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Wet Gas Pipeline Liquid Holdup and Pressure Calculation by Different Calculation Methods

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ABSTRACT

When wet gas is transported in a pipeline, liquid (condensate and water) will drop out due to temperature and pressure changes along the pipeline. The prediction of liquid holdup inside a pipeline is very important, as it will affect the prediction of pipeline pressure drop, downstream slug catcher design, scraping operation, etc. In performing pipeline steady-state liquid holdup and pipeline pressure drop calculations, one can choose either multiphase dynamic simulator or multiphase steady-state simulator. It was found that there could be significant differences in liquid holdup prediction when comparing the calculation results from different simulation methods. Using a typical hilly terrain, this paper presents the calculation results for wet gas pipeline liquid holdup and pressure. Different water and condensate loadings are considered. Gas flowrate is varied and different calculation methods are used.

INTRODUCTION

Heavy component and water exists in the gas produced from gas production wells or gas-oil separation facilities. The pipeline can be in multiphase flow conditions when this wet gas is transported. It is very important to accurately calculate the pressure drop and liquid holdup in the multiphase flow pipeline for the design of the pipeline and other processing facilities. The accurate prediction of liquid holdup inside pipeline is also important for pipeline operation as the accumulated liquid inside the pipeline can potentially flood its downstream slug catcher due to slugging flow, gas flowrate rampup, or scraping.

Two different approaches have been practically used to Model pipeline multiphase flow. Ellul [1] has summarized these two approaches as Steady-State Approach and Transient Approach. Over the years, multiphase flow inside a pipe has been widely studied and correlations have been proposed to model the multiphase flow phenomena. These correlations include Beggs & Brill [2], Oliemans [3], Eaton [4], flanagan [5], etc. These correlations have been used for describing steady-state multiphase flow. Another method that used in steady-state calculations is the so-called Mechanistic Method [1]. The representatives for this method are OLGA Steady-State [6], Tacite Steady-State, and Xiao [7]. Empirical correlations and mechanistic methods are used in the softwares that are specifically designed for pipeline multiphase steady-state flow calculations.

Dynamic simulations for pipeline multiphase flow have become more popular. The advance of computer power has made the dynamic simulation less time consuming. Dynamic simulation is based on solving the fundamental fluid flow equations in conservation of momentum, mass, and energy.

Liquid holdup and pressure prediction can have significant differences among different calculation methods as well as in comparison with experimental data [6]. Shea [6] has compared several empirical correlations, mechanistic methods, and dynamic simulation results with experimental data. Ellul [1] summarized different approaches in multiphase flow modeling and compared the calculation results using an example. Steady-state and transient cases (ramp-up, scraping) are studied. This paper studies multiphase pipeline pressure and liquid holdup predictions from different calculation methods that are available in commercial software using a typical hilly terrain. Different flowrates and liquid loading (for both condensate and water) are used.

THE MULTIPHASE PIPELINE MODEL

Simulation Software

OLGA™, used in this study, is a dynamic one-dimensional fluid model for three-phase hydrocarbon-water flow in pipelines. Gas, oil/condensate, and water are the three

separated phases that can be modeled in OLGA. Its dynamic nature makes OLGA useful in a wider range of applications in comparison with correlations which are limited by its generating conditions. OLGA has been improved continuously due to the increased experimental database from laboratory as well as from two-phase and three-phase field data. There are six conservation equations that need to be solved in OLGA without water. The equations are three mass balance equations, two momentum equations, and one energy conservation equation. Continuity equations for bulk water and water droplets are added when water is present. To perform OLGA simulations, tabulated phase equilibrium and other fluid property data were generated using PVTSIMTM in this paper.

PIPEPHASETM is also used in this study. PIPEPHASE is a steady-state simulation program that simulates steady-state multiphase flow in pipeline and pipeline networks. PIPEPHASE with its proven solution algorithm and user-friendly window based user interface is widely used in oil and gas industry. The calculation models used in PIPEPHASE for multiphase flow include empirical models and mechanistic models. In this study, Beggs & Brill and Eaton are used to represent the empirical models. The mechanistic models used are OLGA Steady-State and Tacite Steady-State.

Pipeline Model

Modeled Pipeline

The chosen pipeline for this study is an onshore and offshore pipeline (Figure 1). The pipeline starts at onshore and goes offshore within the first 1 mile. Its elevation decreases to the location at about its 7 mile position. The pipeline starts to go upward at this location to the end of the pipeline. The pipeline is about 35 miles long and its OD is 32".

Since this is a wet-gas pipeline, liquid and gas equilibrium inside the pipeline depends on the operation temperature and pressure. To eliminate the effect of temperature to liquid drop out, it is assumed that the fluid temperature inside pipeline is isothermal at 50 °F.

Pipeline outlet pressure is fixed at 200 psig and its inlet pressure is calculated. Gas flowrates of 25 MMSCFD to 300 MMSCFD are used in the study. These flowrates correspond to gas velocities from about 3 ft/s to 30 ft/s.

Modeled Gas Properties

The gas compositions are listed in Table 1. Considered condensate loading varies from 10 to 100 bbls/MMSCFD. Water loading varies from 1 to 50 bbls/MMSCFD. The condensate loading and water loading are calculated using the pipeline outlet conditions, which are 50 °F and 200 psig.

RESULTS AND DISCUSSIONS

Correlation Method vs. Dynamic Simulation

The Beggs and Brill correlation [2] is based on experimental data which was generated from 1" and 1.5" diameter pipe. Water and air were used to simulate two-phase flow. Gas and liquid flowrate were varied and all flow patterns were observed when the pipe was at horizontal position. The pipe was also changed into different angles to obtain the effects to liquid holdup and pressure gradients. The experimental data for Eaton correlations were generated using 2" and 4" pipe with about 1,700 ft long. Two phase flow friction factor and liquid holdup correlations were developed.

The simulation results for liquid holdup and pressure using Beggs and Brill and Eaton correlations and their comparison with dynamic simulations are shown in Figure 3 to Figure 10. Gas flowrates varied from 25 MMSCFD to 300 MMSCFD, These gas flowrate represents superficial gas velocity inside pipeline from about 3 ft/s to 35 ft/s (Figure 2). The condensate loading is from 10 to 100 bbls/MMSCFD and water loading is from 1 to 50 bbls/MMSCFD.

Figure 3 and Figure 4 are the liquid holdup and pressure for various gas flowrates. Condensate loading was kept at 26 bbls/MMSCFD and there is no water in these cases. There is no significant change in liquid holdup from the Beggs and Brill correlation as well as Eaton correlation, although the superficial gas velocity has changed from 3 ft/s to about 35 ft/s. The maximum liquid holdup is 8,641 bbls at 25 MMSCFD and the minimum liquid holdup is 7,230 bbls at 150 MMSCFD for Beggs and Brill correlation. The liquid holdup from Eaton correlation varies between 3265 bbls (at 150 MMSCFD) and 6,471 bbls (at 25 MMSCFD). The dynamic simulation shows significant liquid buildup at low gas flowrate. The liquid holdup at 25 MMSCFD is 51,594 bbls. Liquid holdup reduces dramatically as gas flowrate increases from dynamic simulations.

Liquid holdup is almost the same for Beggs and Brill correlation and the dynamic simulation at close to 100 MMSCFD. The liquid holdup is higher for the Beggs and Brill correlation at gas flowrate above 100 MMSCFD. 100 MMSCFD gas flowrate corresponds to about 12 ft/s superficial gas velocity. Liquid holdup from Eaton correlation is almost the same as dynamic simulation at gas flowrate of 150 MMSCFD and above.

Since the Beggs and Brill correlation does not show huge liquid buildup at low gas velocity, the pressure drop in the pipeline is very low at low gas flowrate (Figure 4). It is 3.3 psi at 25 MMSCFD (about 3 ft/s superficial gas velocity). The pressure drop from the dynamic simulation is 77 psi due to huge liquid accumulation inside pipeline. The differences in

pressure drop are reduced as gas flowrate increases. It is 27 psi at 150 MMSCFD from the Beggs and Brill correlation and 37 psi from the dynamic simulation. Eaton correlation predicts the pressure drop significantly higher than Beggs and Brill correlation for all the flowrate considered. Its pressure drop predictions follow the same trend with the Beggs and Brill prediction as its liquid holdup prediction at low gas velocity is also much lower than the prediction from dynamic simulation.

Results for both water and condensate loading at 26 bbls/MMSCFD are shown in Figure 5 and Figure 6. Gas flowrates are from 25 MMSCFD to 300 MMSCFD. Liquid holdup change from the Beggs and Brill correlation is relatively small as flowrate changes. The maximum liquid accumulation is at 25 MMSCFD with 12,210 bbls and the minimum liquid accumulation is at 150 MMSCFD gas flowrate, which is 9,913 bbls. Eaton correlation predicts the maximum liquid holdup is 10,690 bbls at 25 MMSCFD and its minimum liquid holdup is about 5,000 bbls at 250 MMSCFD. Dynamic simulation gives the same liquid holdup trend as with only condensate in the system. Huge liquid accumulation at low gas flowrate and the liquid holdup reduced very quickly as gas flowrate increase. The liquid holdup is 52,309 bbls at 25 MMSCFD and 5,629 bbls at 300 MMSCFD. Liquid accumulation is about the same from the Beggs and Brill and dynamic simulation, at about 150 MMSCFD. The liquid accumulation from the Beggs and Brill is higher at a gas rate above 150 MMSCFD. Liquid holdup from Eaton correlation is generally lower than the liquid holdup predicted from dynamic simulation. The differences, however, are gradually become much smaller at higher gas rate. The Beggs and Brill correlation does not predict higher pressure drop at low gas flowrate, as it can not predict high liquid accumulation. Although Eaton correlation predicts higher pressure drop at lower gas flowrate, this prediction is mainly due to the facts that it predicts much higher pressure drops at all flowrates considered as comparing with other methods.

Liquid loading effects to liquid holdup and pressure prediction were studied using a constant gas flowrate of 150 MMSCFD. Cases for changing condensate loading from 10 to 100 bbls/MMSCFD while keep water loading at zero were simulated. These results are shown in Figure 7 and Figure 8. Cases of changing water loading from 1 to 50 bbls/MMSCFD while keeping condensate loading constant at 26 bbls/MMSCFD (Figure 9 and Figure 10) were also studied. The results show that Beggs and Brill correlation and Eaton correlation as well as dynamic simulation predict higher liquid holdup and pressure as condensate and water loading becomes higher. Unlike the cases at different gas flowrates, all the methods are following the same trend. Although Liquid holdup from Eaton correlation matches closely with other methods, the pressure prediction from Eaton correlation is always much higher than other methods. Beggs and Brill correlation gives slightly higher liquid holdup prediction. Its pressure prediction is closer to dynamic simulation results than that from Eaton correlation.

Mechanistic Method vs. Dynamic Simulation

Another option available in the steady-state multiphase pipeline simulators is the mechanistic method. The two mechanistic methods studied are OLGA Steady-State and Tacite Steady-State.

Figure 3 and Figure 4 show the simulation results at 26 bbls/MMSCFD condensate loading with various gas flowrate. The cases for both condensate and water loading at 26 bbls/MMSCFD are shown in Figure 5 and Figure 6. Unlike correlation methods in predicting liquid holdup and pressure at low flowrate, mechanistic methods predict significantly high liquid holdup that is comparable with dynamic simulation results. OLGA Steady-State predicts liquid holdup of 44,916 bbls at 25 MMSCFD with 26 bbls/MMSCFD and zero water. With both condensate and water loading at 26 bbls/MMSCFD, 49,205 bbls of liquid is predicted for 25 MMSCFD using OLGA Steady-State. The predictions from Tacite Steady-State are 37,861 bbls and 41,886 bbls for the above two cases. The liquid holdup from the two mechanistic methods follows the same trend as dynamic simulation results. Since the liquid holdup at low gas flowrate is predicted to be very high using mechanistic method, the pressure is high at low flowrate, which is different from the correlation methods. The Mechanistic methods and dynamic simulation show that the minimum pressure is at the flowrate of 100 MMSCFD to 150 MMSCFD, which is about 15 ft/s gas superficial velocity.

Simulations were performed for various condensate loading (10 bbls/MMSCFD to 100 bbls/MMSCFD) while keeping gas flowrate at 150 MMSCFD and water loading at zero (Figure 7 and Figure 8). Simulation results for water loading from 1 to 50 bbls/MMSCFD while keeping condensate loading at 26 bbls/MMSCFD and gas rate at 150 MMSCFD are presented in Figures 9 and 10. The liquid holdup and pressure drop follow the same trend for the two mechanistic methods as the dynamic simulation results.

CONCLUSIONS

Calculated results from correlation and mechanistic methods for wet gas pipeline multiphase flow are compared with dynamic simulation results. Various gas flowrate, condensate loading, and water loading are used. The results show that the Beggs and Brill correlation can not be used at a gas superficial velocity below 10 ft/s as it predicts a very low liquid holdup and this also causes low pressure drop prediction. Since gas velocity is usually above 15 ft/s for gas pipeline, the Beggs and Brill should give reasonable pressure prediction. The liquid holdup prediction from the Beggs and Brill is usually higher than the dynamic simulation results at a gas velocity above 15 ft/s. Liquid holdup volume prediction from Eaton correlation at gas velocity above 15 ft/s closely match

dynamic simulation results. Its pressure prediction is, however, much higher than other methods. It is, therefore, not a good method for pressure predictions.

The Mechanistic method performs very well at low gas flowrates (below 10 ft/s gas velocity) in comparison with the correlation methods. This is especially important when estimating the ramp-up liquid volume from the steady-state simulator. Since the scraping and ramp-up operations are dynamic phenomena, dynamic simulations are always preferred over a steady-state simulator.

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Jianzhi Ge is a senior process engineer with Saudi Aramco, where he primarily focuses on single and multiphase pipeline simulations. He has been working in the field of pipeline simulations for more than 10 years since he completed his PhD from Colorado School of Mines. He is a member of Society of Petroleum Engineers (SPE).

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TABLES

Condensate Loading (bbls/MMSCFD)	10	20	26	30	40	50	75	100
Component	Mol%	Mol%	Mol%	Mol%	Mol%	Mol%	Mol%	Mol%
CO ₂	6.563	6.494	6.454	6.427	6.362	6.299	6.149	6.007
H ₂ S	6.673	6.642	6.624	6.612	6.583	6.554	6.486	6.422
N ₂	0.358	0.354	0.351	0.349	0.344	0.340	0.329	0.319
C ₁	49.400	48.779	48.412	48.175	47.586	47.013	45.649	44.370
C ₂	18.255	18.144	18.078	18.035	17.930	17.827	17.582	17.352
C ₃	12.382	12.548	12.647	12.710	12.867	13.020	13.385	13.727
iC ₄	1.233	1.296	1.333	1.357	1.416	1.474	1.612	1.741
nC ₄	3.907	4.204	4.379	4.492	4.773	5.047	5.698	6.309
iC ₅	0.493	0.586	0.641	0.677	0.765	0.851	1.055	1.246
nC ₅	0.589	0.729	0.812	0.865	0.998	1.127	1.435	1.723
nC ₆	0.127	0.192	0.230	0.255	0.317	0.377	0.519	0.653
nC ₇	0.018	0.032	0.040	0.045	0.058	0.071	0.101	0.130

Table 1 – Gas Composition at Different Condensate Loading

FIGURES

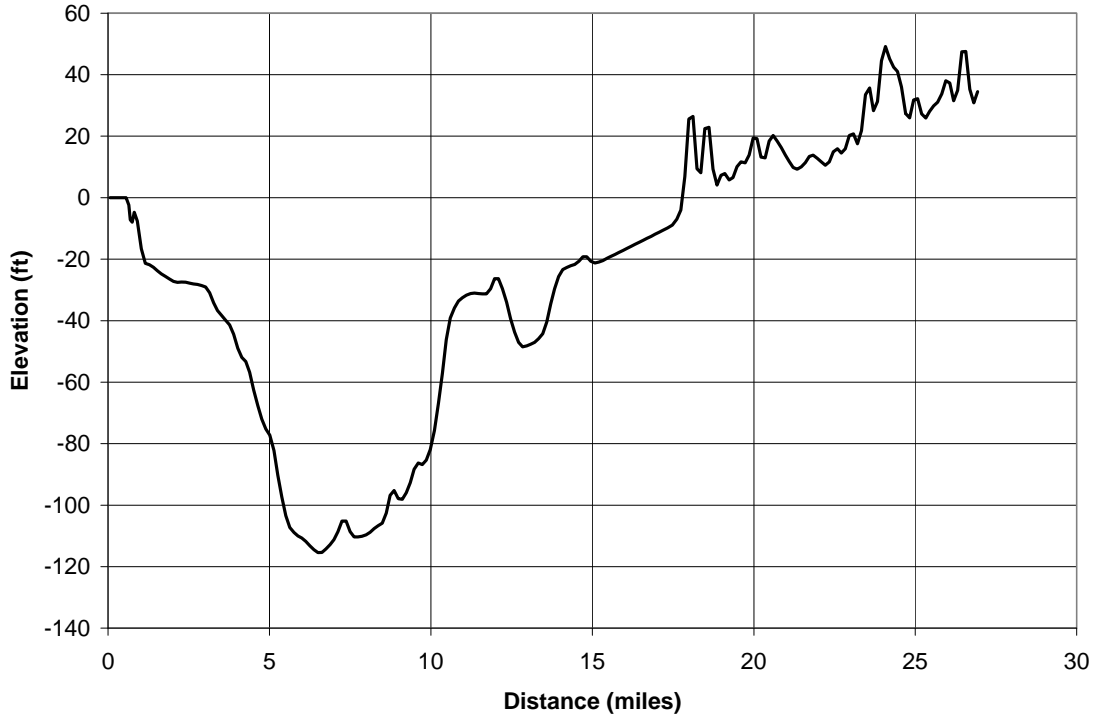


Figure 1 – Pipeline Profile

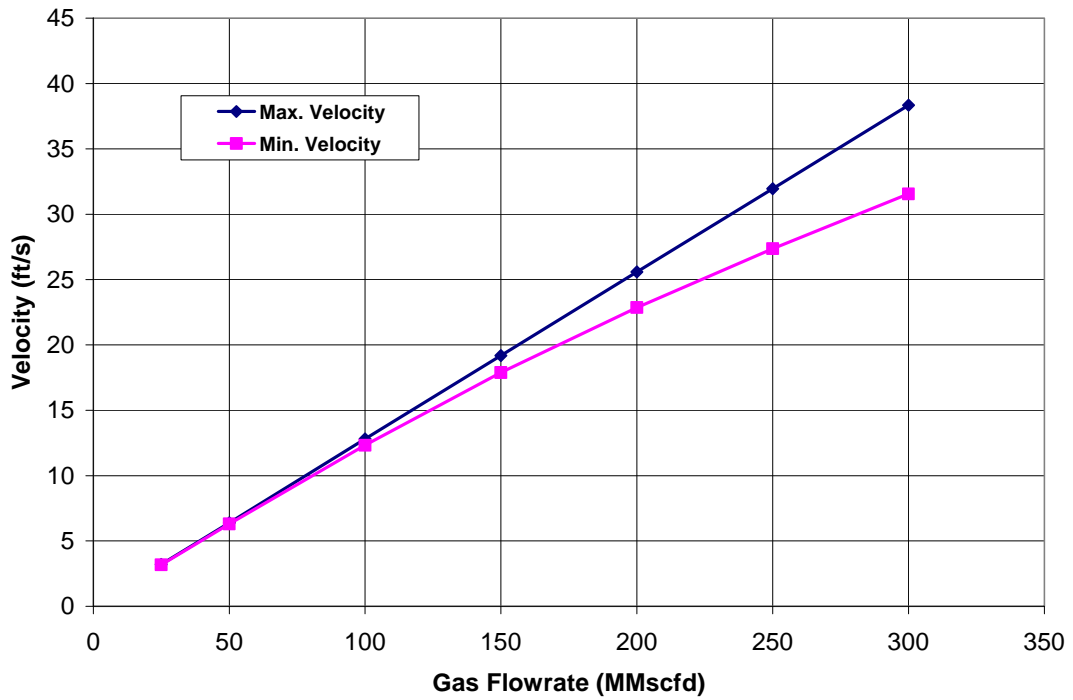


Figure 2 – Pipeline Superficial Gas Velocities at Different Gas Flowrate

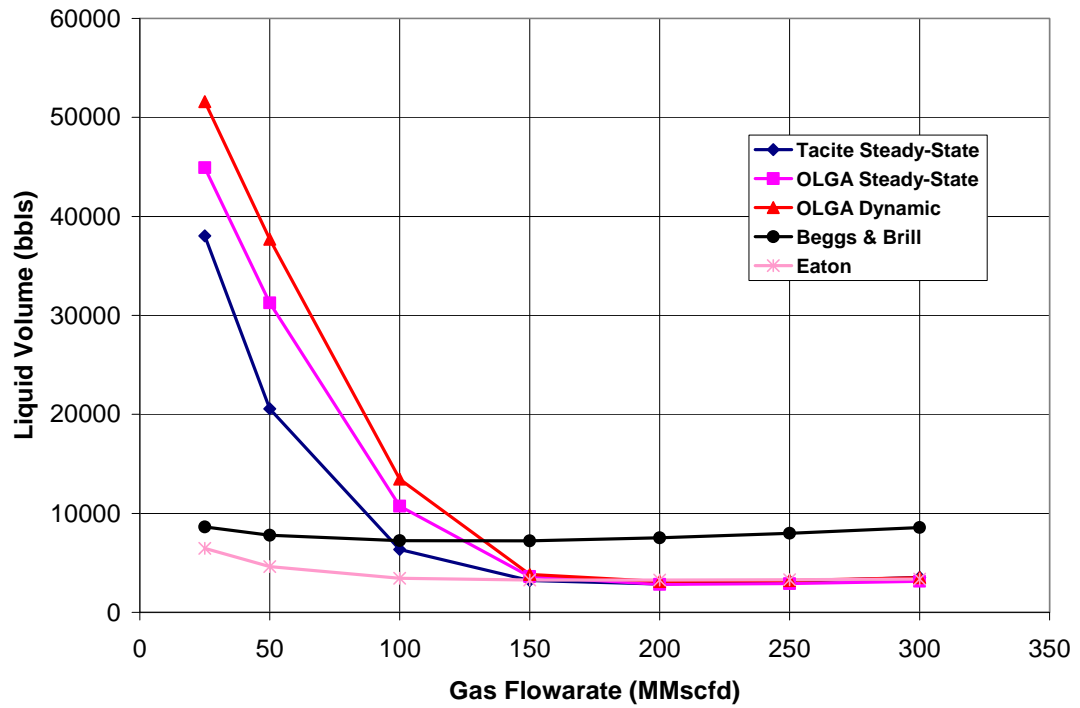


Figure 3 – Liquid holdup for 26 bbls/MMSCFD Condensate Loading and Zero Water Loading

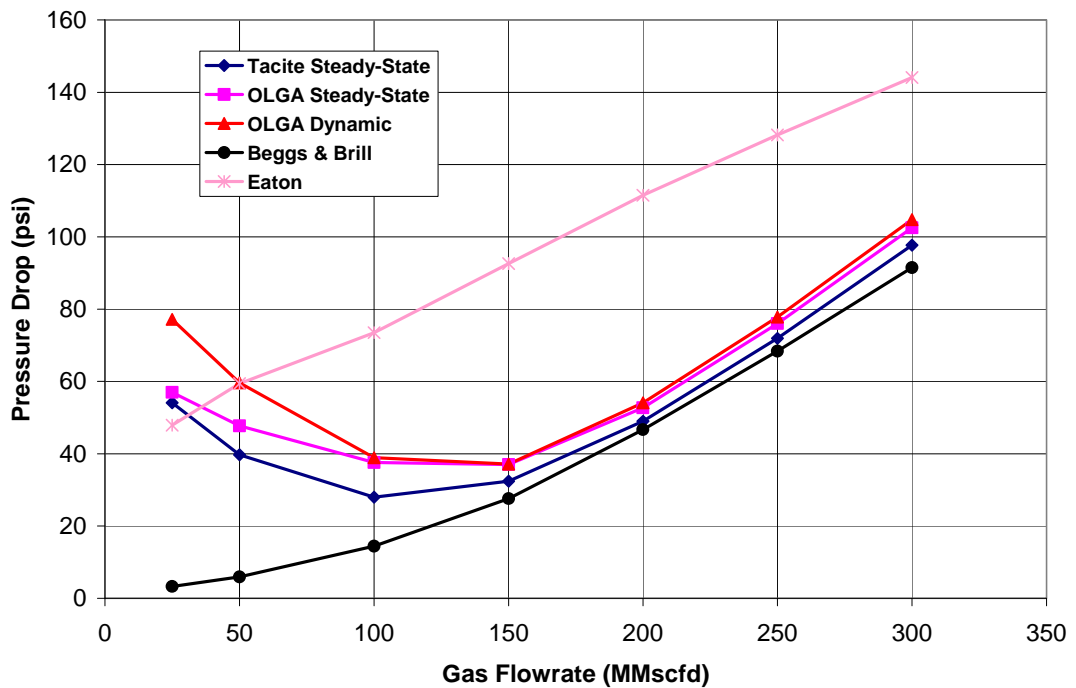


Figure 4 – Pressure for 26 bbls/MMSCFD Condensate loading and Zero Water Loading

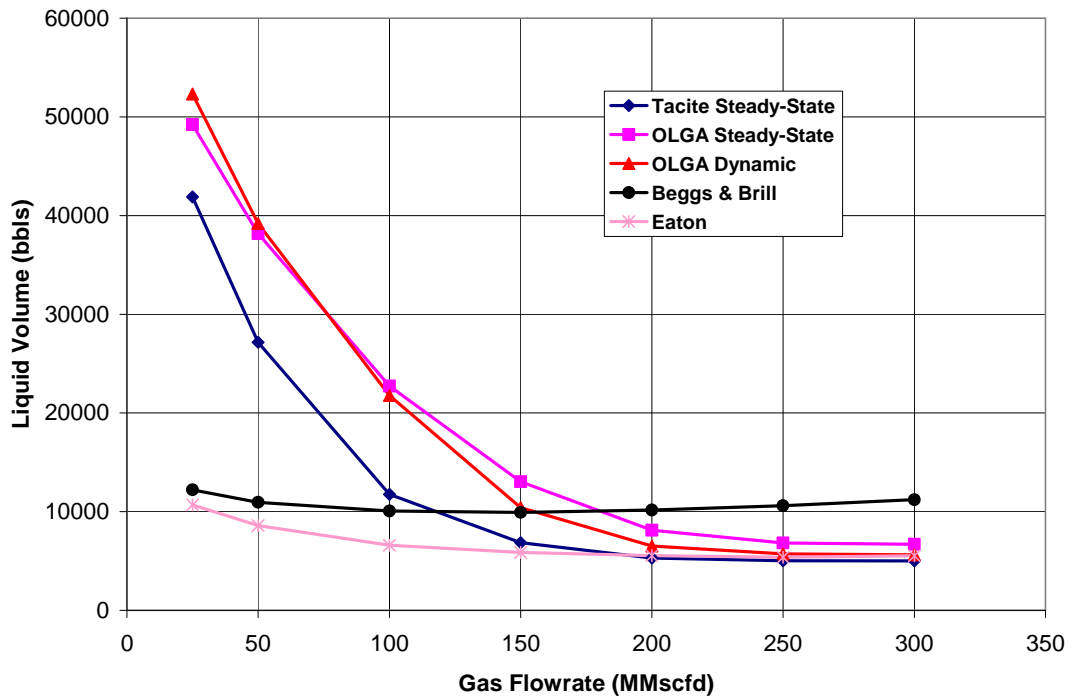


Figure 5 – Liquid Holdup for 26 bbls/MMSCFD Condensate Loading and 26 bbls/MMSCFD Water Loading

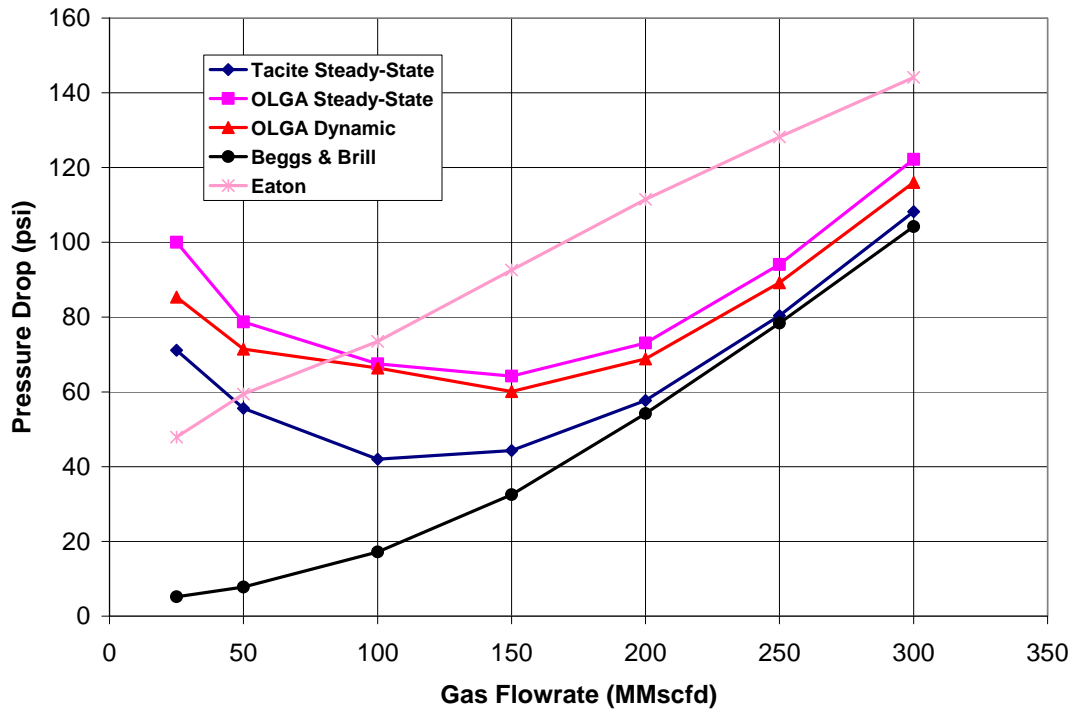


Figure 6 – Pressure for 26 bbls/MMSCFD Condensate Loading and 26 bbls/MMSCFD Water Loading

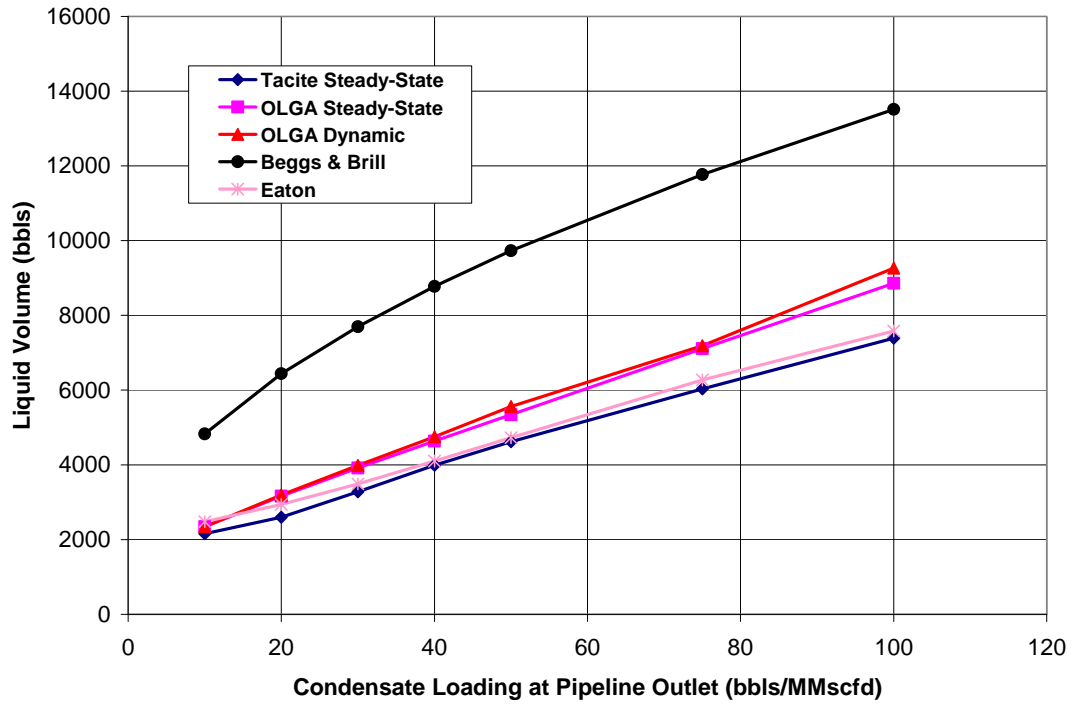


Figure 7 – Liquid Holdup for 150 MMSCFD Gas Flowrate and Zero Water Loading

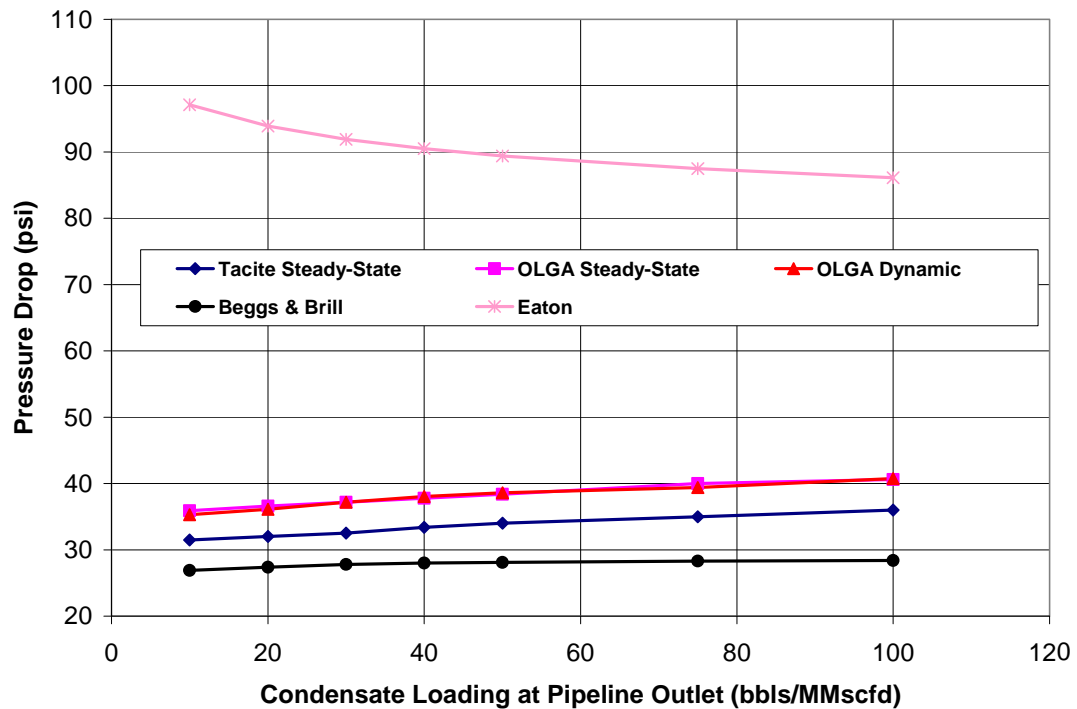


Figure 8 – Pressure for 150 MMSCFD Gas Flowrate and Zero Water Loading

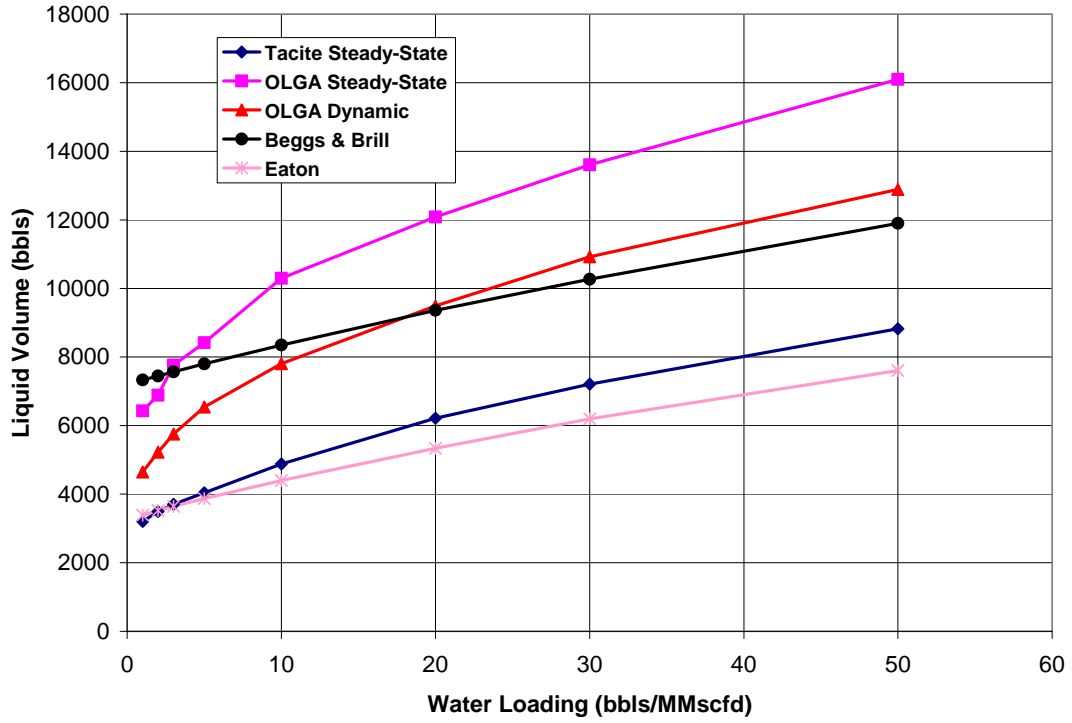


Figure 9 – Liquid Holdup for 150 MMSCFD Gas Flowrate and 26 bbls/MMSCFD Condensate Loading

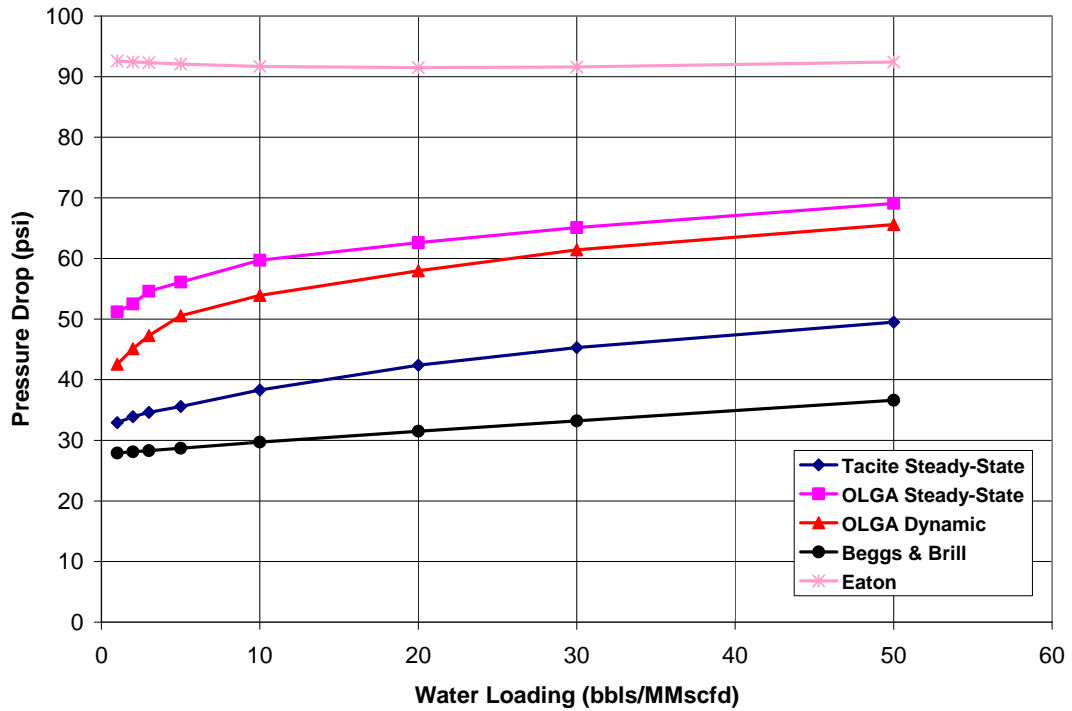


Figure 10 – Pressure for 150 MMSCFD Gas Flowrate and 26 bbls/MMSCFD Condensate Loading