

RESEARCH PAPER

Prediction of hydrate formation in Ilam gas refinery pipeline using computational fluid dynamic

Aghil Mamasani, Ahmad Azari*, Amir Abbas Izadpanah, Mohammad Jamali

Faculty of Petroleum, Gas and Petrochemical Engineering (FPGPE), Persian Gulf University (PGU), P.O. Box 75169-13817, Bushehr, Iran

ARTICLE INFO

Article History:

Received 16 April 2019

Revised 9 October 2019

Accepted 24 November 2019

Keywords:

Natural gas pipeline

hydrate formation

pipeline design

CFD

ABSTRACT

Hydrate formation in refinery gas pipelines is one of the major problems of refinery gas companies. There are a large number of investigations about this phenomenon. The necessity of facing this problem has been considered in many cases. Some chemical methods and technologies have been used in order to inhibit the hydrate formation in pipelines or to predict it. In this study, a computational fluid dynamic (CFD) modeling was employed to predict the probability of hydrate formation in the gas pipeline. The proposed model was validated using the operational data of Ilam refinery gas pipeline. The pipeline was simulated and the results were compared with the experimental data. The obtained numerical results showed enough agreement with the experimental data. Regarding pressure gradient in the pipeline, hydrate formation temperature was calculated and the possibility of hydrate formation in the pipeline was evaluated according to the comparison between the hydrate formation temperature and the actual temperature. In addition, various parameters such as inlet temperature, ambient temperature, and gas flow rate were studied in order to find the hydrate formation probability using the sensitivity analysis method. Results showed that the inlet and ambient temperatures are usually higher than the hydrate formation temperature, so the probability of hydrate formation is low in the pipeline. Moreover, the results clearly showed that increasing the gas flow rate or decreasing the gas inlet temperature can increase the probability of hydrate formation in the pipeline.

How to cite this article

1. INTRODUCTION

Natural gas is a kind of fossil fuel which is accessible, clean-burning, and less harmful than other fuels and also as a non-renewable resource, it is widely used in homes, factories and power plants. In the last decade, global demands for energy appreciate the significant circumstances due to the environmental concerns. To serve this purpose, gas exploration and the extraction of natural gas for transmitting it from the gas field to consuming area are very important. The

importance of NGH in oil industry relates to the formation of artificial gas hydrate which blocks the pipelines in Polar Regions in 1930. Gas hydrates are often identified as an obstacle in the gas industry since 1934 [1]. Gas hydrate is similar to snow and in certain temperature and pressure conditions, lattice of water surrounds gas molecules such as methane, ethane or carbon dioxide and generates a stable solid which is similar to water ice [2]. Gas hydrates are kept at atmospheric pressure and about -20°C temperature [3]. If gas hydrate forms

* Corresponding Author Email: azari.ahmad@pgu.ac.ir
azari.ahmad@gmail.com

in a pipeline, it leads to many problems such as lower gas transmission, damage to the pipeline and devices [4]. The hydrate is destructive since it causes the blockage of pipelines and also causes failure to the transmission of gas to the refinery. Consequently, scholars should address this problem and propose some methods to prevent the formation of gas hydrate in the pipelines. Essential requirements for the formation of hydrate are low temperature, high pressure and the entity of natural gas or light hydrocarbon in the presence of water [5]. Consideration of one of these three factors is required for the elimination and control of the hydrate formation in pipeline. There are several methods for delaying the formation of hydrate and even preventing the formation of hydrate in the pipeline which include: controlling temperature and pressure, clearing the fluid and using inhibitors which are used for the environmental and economic conditions [6]. The mentioned methods change the operating conditions of the process for the maintenance of the temperature and pressure conditions outside the hydrate formation region. Removing water from the gas flow in the transmission pipelines and also through the addition of chemical compounds can prevent the hydrate formation by maintaining the temperature and operating pressure outside the range of hydrate formation [7].

There are many studies about this undesirable phenomenon. The studies offered some solutions [8-11]. In 1998, Kelker et al. [12] proposed a mathematical model to study the hydrate formation. They reported that sudden pressure drop on either side of the hydrated mass causes its phase to be frozen and the decline of high pressure can also increase the drying time of the ice mass relative to the hydrate. Jasym et al. [13] presented a CFD model for the formation of hydrates in the gas flow assuming turbulent flow regime. They studied two Brownian and inertia regimes mechanisms which consider the particle size. The smaller particles deposit as a result of Brownian regime and in inertia regime the particle deposition increases with the particle size. Balakin et al. [14] used a 3-D computational model and also experimental methods for the hydrate formation prediction. Freon R11 was used to create the model and assumed that the flow is turbulent. The Eulerian-Eulerian model was used for the numerical simulation of the two-phase equations governing the problem. Mean particle size and solid

stress were studied in this paper and they got the same results for the mean particle size as Fatnes get [15]. In addition, they reported that the solid pressure of Gidaspow had the best agreement regarding the experimental results. Wang et al. [16] studied hydrate slurry for the low pressure turbulent flow in the pipeline. They compared the pressure drop as a function of the hydrate volume and the average velocity compared with experimental data. They found that mean velocities in pipeline increases due to the pressure drop. Nazeri et al. [17] designed a laboratory system to predict the formation of hydrates in different conditions of start-up, and shutdown in upstream pipeline. Also, Sule et al. [18] studied the hydrate formation in an L-shaped tube. They found that increasing the velocity of the straight length of pipe increased the hydrate formation, but this phenomenon did not occur in the curved shape and the L-shaped of the pipe. Furthermore, the viscous hydrocarbons increased the potential for the hydrate formation. Increasing the water content increased the risk of hydrate formation.

In this study, a new approach was employed to predict the hydrate formation with the computational fluid dynamics. The probability of hydrate formation in the gas pipeline for transfer of gas to Ilam Refinery was investigated. In this work, three survival equations were solved simultaneously while previous works used one survival equation and an equation of state to predict the hydrate formation. For this reason, when using three survival equations, the prediction accuracy of the hydrate formation was higher. Moreover, the prediction of hydrate formation with CFD software was less favored, which was the focus of the current study. The temperature of hydrate formation, pressure and temperature profiles were obtained. Its inputs and outputs were evaluated with actual data obtained from the pipeline to assess the accuracy of this modeling and its solution method (based on the finite element method) in predicting the pipeline conditions. Different situations and conditions of the pipeline were considered and the operating conditions of the pipeline in which there was no hydrate formation were presented. Herein, considering the Ilam refinery pipeline, the effects of various parameters such as pipeline inlet temperature, ambient temperature, gas temperature, and pipe insulation thickness were investigated. The obtained results are next discussed.

2. Mathematical formulation

2.1. Fluid flow equation:

Temperature and pressure distribution in the pipeline were obtained according to continuity and momentum equations [19]. These equations are as follows:

$$\nabla \cdot (\rho u A) = 0 \quad (1)$$

$$-\nabla P - f_D \frac{\rho}{2d_h} u |u| = 0 \quad (2)$$

where A (m²) is cross section area, ρ (kg/m³) is density, u (m/s) is velocity of fluid flow, P (Pa) is pressure. The right hand side of the equation (2) represents the pressure drop due to the internal shear stress. Darcy friction factor is a term which is a function of the Reynolds number and the roughness of the pipe divided by the hydraulic diameter and can be obtained from the following Haaland equation [20]:

$$\sqrt{\frac{1}{f_D}} = 1.81 \log_{10} \left(\left(\frac{e}{3.7} \right)^{1.11} + \left(\frac{6.9}{Re} \right) \right) \quad (3)$$

2.2. Heat Transfer

Energy equation in the pipeline was obtained from the following equation [20].

$$\rho A C_p u \nabla T = \nabla \cdot (A k \nabla T) + f_D \frac{\rho}{d^2 d_h} |u|^3 + Q_{wall} \quad (4)$$

Where (J/kg.K) is the heat capacity at constant pressure, T (K) is the temperature and k (w/m.K) is the thermal conductivity. The second term on the right hand side of the equation (4) is the released heat due to the internal friction. Consequently, it necessitates to consider Q_{wall} in the heat transfer equation which represents heat sink or other heat source in the pipeline.

$$Q_{wall} = K_{eff} p (T_{ext} - T) \quad (5)$$

where p (m) is the pipe circumference, K_{eff} is effective heat transfer coefficient (w/m².k), T (k) is the surface temperature and T_{ext} (K) is the ambient temperature. The total heat transfer is the convective heat transfer coefficient for the fluid film inside the pipeline, heat transfer coefficient in wall and the convective heat transfer coefficient for the fluid film outside the pipeline.

The effective heat transfer coefficient (K_{eff}) for the rotating tube is obtained from the following equation [20]:

$$K_{eff} = \frac{\pi^2}{\frac{1}{r_o h_{int}} + \frac{1}{r_N h_{ext}} + \sum_{n=1}^N \left(\frac{\ln\left(\frac{r_n}{r_n - 1}\right)}{k_n} \right)} \quad (6)$$

Here h_{int} is the heat transfer coefficient inside the pipeline, r is the pipeline radius, h_{ext} is the heat transfer coefficient outside the pipeline. In the present study, the ambient temperature was assumed to be constant and the heat transfer around the pipe was quasi-steady. Tube heat transfer coefficient was calculated as:

$$h_{int} = Nu_{int} \frac{K_{oil}}{d} \quad (7)$$

Nusselt correlation for the large Reynolds number range and the transition region is as the following [20]:

$$Nu_{int} = \frac{\left(\frac{f_D}{g} (Re - 1000) Pr \right)}{1 + 12.7 \sqrt{\frac{f}{D}} \left(Pr^{\frac{2}{3}} - 1 \right)} \quad (8)$$

Outside tube heat transfer is specified as follows:

$$h_{ext} = Nu_{ext} \frac{K_{air}}{d} \quad (9)$$

2.3. Prediction of hydrate formation by the gas gravity method

Heretofore, some methods have been proposed to predict the conditions in the NGH formation, but almost all of these methods require the gas composition analysis. Therefore, if the percentages of the gas composition are not determined, the previous methods are not able to predict the hydrate formation. In this case, the Katz gravity [21] chart can be used to predict the temperature and the pressure of hydrate formation. A comprehensive relationship can be used instead of the graph. Hydrate temperature is predicted due to the pressure of the gas and its specific gravity. Hydrate forms when the temperature is less than the predicted hydration temperature [22].

$$T_h = 13.47 \ln(P) + 34.27 \ln(SG) - 1.675 [\ln(P) * \ln(SG)] - 20.35 \quad (10)$$

where T (°F) is the gas flow temperature, P (psi) is pressure and SG is the specific gravity of gas.

3. Validation and computational domain

3.1. Numerical method

In this study, Multiphysics was used for CFD simulation. This is a powerful software which is used by many researchers to model various physical phenomena [23-25]. It was employed in order to

simulate the gas transmission line to Ilam refinery. Tange Bijar gas field is located in Ilam province, 70 kilometers southwest of Ilam city, and the gas reservoir of this field has a processing capacity of 7 million cubic meters of gas per day. After processing gas in Tange Bijar gas operation center, it is sent to Ilam gas refinery and the gas condensate is transported to Ilam refinery by a 22-inch pipeline. The gas and pipeline parameters are tabulated in Table 1 and the composition of entering gas into the pipeline are listed in Table 2. It should be noted that the composition of the gas in the pipeline is constant during a long period of time.

Table 1. The specification of gas and pipelines

specifications	value
length of the pipeline (km)	30
pipe diameter (in)	22
inlet temperature (°F)	113
input flow rate (Mol/hr)	10000
gas flow (Kg/hr)	13000
liquid flow (Kg/hr)	20
gas density (Kg/m ³)	0.89
gas viscosity (Pa.s)	0.013
gas speed (m/s)	2.13
thickness of the pipe wall (m)	0.00956
conductive heat transfer coefficient of wall (W.m.k)	0.4
thickness of the insulation layer (m)	0.005
conductive heat transfer coefficient of insulation (W/m.k)	0.129

Table 2. The composition of the gas entering the pipeline

component	mole fraction	vapor phase	liquid phase
N ₂	1.88e-02	1.91e-02	2.05e-03
CO ₂	7.90e-03	7.93e-03	6.36e-03
H ₂ S	1.60e-03	1.57e-03	3.16e-03
methane	0.93252	0.9432916	0.2976367
ethane	1.70e-02	1.69e-02	2.44e-02
propane	4.80e-03	4.50e-03	2.25e-02
i_butane	1.60e-03	1.34e-03	1.71e-02
n_butane	2.40e-03	1.87e-03	3.34e-02
i_pentane	1.20e-03	6.96e-04	3.09e-02
n_pentane	1.40e-03	6.81e-04	4.37e-02
n_hexane	7.50e-03	1.89e-03	0.337303336
n_heptane	1.70e-03	1.61e-04	9.22e-02
H ₂ O	1.60e-03	1.11e-04	8.92e-02

Boundary conditions were inlet velocity at the inlet and no slip condition at the wall boundary. The simulation was carried out according to the available data and predicted the pipeline condition. The initial and terminal conditions of the tubes were available from the temperature and pressure of pipeline in Ilam refinery (inlet temperature is about 113 °F, outlet temperature is 77 °F, inlet relative pressure 7.8e04 pa and the outlet relative pressure is 7.2e04 pa).

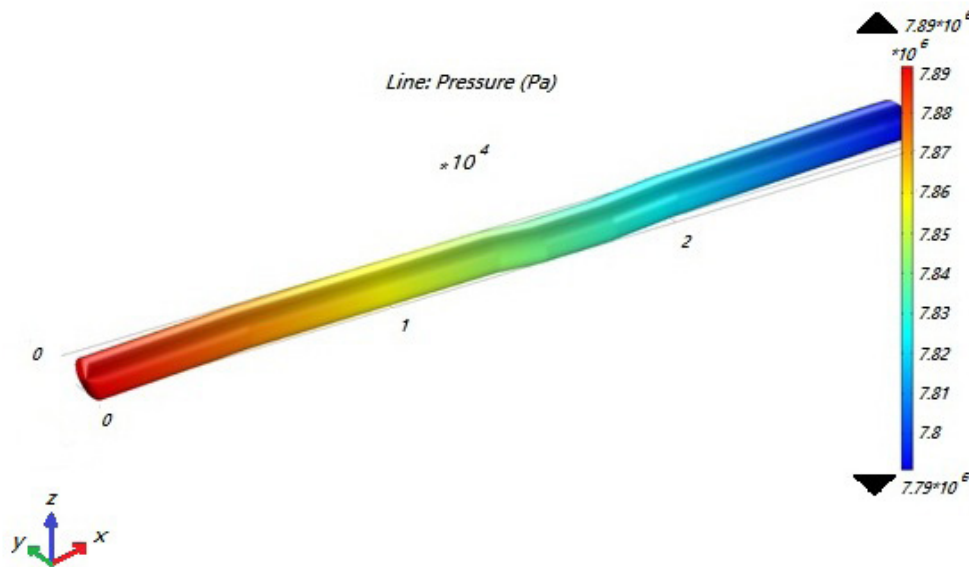
In order to validate the numerical results of COMSOL and HYSYS [26-28], the results were compared with the experimental data. The mechanistic difference between them is that COMSOL models transport phenomena, while HYSYS is based on the thermodynamic relationships. Regarding the applications, HYSYS simulates very specific chemical plant equipment, while COMSOL simulates whatever physical system you set up: ranging from fluid flow, heat transfer, mass transport, electricity and magnetism, mechanical

deformation of materials, etc. and all of these could depend on each other. You will need to draw the geometry, choose the physics, set up the boundary conditions, etc. With HYSYS the equipment is already predetermined: for example, you will select a “Condenser” from a list of available equipment, choose what temperature it is operating at and what fluid goes into it. HYSYS does not provide any details about what is actually happening inside the equipment. This paragraph was added for this item.

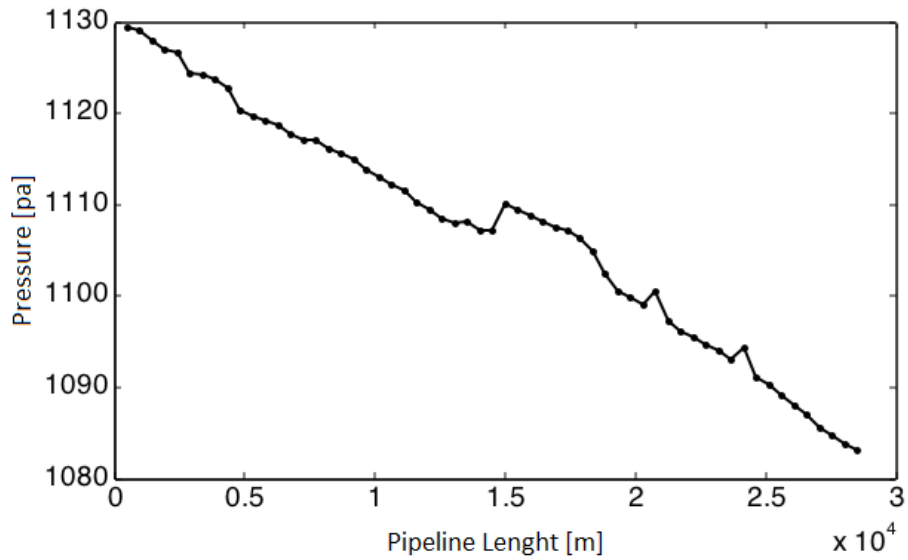
The temperature and pressure along the pipeline were obtained by COMSOL Multiphysics. The temperature and pressure along the pipeline were predicted according to Mokhatab et al. [22] method, which is based on the hydrate formation tables and GRAVITY method [22]. The predicted values for the temperature and pressure using the software with experimental data, which are very close to the experimental data, are shown in Table 3. Therefore, the numerical results had enough reliability for the simulation of the problem.

Table 3. The results of COMSOL and HYSYS compared with the experimental data

Method	Inlet Temperature(°F)	Inlet Pressure(pa)	Outlet Temperature(°F)	Outlet Pressure(pa)
COMSOL	113	7.8e04	78.8	7.3e04
HYSYS	113	7.8e04	77.9	7.4e04
Experimental	113	7.8e04	77.18	7.2e04



(a)



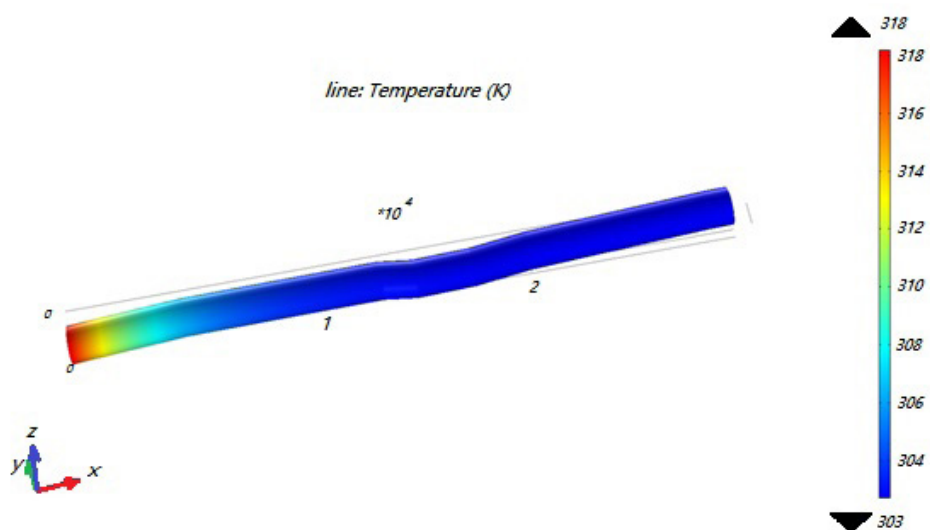
(b)

Figure 1. Pressure variation along the pipeline, a) three dimensional contour and b) one dimensional profile

Figure 1 shows the gas pipeline profile from the origin to the refinery. It should be mentioned that all the graphs along the pipeline were plotted based on the area weighted average of the properties like temperature and pressure. The length of the pipeline was about 28.5 km and only height changes along the vertical and horizontal were considered. Fractures observed in the pressure graph related to these elevations in height. A pressure distribution

contours geometric model is given in Figure 1(a). Pressure drop in the pipeline played an essential role in our study. The simulation of the pipeline in Figure 1(b) calculated the pressure drop across the pipeline and also, as shown in the Figure 1(b), the pressure was specified in the pipeline.

Figure 2(a) shows the temperature distribution contours along the pipeline. Figure 2(b) shows a diagram of temperature throughout the model.



(a)

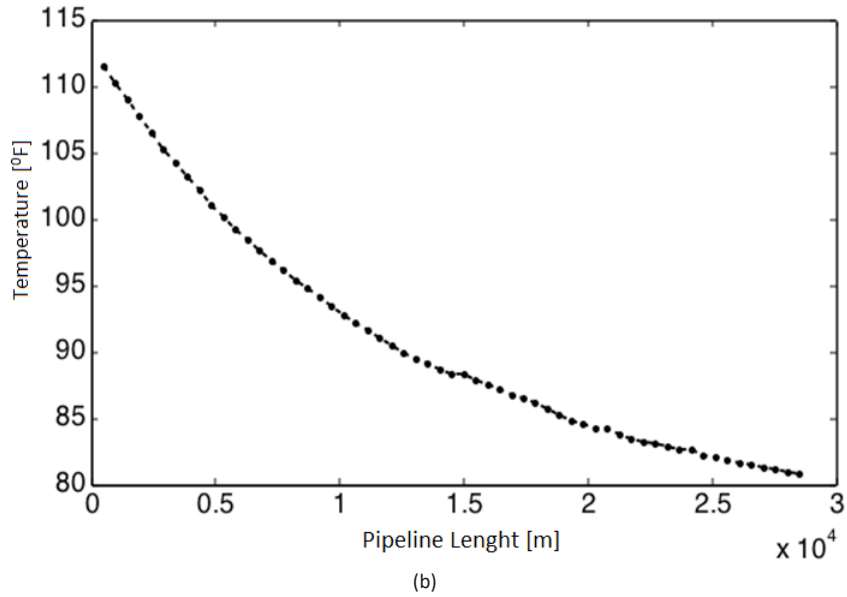


Figure 2. Temperature variation along the pipeline a) three dimensional contour and b) one dimensional profile

Pressure profile is illustrated in Figure 1. Moreover, Figure 2 shows the temperature profile which is obtained in the pipeline. It is evident that these two parameters declined along the pipeline, but it is clear that the temperature drop was higher at the beginning of the pipeline. Regarding the equation of energy (Eq. (4)), higher temperature gradient leads to increasing heat transfer in the pipeline. The temperature gradient was higher at the beginning of the pipeline, so the heat transfer was higher in this region which resulted in the higher temperature gradient in this part.

3.2. Grid sensitivity studies

Before applying the numerical method, a grid independency study was carried out and the optimal numbers of grid applied for this computational domain were 76321. This number is determined by using different numbers of mesh in a single type according to the outlet temperature of the pipeline (an inlet temperature is 113 °F and the outside temperature is 40 °F) (Table4). Further increase in the number of meshes to 239862, the output temperature did not affect the number of meshes and it was independent from the grid size (see Figure 3).

Table 4. Output temperature for different grid sizes

number of grids	158	3749	14854	76321	239862
output temperature	45.71	43.92	42.94	42.12	42.1

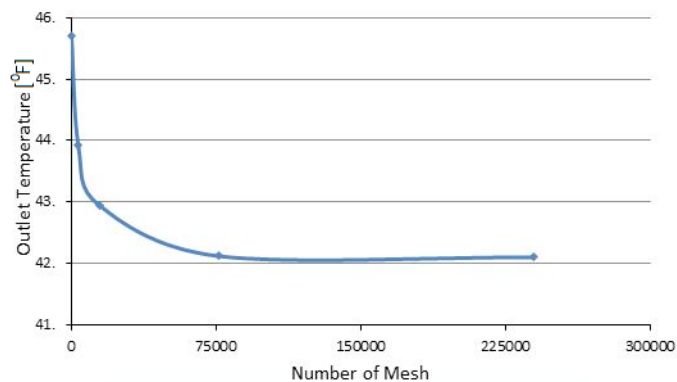


Figure 3. Outlet temperature evaluation at different grid size

4. Results and discussion

In this research, a new technique was introduced to obtain the best result with high accuracy using the available data. In addition, the pipeline was considered in different conditions and the probability of hydrate formation was investigated in order to allow the pipeline operators to make the right decision in different conditions and to prevent the formation of gas hydrates in the pipeline. Inlet temperature, ambient temperature and flow rate were the other studied parameters to find their effects on the hydrate formation along the pipeline.

4.1. Hydrate formation conditions

One of the ways to prevent the hydrate formation

is the control of gas temperature, for example by heating the system by means of the electrical heating. It is prevented from reaching the gas temperature to the point of hydrate formation. So, we applied the numerical simulation by COMSOL and HYSYS to predict the temperature profile. Ambient temperature was 70 ° F, the gas inlet temperature was 100 ° F and inlet gas flow rate was 30000 kmol/hr. The temperature of the hydrate formation was calculated according to the pressure and the temperature profiles obtained with the COMSOL and HYSYS software and its profile were determined. The temperature of NGH formation was predicted along the pipeline according to its characteristics such as the composition, pressure, temperature, etc.

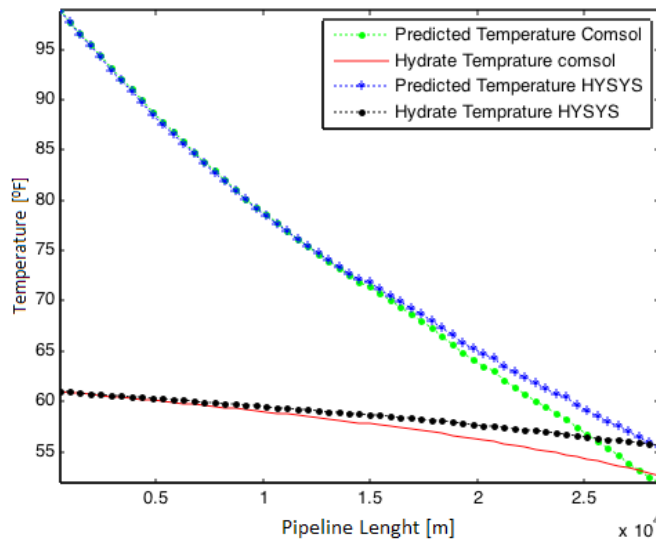
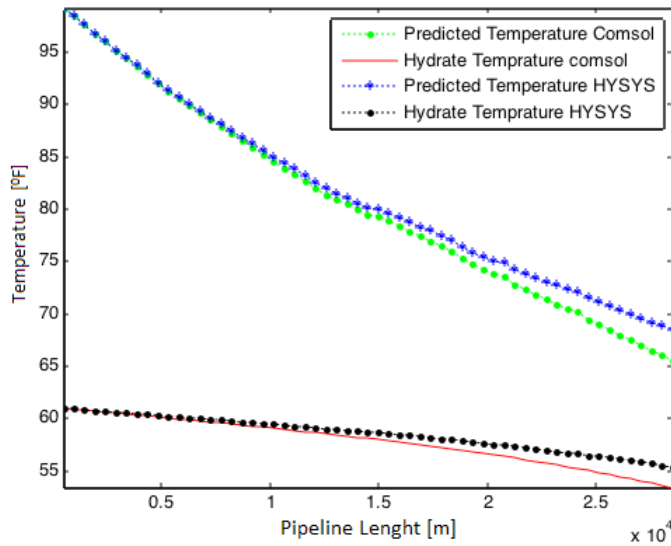


Figure 4. Hydrate temperature estimation along the pipeline

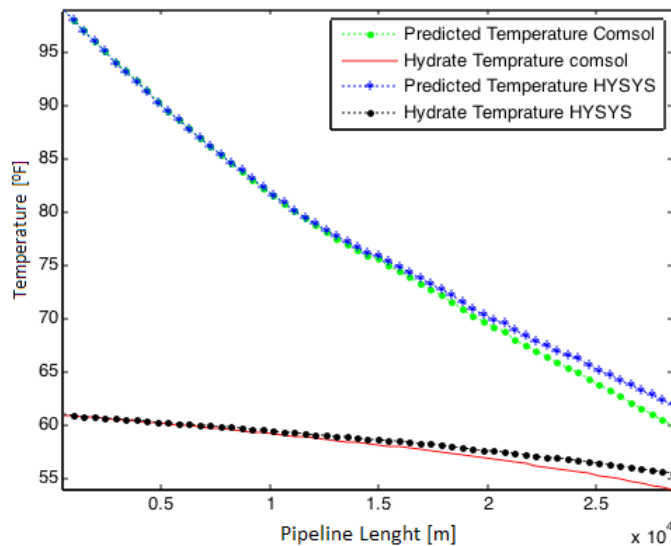
In figure 4, the numerical results show that the predicted temperature is higher than the hydrate temperature formation along the pipeline. The probability of hydrate formation increases in the pipelines where the temperature of the gas is less than the hydrate formation temperature. Therefore, the “probability” of hydrate formation is said to be the methods to predict the hydrate formation, which is associated with uncertainty and some assumptions. According to figure 4, both COMSOL and HYSYS software were employed for the simulation to approve their capabilities for the modeling of such investigation. The results of both softwares were almost the same and the slight deviation of the results was due to the difference between the employed numerical procedures by

these softwares. For example, a three dimensional model is solved in Comsol while Hysys solves the problem linearly. However, COMSOL multiphysics converge faster than HYSYS and since computational time is one of the most important characteristics of the numerical simulations, COMOSL is in the priority for modeling this phenomenon. In addition, COMSOL is a multiphysics software and users are able to study the effects of other physics like an external magnetic field on this phenomenon simultaneously.

Inlet temperature, ambient temperature and flow rate are the other studied parameters to find their effects on the hydrate formation along the pipeline. Herein, two conditions for the formation of hydrate were applied according to the ambient temperature, inlet temperature and flow rate.



(a) $T_a = 60^\circ \text{F}$, $T_{in} = 100^\circ \text{F}$, $Q_{in} = 10,000 \text{ kmol/hr}$



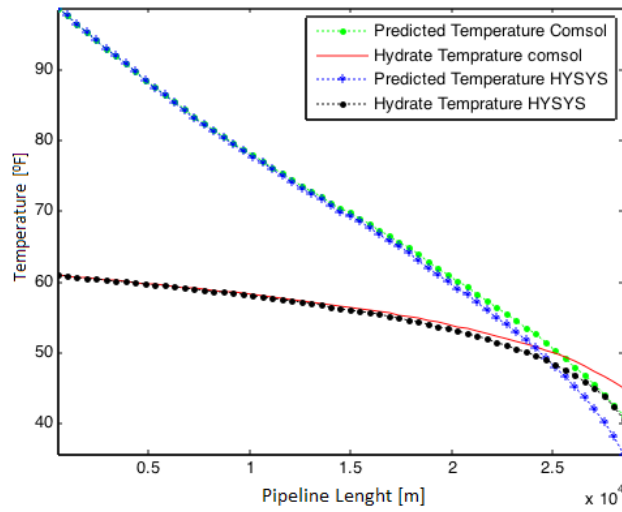
(b) $T_a = 60^\circ \text{F}$, $T_{in} = 100^\circ \text{F}$, $Q_{in} = 30,000 \text{ kmol/hr}$

Figure 5. The temperature predicted by the CFD modeling and HYSYS software and the temperature of hydrate formation in the pipeline

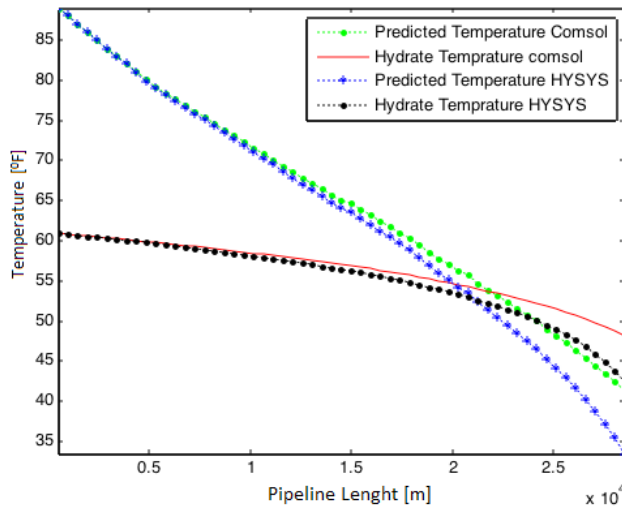
Figure 5(a) shows different ambient temperature and inlet gas temperature at different flow rates. Regarding figure 5(a, b), the hydrate is not formed along the pipeline, so this condition is preferable for the pipelines. It is undeniable that operators cannot change the ambient temperature and to some extent the inlet flow rate in the pipeline cannot be changed

too much, but the inlet temperature of the pipeline can be altered via the embedded heaters.

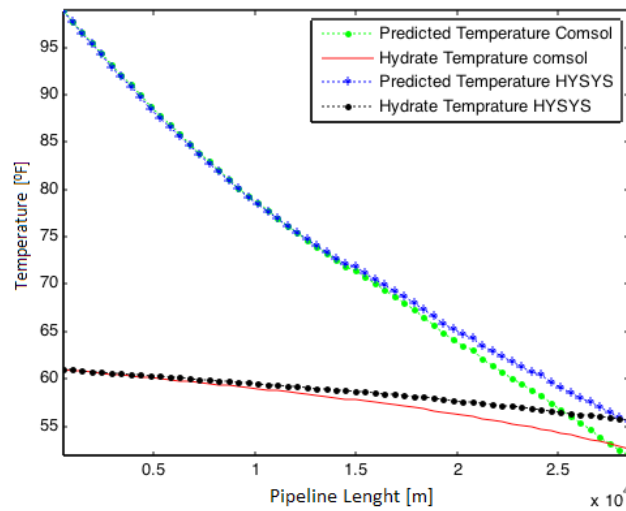
Moreover, the conditions in which the hydrate formation occurs were considered. Inlet temperature, ambient temperature and flow rate were the studied parameters which are shown in Figure 6.



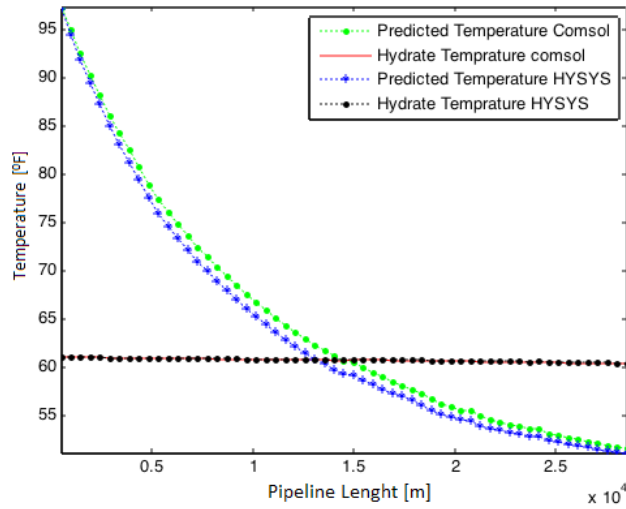
$T_a = 30^\circ \text{F}$, $T_{in} = 100^\circ \text{F}$, $Q_{in} = 40,000 \text{ kmol/hr}$



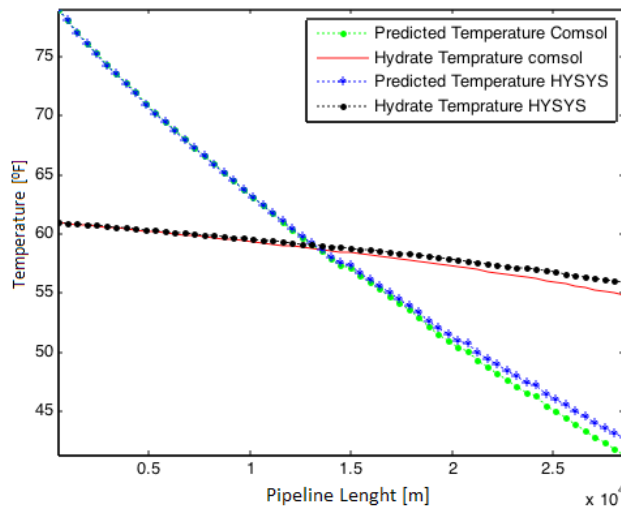
(b) $T_a = 30^\circ \text{F}$, $T_{in} = 90^\circ \text{F}$, $Q_{in} = 40,000 \text{ kmol/hr}$



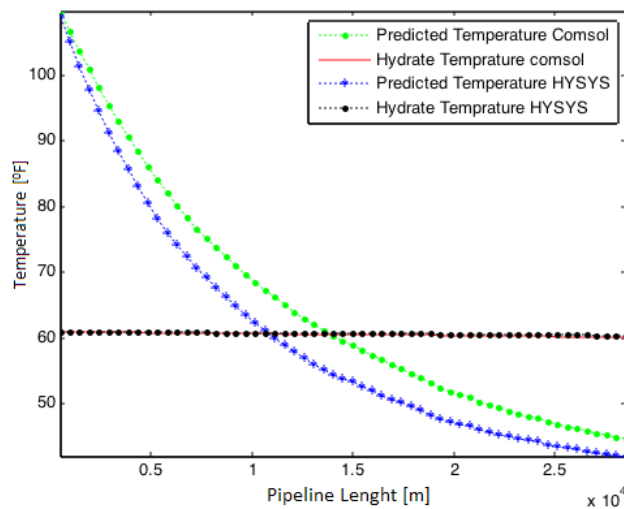
(c) $T_a = 40^\circ \text{F}$, $T_{in} = 100^\circ \text{F}$, $Q_{in} = 30,000 \text{ kmol/hr}$



(d) $T_a = 40^\circ \text{F}$, $T_{in} = 100^\circ \text{F}$, $Q_{in} = 10,000 \text{ kmol/hr}$



(e) $T_a = 40^\circ \text{F}$, $T_{in} = 80^\circ \text{F}$, $Q_{in} = 30,000 \text{ kmol/hr}$

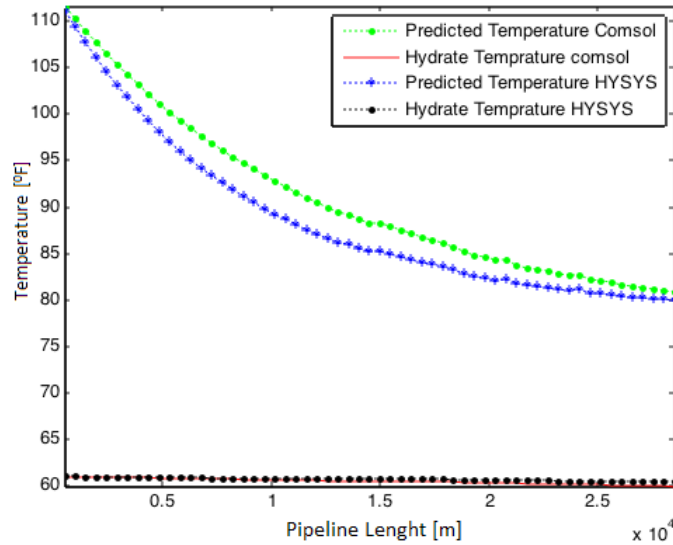


(f) $T_a = 40^\circ \text{F}$, $T_{in} = 113^\circ \text{F}$, $Q_{in} = 10,000 \text{ kmol/hr}$

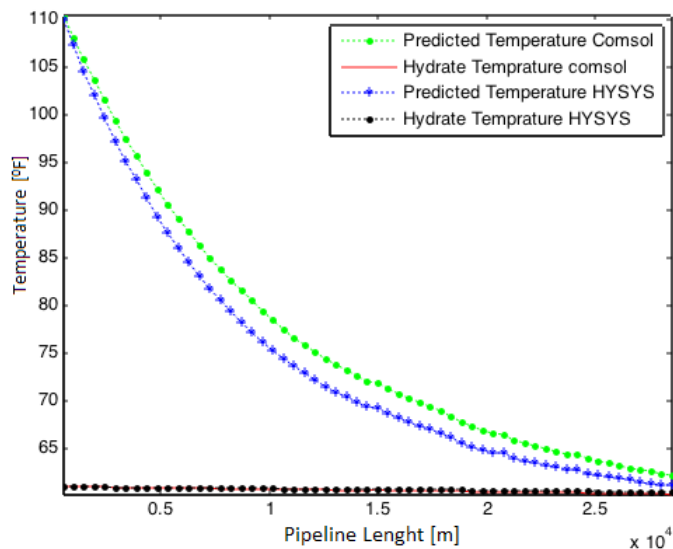
Figure 6. The temperature predicted by the CFD modeling and HYSYS software and the temperature of the hydrate formation in the pipeline

According to Figure 6, the pipeline is in the condition of hydrate formation. For instance, the lower ambient temperature and the more flow rate cause this phenomenon. In all these cases, the hydrate is formed at the end of the pipeline. Therefore, to address this problem, the effective parameters should be modified. The actual temperature conditions of Ilam pipeline

were analyzed with sensitivity analysis in order to investigate the probability of hydrate formation along this pipeline. For example, comparison of figure 6 (c) and (d) shows that with the increase of the flow rate, the COMSOL software predicts the hydrate temperature in shorter distance from the pipeline inlet than the HYSYS software.



(a) $T_a = 80^\circ \text{F}$, $T_{in} = 113^\circ \text{F}$, $Q_{in} = 10,000 \text{ kmol/hr}$



(b) $T_a = 60^\circ \text{F}$, $T_{in} = 113^\circ \text{F}$, $Q_{in} = 10,000 \text{ kmol/hr}$

Figure 7. The temperature predicted by the CFD modeling and HYSYS software and the temperature of hydrate formation in the pipeline

The ambient temperature is altered in different seasons of the year and according to figure 7 the hydrate formation is possible in low temperature

of the ambient, so it is essential to change the inlet condition (e. g. gas preheating) to keep the pipeline in the conditions that the hydrate does not form.

4.2. Effects of fluid flow and the pipeline conditions on the hydrate formation

Herein, the insulation was used in order to maintain the fluid temperature constant and its thickness is highly important in this application. Therefore, the effect of insulation thickness according to the temperature variations and subsequently the probability of hydrate formation

was investigated. The insulation of the pipeline makes a concrete and the thermal conductivity of 0.117 Btu/hr.ft.°F. The thickness of the pipeline (insulation) is selected regarding the resultant temperature drop to avoid the hydrate formation. Figure 8 shows the pipeline temperature according to the different insulation thicknesses.

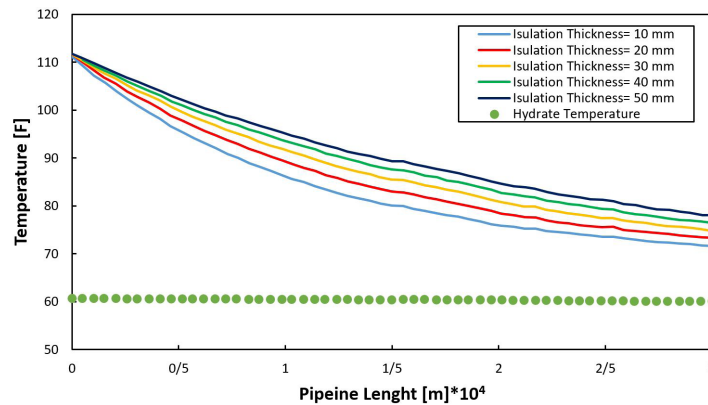


Figure 8. Effect of insulation thickness on the hydrate condition

According to Figure 8, if the insulation thickness increases, the hydrate formation and the heat loss along the pipeline decrease and the insulation thickness of 5 mm is suitable both physically and economically. Consequently, the simulation of Ilam

pipeline was conducted with the insulation thickness of 5 mm in COMSOL software.

In Figure 9, four different flow rate of the hydrate formation and inlet flow rate are shown in the same inlet and ambient temperature.

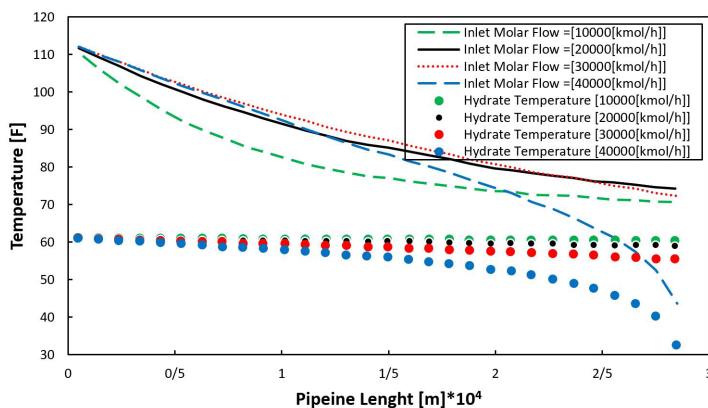


Fig 9. Temperature profile in four different input flow rate, $T_{in} = 113^\circ\text{F}$ and 80°F ambient temperature and equivalent temperature of the hydrate formation

According to figure 9, changing the flow rate does not have significant effects on the hydrate formation through the pipeline. In addition to the flow rate effect on the hydrate formation, fluid inlet temperature effects on the hydrate formation were

investigated while the pipeline insulated.

According to Figure 10, ambient temperature is 80°F , fluid flow rate is 10000 kmol/hr and the hydrate formation in three levels of input gas temperatures of 90,110,130 °F are considered.

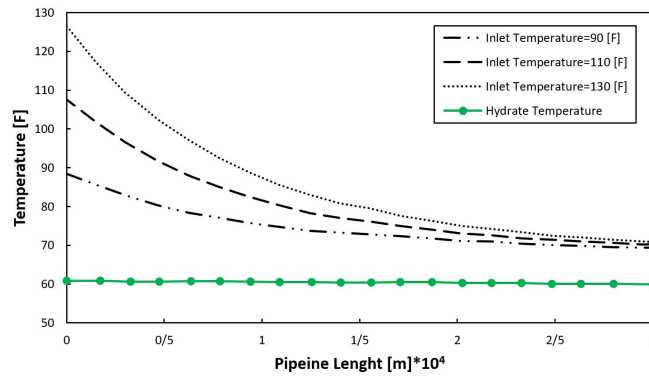


Figure 10. Temperature profile in three different inlet temperature, $Q= 10000$ kmol/hr and $T_{am} = 80$ ° F and the equivalent temperature of hydrate formation

From the results it can be seen that in these temperatures, the hydrate formation does not accure. In the mentioned condition, the fluid inlet

temperature does not have significant effects on the hydrate formation.

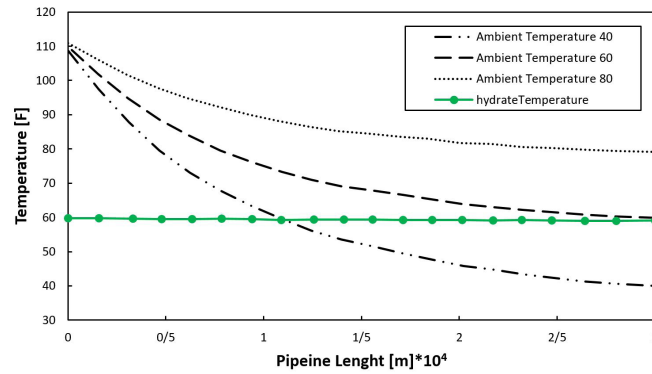
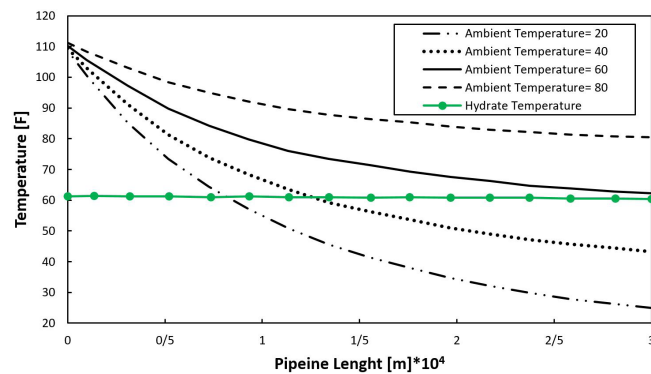


Figure 11. The predicted temperature curve in the three different ambient temperatures, $Q= 10000$ kmol/hr and $T_{in} = 113$ ° F and the equivalent temperature of the hydrate formation

The other studied parameter was ambient temperature. As can be seen from figure 11, if the ambient temperature reduces during the cold season, the probability of the hydrate formation becomes very high along the pipeline and the insulation is not effective anymore. In order to prevent the hydrate formation in these situations, preheating of the

fluid at the inlet of the pipeline or using antifreeze additives in the fluid can be the effective ways.

Furthermore, figure 12 illustrates the effect of ambient temperature variation and insulation thickness. Three insulation thicknesses 10, 20, 30 mm are considered with the same input temperature and flow rate.



a) $\epsilon = 10$ mm

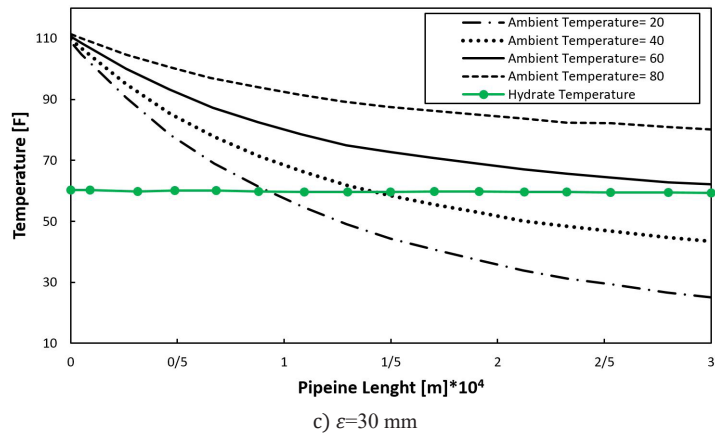
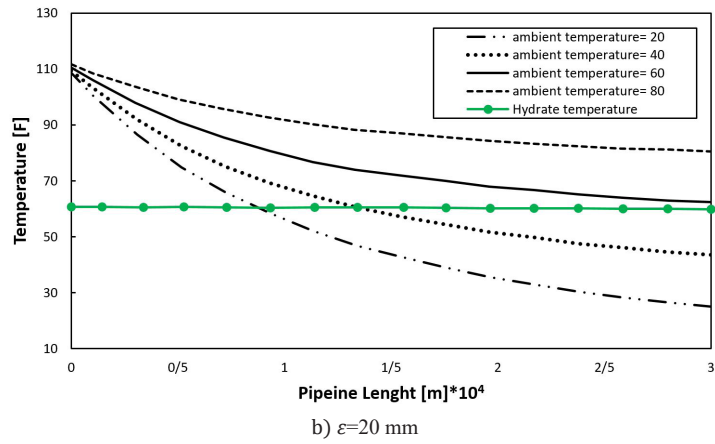
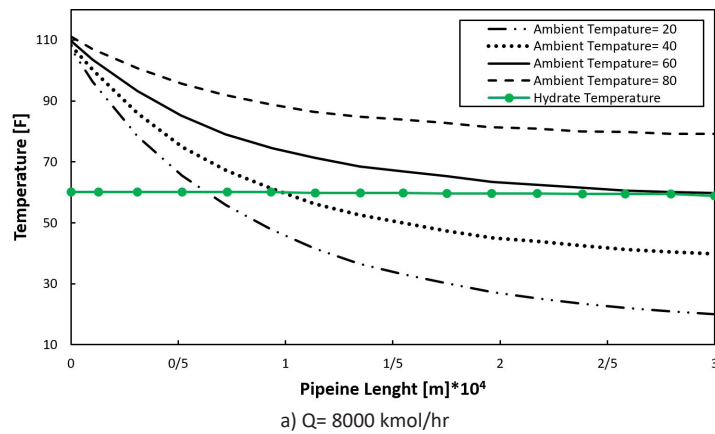


Figure 12. Temperature profile at different insulation thicknesses for $Q = 10000$ kmol/ hr

According to figures 12, changes in the thickness of the insulation do not have any significant effect on the formation of hydrate and this method is not applicable for the reduction of hydrate formation.

Figure 13 shows the effects of ambient temperature changes and the flow rate reduction on the hydrate formation.



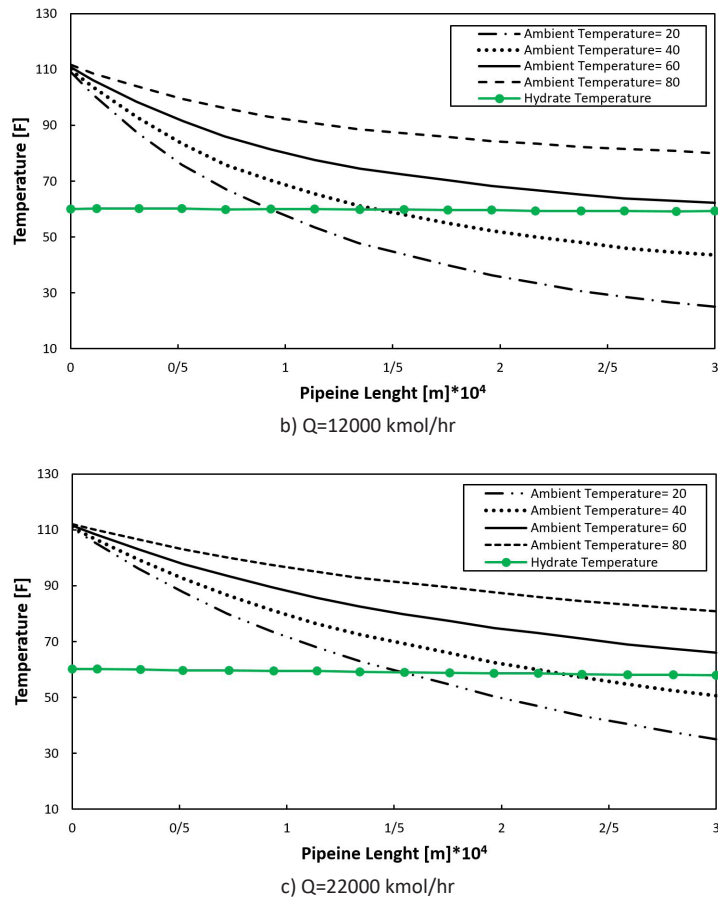


Figure 13. Effect of fluid flow rate and the ambient temperature on the hydrate formation

Regarding Figure 13, when both flow rate and the ambient temperature decrease, there is the probability of hydrate formation at the beginning distance of the pipeline. Figure 13 also shows that if the inlet flow rate increases, the possibility of the hydrate formation decreases. Consequently, it is highly important to increase the gas flow rate in the cold weather. This is an effective and better way than increasing pipeline insulation which has higher financial costs.

According to the results, in the operational conditions of the pipeline, it is obvious that lower ambient temperature have great influence on the possibility of the hydrate formation. Insulation and inlet temperature are not effective ways to handle this problem. However, when the inlet flow rate increase, the hydrate formation possibility decreases which is more economical than the insulation of the pipeline.

4. Conclusion

In this study, CFD method was employed to simulate and predict the probability of the hydrate formation in Ilam gas refinery pipeline. The numerical

results compared with the experimental data showed a good agreement with each other. Hydrate formation temperature was obtained regarding the pipeline pressure and the actual temperature was calculated employing the actual boundary conditions of Ilam gas refinery pipeline. Then, these temperatures were compared with each other to find the probability of the hydrate formation through the pipeline. The effects of various parameters including: a) gas flow rate, b) initial gas temperature, c) pipeline insulation, d) ambient temperature were considered on the probability of the hydrate formation. The results showed that the inlet and ambient temperatures were usually higher than the hydrate formation temperature, so the probability of hydrate formation was low in the inlet. However, due to the pressure and temperature reduction at the pipeline outlet, in some situations the hydrate formation was possible there. Furthermore, if the inlet flow rate increases, the possibility of the hydrate formation possibility decreases. On the other hand, pipeline insulation postponed the hydrate formation, but it was not

effective like increasing inlet temperature or flow rate and changing the recent parameters was more influential for the reduction possibility of the hydrate formation. In addition, the capability of COMSOL and HYSYS for modeling such phenomenon was studied. The numerical results of this software were almost the same and the little difference in the results was due to different utilized numerical solving method by them. However, COMSOL multiphysics is better than HYSYS because it performs calculations and converge faster and provides more conditions to solve the problem. Also COMSOL can be used to simulate various physics simultaneously. Consequently, this software is preferred for the simulation of this phenomenon.

Nomenclature

Symbols	title
A (m ²)	sound velocity
A (m/s)	cross section
a, b	equation constant
C_p (J/kg.°C)	specific heat capacity at constant pressure
d_h (m)	hydraulic diameter
\dot{E} (J)	power input and output
F_D	Darcy friction factor
F_f (N)	friction force
F_g (N/kg)	gravity convective
F_p (N/m ³)	pressurize force
F_w	fanning friction factor
g (m/s ²)	gravitational acceleration
H (W/m ² K)	heat transfer coefficient
K (W/m.K)	thermal conductivity
M_w (g/mol)	molecular weight
NGH	natural gas hydrate
Nu	Nusselt number
P (pa)	pressure
P_c (psia)	critical pressure
Pr	Prandtl number
Q_n (J)	heat transfer
R (J/K.mol)	gas constant
Re	Reynolds number
S (J/K)	entropy
T (°F)	temperature
T_c (°F)	critical temperature

U (m/s)	fluid velocity
V (m ³)	volume
W (mg/m ³)	amount of water in the gas
W_n (J)	total woke by normal force
W_{shaft} (J)	mechanical work
W_{shear} (J)	shear force work
ε (mm)	thickness
ρ (kg/L)	density

References

1. Farkhondeh, M. and A. Gheisi, An introduction to natural gas hydrate. Transportation. Methane gas hydrate report. Tehran University, 2002.
2. Sloan, E.D., Fundamental principles and applications of natural gas hydrates. Nature, 2003. 426(6964): p. 353-363.
3. Davarnejada, R., J. Azizia, and J. Azizib, Prediction of Gas Hydrate Formation using HYSYS Software. International Journal of Engineering-Transactions C: Aspects, 2014. 27(9): p. 1325.
4. Schuster, J.J., et al., Simultaneous analysis of the dispersed liquid and the bulk gas phase of water sprays using Raman spectroscopy. Applied spectroscopy, 2016. 70(6): p. 1055-1062.
5. Farzaneh-Gord, M., et al., Investigation of hydrate formation in natural gas flow through underground transmission pipeline. Journal of Natural Gas Science and Engineering, 2013. 15: p. 27-37.
6. Pickering, P., et al. Evaluating new chemicals and alternatives for mitigating hydrates in oil & gas production. in IIR Conference, Aberdeen, Escocia. 2001.
7. Al-Adel, S., et al., The effect of biological and polymeric inhibitors on methane gas hydrate growth kinetics. Fluid Phase Equilibria, 2008. 267(1): p. 92-98.
8. Wang, Z., et al., Modeling of hydrate layer growth in horizontal gas-dominated pipelines with free water. Journal of Natural Gas Science and Engineering, 2018. 50.
9. Babakhani, S.M., et al., A new approach of studying mixed gas hydrates involving propane at non-equilibrium conditions and final state: An experimental study and modeling. Chemical Engineering Science, 2018. 179: p. 150-60.
10. Wang, Z., et al., A new hydrate deposition prediction model for gas-dominated systems with free water. Chemical Engineering Science, 2017. 163: p. 145-154.
11. Liu, L., et al., Numerical study on the pipe flow characteristics of the cemented paste backfill slurry considering hydration effects. Powder Technology, 2019. 343: p. 454-464.
12. Kelkar, S., M. Selim, and E. Sloan, Hydrate dissociation rates in pipelines. Fluid Phase Equilibria, 1998. 150: p. 371-382.
13. Jassim, E.I., M.A. Abdi, and Y. Muzychka. A CFD-Based Model to Locate Flow-Restriction Induced Hydrate Deposition

in Pipelines. in Offshore technology conference. 2008. Offshore Technology Conference.

14. Balakin, B., A. Hoffmann, and P. Kosinski, Experimental study and computational fluid dynamics modeling of deposition of hydrate particles in a pipeline with turbulent water flow. *Chemical Engineering Science*, 2011. 66(4): p. 755-765.

15. Fatnes, E.D., Numerical simulations of the flow and plugging behaviour of hydrate particles. 2010, The University of Bergen.

16. Wang, W., et al., Experimental study on flow characters of CH₃ CCl₂ F hydrate slurry. *international journal of refrigeration*, 2008. 31(3): p. 371-378.

17. Nazeri, M., B. Tohidi, and A. Chapoy, An evaluation of risk of hydrate formation at the top of a pipeline. *Oil and Gas Facilities*, 2014. 3(02): p. 67-72.

18. Sule, I., et al., CFD Analysis of Hydrate Formation in Pipelines. *Petroleum Science and Technology*, 2015. 33(5): p. 571-578.

19. Fox, R.W., A.T. McDonald, and P.J. Pritchard, Introduction to fluid mechanics. Vol. 5. 1998: John Wiley & Sons New York.

20. Bergman, T.L. and F.P. Incropera, Fundamentals of heat and mass transfer. 2011: John Wiley & Sons.

21. Katz, D.L.V., Handbook of natural gas engineering. 1959: McGraw-Hill.

22. Mokhatab, S. and W.A. Poe, Handbook of natural gas transmission and processing. 2012: Gulf professional publishing.

23. Dehghan Manshadi, M.K., et al., Electroosmotic micropump for lab-on-a-chip biomedical applications. *International Journal of Numerical Modelling: Electronic Networks, Devices and Fields*, 2016. 29(5): p. 845-858.

24. Kamali, R. and M.K.D. Manshadi, Numerical simulation of the leaky dielectric microdroplet generation in electric fields. *International Journal of Modern Physics C*, 2016. 27(01): p. 1650012.

25. Kamali, R., M.K.D. Manshadi, and A. Mansoorifar, Numerical *analysis of non Newtonian fluid flow in a low voltage cascade electroosmotic micropump*. *Microsystem Technologies*, 2016. 22(12): p. 2901-2907.

26. Hanyak, M.E., Chemical process simulation and the Aspen HYSYS software. 2012: Department of Chemical Engineering, Bucknell University.

27. COMSOL Multiphysics User's Guide, version 4.3, COMSOL AB, Stockholm, Sweden.

28. Aspen HYSYS® v. 9.0. www.aspentech.com.

پیش بینی شرایط تشکیل هیدرات در خط لوله‌ی پالایشگاه گاز ایلام با استفاده از دینامیک سیالات محاسباتی

عقیل ممسنی، احمد آذری*، امیر عباس ایزدپناه، محمد جمالی

دانشکده مهندسی نفت، گاز و پتروشیمی، دانشگاه خلیج فارس، کدپستی ۷۵۱۶۹-۱۳۸۱۷، بوشهر، ایران

چکیده

تشکیل هیدرات در خطوط لوله‌ی انتقال گاز پالایشگاه یکی از مهمترین مشکلات شرکت‌های گاز رسانی است. تحقیقات زیادی در مورد این پدیده انجام شده است که در بسیاری از موارد ضرورت رویارویی با این مشکل مورد توجه قرار گرفته است. برخی از روش‌ها و فناوری‌ها به منظور جلوگیری از تشکیل هیدرات در خطوط لوله‌ی انتقال گاز یا پیش‌بینی آن استفاده شده است. در این مطالعه، از مدل‌سازی دینامیک سیالات محاسباتی (CFD) برای پیش‌بینی احتمال تشکیل هیدرات در خط لوله‌ی گاز استفاده شده است. در این کار اعتبارسنجی مدل پیشنهادی با استفاده از داده‌های عملیاتی خط لوله‌ی انتقال گاز پالایشگاه ایلام انجام شد. پس از شبیه‌سازی خط لوله، نتایج عددی با داده‌های تجربی مقایسه شدند که نشان داد توافق خوبی با داده‌های تجربی دارند. با توجه به شیب فشار در خط لوله، دمای تشکیل هیدرات محاسبه و احتمال تشکیل هیدرات در خط لوله با توجه به مقایسه بین دمای تشکیل هیدرات و دمای واقعی ارزیابی شد. علاوه بر این، پارامترهای مختلفی از قبیل دمای ورودی، دمای محیط و سرعت جریان گاز به منظور پیدا کردن احتمال تشکیل هیدرات با استفاده از روش آنالیز حساسیت مورد مطالعه قرار گرفت که نتایج نشان داد که دمای ورودی و دمای محیط معمولاً بالاتر از دمای تشکیل هیدرات است، بنابراین احتمال تشکیل هیدرات در خط لوله کم است. هم‌چنین، نتایج به وضوح نشان داد که افزایش سرعت جریان گاز یا کاهش دمای ورودی گاز به خط لوله می‌تواند احتمال تشکیل هیدرات را افزایش دهد.

مشخصات مقاله

تاریخچه مقاله:

دریافت ۲۷ فروردین ۱۳۹۸

دریافت پس از اصلاح ۱۷ مهر ۱۳۹۸

پذیرش نهایی ۳ آذر ۱۳۹۸

کلمات کلیدی:

خط لوله‌ی گاز

تشکیل هیدرات

طراحی خط لوله

دینامیک سیالات محاسباتی

* عهده‌دار مکاتبات:

azari.ahmad@gmail.com

azari.ahmad@pgu.ac.ir

تلفن: +۹۸۹۱۷۳۲۳۸۶۳۹

دورنگار: +۹۸۷۷۳۳۴۴۵۱۸۲

نحوه استناد به این مقاله: