-3, Gulf Professional Publishing, Elsevier, 30 corporate Drive, Suite 400, Burlington, MA 01803, USA, (2009).

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العزل الحرارى للتقليل من تكوين هيدرات الغازأثناء نقل الغاز الطبيعى فى خطوط الأنابيب

علاء غزال ، فاطمة خليفة جاد ، مصطفى السيد عوض ، سعدالدين محمد دسوقى ،
إيمان نعيمى و منى محمود دردير
معهد بحوث البترول – القاهرة و كلية البترول وهندسة التعدين – جامعة السويس – مصر.

تنفق ملايين الدولارات سنويا في مجال صناعة البترول للتغلب علي مشكلة تكوين هيدرات الغاز. الغاز الطبيعي المنتج من الابار غالبا مايكون مشبع بوجود نسبة من الماء المصاحبه له اثناء استخراجه ، و تكوين هيدرات الغاز تعتبر واحده من اخطر المشكلات التى تنشأ اثناء نقل الغاز الطبيعي في المواسير ويمكن ان تتسبب في انسداد خطوط نقل الغاز او اتلاف المعدات اذا لم يتم السيطرة عليها.نتيجه لدرجات الحرارة المنخفضة والتغيرات الثرموديناميكية ومع وجود نسبة من الماء في الغاز الطبيعي اثناء الانتاج تنشأ هيدرات الغاز.توقع درجات الحراة والضغوط التي بموجبها هيدرات الغاز تبدا في التكون يعتبر من الاشياء الضرورية للتعامل مع تلك المشكلة.هناك طرق عديدة تستخدم للتخلص من مشكلة تكوين الهيدرات منها العزل الحراري للمواسير اوالتسخين او حقن مواد كيميائية. و فى هذه الدراسه تتركز علي التغلب علي الهيدرات باستخدام العزل الحراري للمواسير ويتم استخدام برنامج المحاكاه HYSYS لدراسه تاثير العزل الحراري . و قد تم تحديد درجه حرارة تكون الهيدرات معمليا باستخدام PVT cell .