Comparative Evaluation of Natural Gas Pipeline Simulators

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Predictions of gas temperature and pressure profiles are essential for the design and operation of natural gas transmission pipelines. In the wake of vast developments of simulation tools in the past decade, gas pipeline simulators are being increasingly utilized for reliable and quick calculations of the volume of natural gas to be transmitted in relation to many factors such as the length and the size of the pipeline, the operating temperature and pressure profiles, the elevation change over the route, etc. The underlying numerical solution methods of such pipeline simulators largely alleviate the need for most of the simplifying assumptions and/or approximations of the analytical equations that often render an inadequate representation of gas flow in the transmission lines.

This study provides a comparative performance analysis of a number of commercial software packages, namely PIPESIM, PIPESYS (Ver. 2.01), PIPEPHASE (Ver. 7.3) and ASPEN HYSYS (Ver. 2004), that are widely used for the simulation of natural gas transmission pipelines. The simulation results presented in this work correspond to flow in a typical gas pipeline, the thermodynamic behavior of which is determined by the Peng-Robinson equation of state [1].

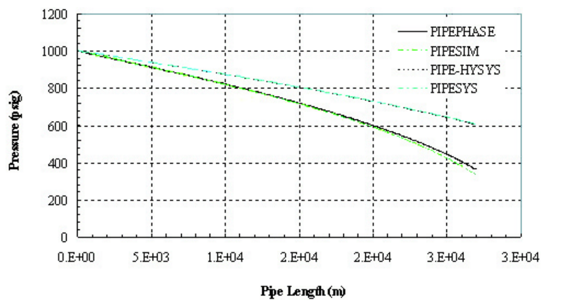

Figure 1: Pressure profiles for the case of fixed overall heat transfer coefficient.

In the first case study, the overall heat transfer coefficient between fluid, i.e. natural gas, and ambient air (6 °C) is assumed to be 3.45 Btu.h^{-1}.ft^{-2}.F^{-1} along the pipeline. Specifications of the simulated pipeline and the inlet flow conditions are given in Table 1. The simulation results of all the aforementioned simulators have been presented in Figures 1 and 2. As can be inferred from pressure profiles depicted in Figure 1, the PIPESYS and ASPEN HYSYS predictions are in good agreement, from which the PIPESIM and PIPEPHASE predictions drift away rather significantly along the pipeline. The temperature profiles for this case study are shown in Figure 2. As can be seen, due to the Joule Thompson effect, the temperature predictions of all four simulators gradually drop below the ambient temperature when the heat transfer coefficient is kept constant [2]. Clearly, the temperature profiles simulated by PIPESYS and PIPE module ASPEN HYSYS match fairly well.

As has been thoroughly discussed by Abdollahi et al. [2], Coulter and Bardon [3] modified Schorre's equation [4] and proposed the following equation for the explicit calculation of the temperature profile along a gas pipeline:

$$T = \left\{ T_0 - \left[T_a + \left(\frac{\eta}{\varphi}\right)\left(\frac{dP}{dL}\right) \right] \right\} e^{-\varphi L} + \left[T_a + \left(\frac{\eta}{\varphi}\right)\left(\frac{dP}{dL}\right) \right] \qquad \varphi = \frac{\pi D_0 U}{\dot{m} C_p} \qquad (1)$$

According to the above equation, temperature profile of fluid asymptotically approaches a temperature slightly below that of its surroundings. This implies that when inlet temperature of the fluid is higher than the ambient temperature, curvature of the temperature profile, i.e. second derivative of temperature with respect to pipe length, should be positive and vice versa.

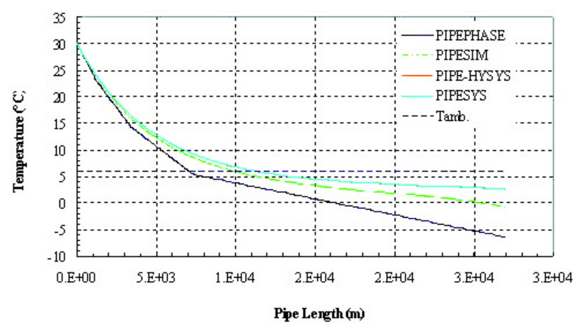

Figure 2: Temperature profiles for the case of fixed overall heat transfer coefficient.

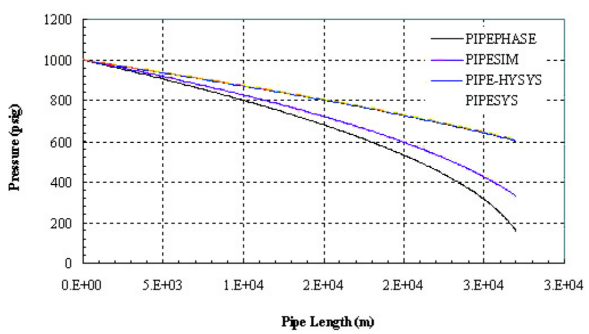

Figure 3: Pressure profiles for the case of estimated overall heat transfer coefficient.

In order to study the impact of heat transfer coefficient variations along the pipeline, in the second case study the heat transfer coefficient has been estimated on the basis of ambient air properties, pipeline specifications and flow conditions. The air properties are listed in Table 2. It is evident from the pressure profiles illustrated in Figure 3 that likewise the previous case the PIPESYS and ASPEN HYSYS pressure predictions agree well. Contrary to the previous case study, the deviation of pressure profiles simulated by PIPESIM and PIPEPHASE is however more pronounced than the pressure profiles predicted by PIPESYS and ASPEN HYSYS.

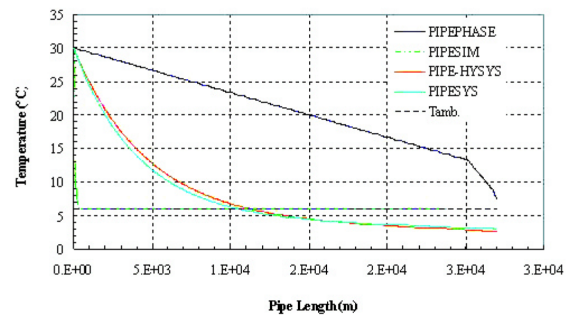

Figure 4: Temperature profiles for the case of estimated overall heat transfer coefficient.

The temperature profiles of the second case study are depicted in Figure 4. As can be seen, the PIPESIM temperature profile rapidly reaches the ambient temperature and then remains constant along a large part of the pipeline. Due to the Joule-Thompson effect [2], the temperature profile should however approach a temperature below the ambient temperature asymptotically as it is the case for the temperature profile predictions provided by PIPESYS and ASPEN HYSYS. Furthermore, PIPEPHASE temperature profile deviates severely from the others. Owing to its negative curvature and non-asymptotical behaviour, this temperature profile is not consistent with that determined by the analytical formulas of gas transmission pipelines [3]. It can therefore be concluded that the PIPESIM and PIPEPHASE temperature predictions are unrealistic.

Table 1 Pipeline specifications and inlet flow conditions

Pipeline Specifications		Inlet Flow Conditions	
D_i (inch)	10.02	T (°C)	30..0
d (inch)	0.365	P (psig)	1000.0
_ (inch)	0.0018	M_t (kg.h^{-1})	100000.0
L (km)	27.0	Gas composition (mole %)	C_1: 85.0
k (Btu.h^{-1}.ft^{-1}.F^{-1})	28.0		C_2: 10.0
n	2700		C_3: 5.0

Table 2 Air properties

SG	0.001
μ (cp)	0.018
T_a (°C)	6.0
u_a (m.s^{-1})	5.0
k_a (Btu.h^{-1}.ft^{-1}.F^{-1})	0.015

Simulation results of the four pipeline simulators corresponding to the end point of the pipeline are summarized in Table 3. The results suggest that the temperature and pressure predictions of PIPESYS and ASPEN HYSYS are in perfect agreement when the overall heat transfer coefficient is either constant or estimated along the pipeline. Nonetheless, the PIPESIM and PIPEPHASE predictions are rather unreliable.

Table 3 Pressure and temperature predictions of the pipeline simulators

	Pressure (psig)				Temperature (°C)			
	PIPESYS	PIPEPHASE	PIPESIM	PIPE-HYSYS	PIPESYS	PIPEPHASE	PIPESIM	PIPE-HYSYS
Fixed U	603.9	361.0	330.0	602.0	2.7	-6.5	-1.0	2.7
Est. U	605.0	158.0	344.0	602.0	3.0	7.4	6.0	2.7

Nomenclature

C_p heat capacity, (J/kg K)
d pipe thickness, (inch)
D_i pipe internal diameter, (inch)
D_o pipe outside diameter, (inch)
k pipe thermal conductivity, ($Btu.h^{-1}.ft^{-1}.F^{-1}$)
k_a air thermal conductivity, ($Btu.h^{-1}.ft^{-1}.F^{-1}$)
L pipe length, (km)
$\dot{m}$ gas mass flow-rate, ($kg.h^{-1}$)
n number of segments
P_o inlet pressure, (psig)
SG specific gravity
T_o inlet temperature of gas, (°C)
T_a ambient air temperature, (°C)
u_a air velocity, ($m.s^{-1}$)
U overall heat transfer coefficient, ($Btu.h^{-1}.ft^{-2}.F^{-1}$)
ε absolute pipe roughness, (inch)
μ air viscosity, (cP)
η Joule–Thompson coefficient (K/Pa)

References

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