Gas Pipeline Hydrodynamic Analysis Based on Beggs-Brill Correlation

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Abstract

A reliable pipeline design requires hydrodynamic analysis. The analysis enables flow rate and pressure gradient investigations in obtaining an optimum configuration. In the other hand, a numerical approach occurs as a complex schematic is proposed. Solving this requirement, an iterative method is posible to be endorsed. This study aims to investigate single-phase gas pipeline hydrodynamic analysis. A model utilized a two-phase pressure gradient correlation, namely Beggs-Brill correlation, to converse single-phase gas pressure gradients into mass flow rates. Furthermore, the numerical method, called Newton-Raphson, is assesed on solving those iterative calculations. The results show that the model is able to solve a complex schematic. The mass flow rates obtain in the deviation up to 0.4 %, whereas the pressure gradients deviation is achieved on a higher value.

Keywords: *hydrodynamic analysis, Beggs-Brill correlation, Newton-Raphson iterative method*

1. Introduction

A high rate on the world energy demand affects on pipeline industry. Furthermore, it deals with various requirements in pipeline design i.e optimum configurations, good system working, and availability of comprehensive evaluations. Furthermore, numerical simulations, giving opportunities reaching these requirements, are often proposed as particular stage on a reliable pipeline design [1, 2].

A hydrodynamic analysis, involving certain models and solution methods, provides numerical simulations in obtaining an optimum design. It covers pressure gradients investigation in accordance with the mass flow rates [3]. Some models which are commonly used include Darcy-Weisbach, Hazen-Williams, and Maning for single-phase liquid, whereas Lacey, Poliflow, Panhandle, and Weymouth for gaseous fluid, meanwhile Dunn-Ross, Aziz et al., and Beggs-Brill can cover two-phase liquid-gas [4, 5]. In the other hand, Hardy-Cross iterative method, Graph Theory, and Newton Raphson are available as the solution schematics [6, 7].

In this study, a single-phase gas pipeline hydrodynamic analysis is developed based on a two-phase pressure gradient model, namely Beggs-Brill correlation, and solved using the Newton-Raphson method. A steady state flow analysis, horizontal pipelines, and ignoring minor losses are taken into the modeling considerations.

2. Methodology

Pipeline hydrodynamic models are commonly determined by both nodal and loop formulations. The first one deals with the mass flow rates, namely mass continuity. In the other hand, the later is related to pressure drop or potential continuity [7].

Beggs-Brill correlation, derived based on a two-phase approach, is a common correlation between the pressure drop and the mass flow rate in a two-phase gas-liquid flow [4, 5]. As the correlation was derived based on a two-phase approach, it implicitely should be applicable also for single phase hydrodynamic, gas and liquid respectively [8].

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The study established to develope the analysis is presented in Figure 1. A model determined using nodal, loop and energy balance formulation assesed the correletion between pressure drop and mass flow rate, namely Beggs-Brill correlation (BB). The solution model was solved using Newton-Raphson iterative method with n-unknowns and n-equations [9]. The physical properties of the fluids are presented in Table 1. A specific pipeline schematic to simulate the model is presented in Figure 2, whereas its nominal dimensions and configurations are in Table 2. Obtaining results were compared to the results whose the model was based on a common pipeline software based on a single-phase equation namely Darcy-Weisbah formulation (CW-DW). The results involve the iteration convergences and mass flow rates and pressure gradients comparison graphs, meanwhile the comparisons show the difference values of the pressure drops as well as the mass flow rates.

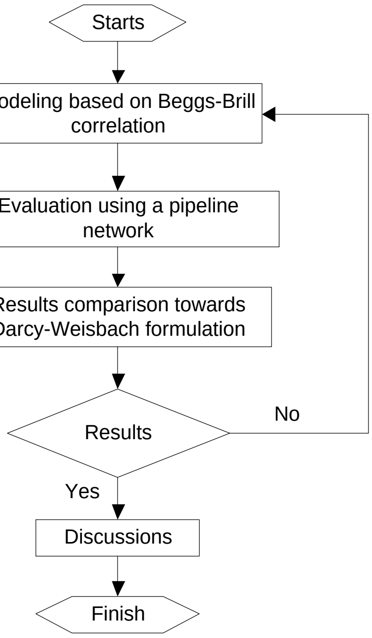

Figure 1. Methodology steps

Tabel 1. Fluids physical properties

Physical properties	Water	Air
Fluid density at 30 °C (kg/m^3)	996	1.165
Surface tension (kg/s^2)	71.97×10^{-3}	-
Dynamic viscousity at 30 °C (kg/m. s)	7.97×10^{-4}	1.87×10^{-5}

Distinguising common flow regimes in two-phase flow into 3 patterns, i.e. segregated, intermittent and distributed, Beggs-Brill recommended a pressure gradient equation for a closed conduit with certain inclination angles [4, 5]. It forms as the following.

$$\frac{dp}{dL} = \frac{\left(f\rho_n v_m^2 / 2d\right) + \rho_s g \sin\theta}{1 - \left(v_m v_{sg} \rho_n / p\right)} \tag{1}$$

Here in the equation:

- *dp/dL* represents the pressure gradient (*Pa/m*),
- *f* is the frictional coefficient (dimensionless),
- ρ_n and ρ_s are the normalized and solution density respectively (kg/m^3), and
- v_m and v_{sg} are the mixture and superficial gas velocity respectively (*m/s*), and ϑ is the inclination angle (^{o}).

Through the pipeline hydrodynamic analysis basic concepts, i.e. mass balance, flow continuty and potential continuity, and in accordance with a pressure gradient model, mathematical formulations can be obtained and solved using the Newton-Raphson method of iteration [7, 9].
The flow continuity is formulated as:

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \quad \text{(At each node)} \tag{2}$$

The principal of potential continuity is formulated as:

$$\sum \Delta p = 0 \quad \text{(In a closed loop)} \tag{3}$$

Whereas the supply-demand balance remains:

$$\sum \dot{m}_{inlet} = \sum \dot{m}_{outlet} \quad \text{(On a scheme)} \tag{4}$$

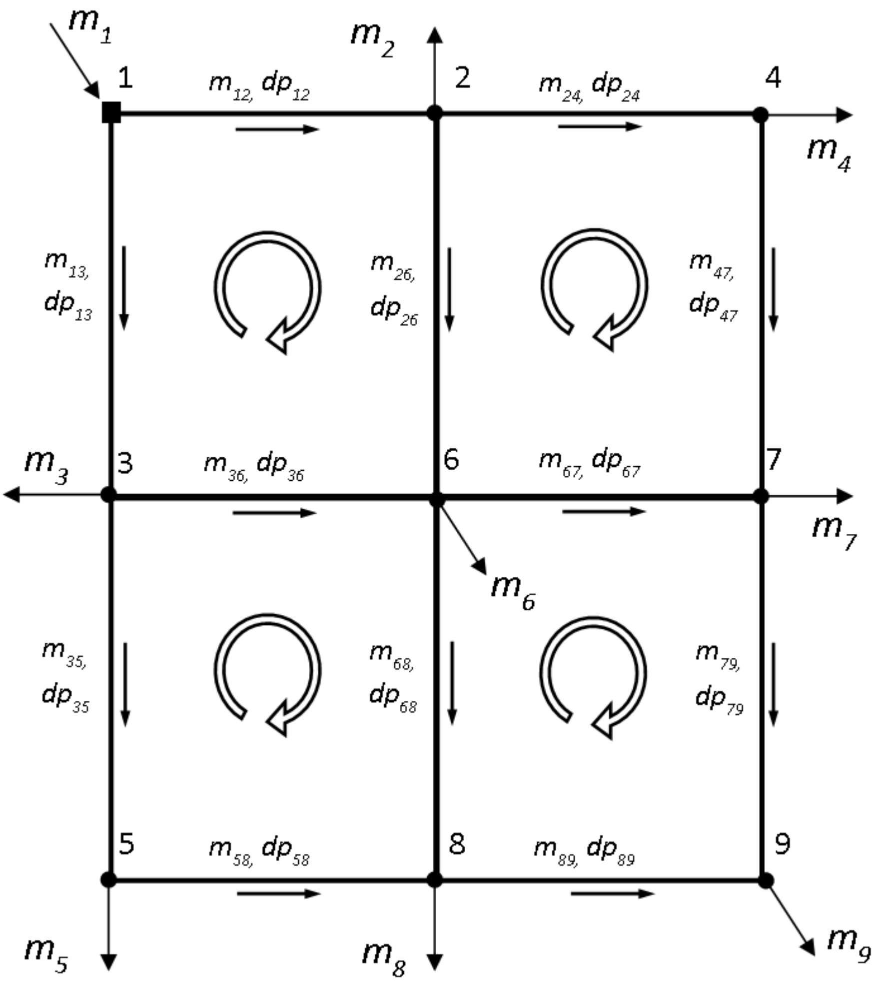

Figure 2. Pipeline schematic to be evaluated

Tabel 2. Pipe segment dimensions

Pipe Segment	Nominal Size	Internal Diameter (mm)	Lenght (m)	Relative Roughness (mm)
1-2	4" sch. 40	102.260	10	0.046
1-3	4" sch. 40	102.260	12	0.046
2-4	3" sch. 40	77.927	10	0.046
3-5	3" sch. 40	77.927	12	0.046
2-6	3" sch. 40	77.927	12	0.046
3-6	3" sch. 40	77.927	10	0.046
4-7	2" sch. 40	52.502	12	0.046
5-8	2" sch. 40	52.502	10	0.046
6-7	2" sch. 40	52.502	10	0.046
6-8	2" sch. 40	52.502	12	0.046
7-9	1-½" sch. 40	40.894	12	0.046
8-9	1-½" sch. 40	40.894	10	0.046

3. Mass Flow Rates and Pressure Drop Convergences

A simulation involving a certain case is conducted to investigate the model. In this simulation, the mass flow rate demanded is set to *0.24 kg/s*, whereas loaded demands are *0.05 kg/s* on node 2 and 3, *0.03 kg/s* on node 4, 5 and 6, *0.02 kg/s* on node 7 and 8, and also *0.01 kg/s* on node 9 respectively. Setting *0.12 kg/s* for the initial mass flow rates and *21 Pa* of initial pressure drop for all segments in this scenario, for 10^{-6} of iteration residual, the mass flow rates and pressure drop calculation convergeces are obtained by 80 and 160 iterations respectively. The graphs is shown in Figure 3 and Figure 4 while the iteration values of some iteration numbers is set in Table 3 and Table 4.

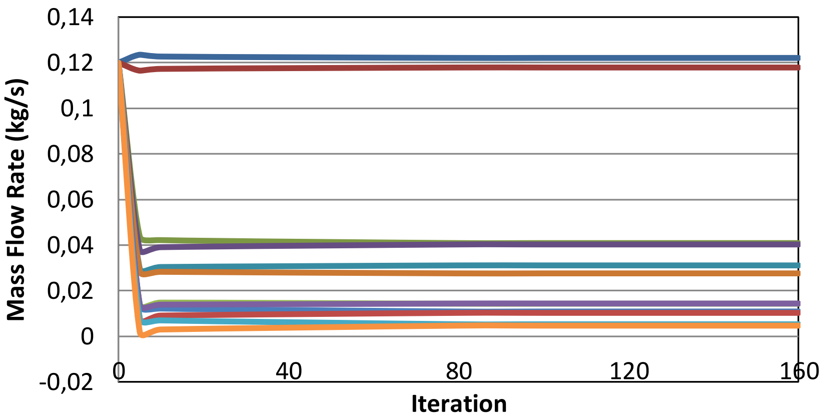

Figure 3. Mass flow rate iteration convergences

Tabel 3. Mass flow rate iteration

Iteration Number	0	5	10	80	100	160
m12	0.12	0.1235	0.1227	0.1221	0.1221	0.1221
m13	0.12	0.1165	0.1173	0.1179	0.1179	0.1179
m24	0.12	0.0438	0.0422	0.0409	0.0409	0.0409
m35	0.12	0.0379	0.0391	0.0403	0.0403	0.0403
m26	0.12	0.0297	0.0304	0.0311	0.0311	0.0311
m36	0.12	0.0286	0.0283	0.0276	0.0276	0.0276
m47	0.12	0.0138	0.0122	0.0109	0.0109	0.0109
m58	0.12	0.0079	0.0091	0.0103	0.0103	0.0103
m67	0.12	0.0142	0.0148	0.0143	0.0143	0.0143
m68	0.12	0.0141	0.0139	0.0144	0.0144	0.0144
m79	0.12	0.008	0.007	0.0053	0.0053	0.0053
m89	0.12	0.002	0.003	0.0047	0.0047	0.0047

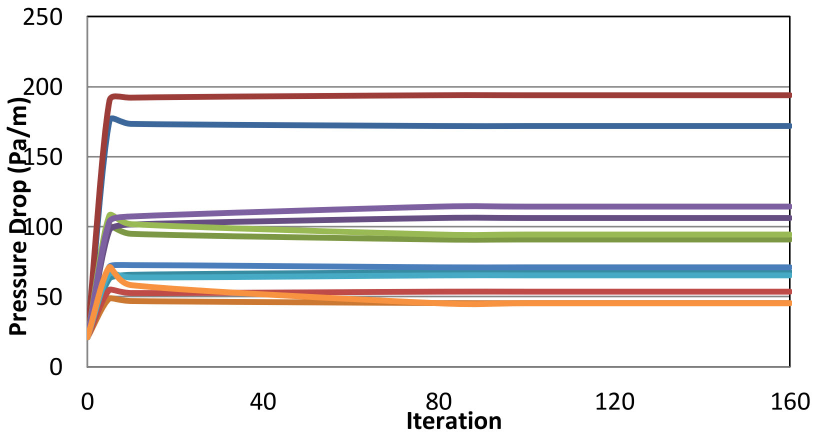

Figure 4. Pressure gradient iteration convergences

Tabel 4. Pressure drop iteration

Iteration Number	0	5	10	80	100	160
dp12	21	175.5445	173.4331	171.9341	171.9327	171.9324
dp13	21	189.81	192.1904	193.9225	193.9241	193.9245
dp24	21	99.618	94.9131	90.8718	90.8682	90.8675
dp35	21	97.5382	101.5754	106.2153	106.2202	106.2212
dp26	21	63.0424	65.661	67.4558	67.4574	67.4577
dp36	21	48.7769	46.9038	45.4674	45.4659	45.4656
dp47	21	71.4252	72.5716	71.0054	71.0002	70.9991
dp58	21	54.9015	52.6514	53.5953	53.5999	53.6008
dp67	21	108.0008	101.8237	94.4213	94.411	94.409
dp68	21	103.6628	107.323	114.3432	114.3543	114.3564
dp79	21	66.791	63.7641	65.2382	65.2477	65.2496
dp89	21	71.129	58.2648	45.3163	45.3045	45.3022

4. Result Deviations

The mass flow rate and pressure gradient comparisons are shown in Figure 5 dan Figure 6, respectively. The graphs show that the pressure gradient deviations are higher than that on the mass flow rate. The mass flow rate gives deviation up to 0.4 % while the pressure gradients reach a value of 14 %.

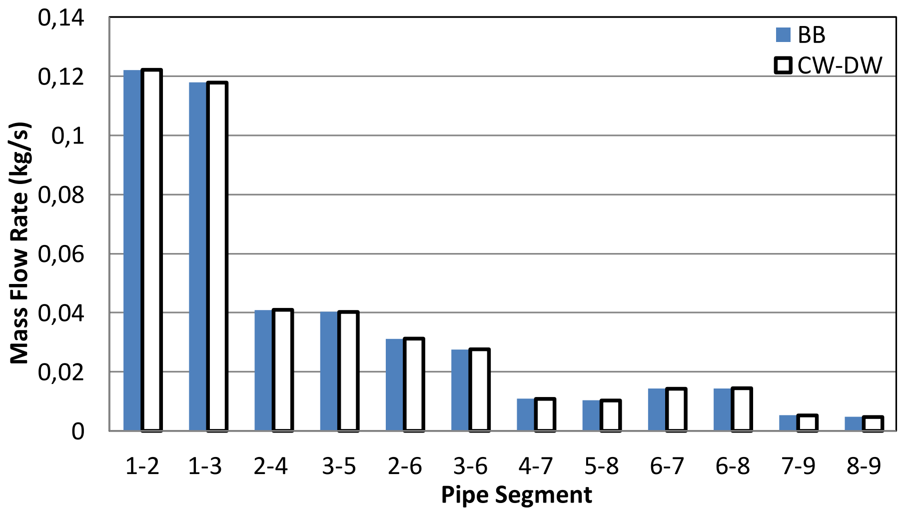

Figure 5. Mass flow rate deviation

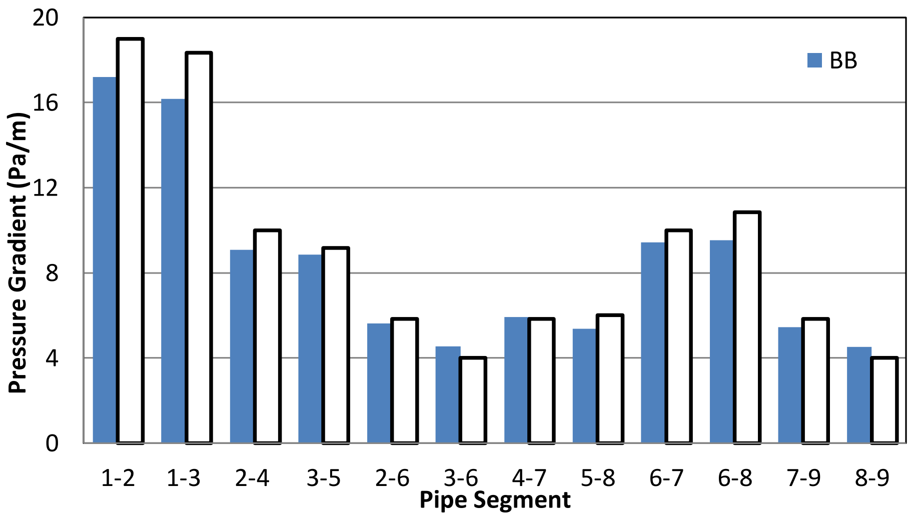

Figure 6. Pressure gradient deviation

Tabel 5. Result deviations

Pipe segment	Mass flow rate (kg/s) BB	CW-DW	Dev. (%)	Pressure gradient (Pa/m) BB	CW-DW	Dev. (%)
1-2	0.1221	0.1221	0.00	17.19	19.00	9.51
1-3	0.1179	0.1179	0.00	16.16	18.33	11.85
2-4	0.0409	0.0409	0.00	9.09	10.00	9.13
3-5	0.0403	0.0403	0.00	8.85	9.17	3.44
2-6	0.0311	0.0312	0.32	5.62	5.83	3.63
3-6	0.0276	0.0276	0.00	4.55	4.00	13.66
4-7	0.0109	0.0109	0.00	5.92	5.83	1.43
5-8	0.0103	0.0103	0.00	5.36	6.00	10.67
6-7	0.0143	0.0143	0.00	9.44	10.00	5.59
6-8	0.0144	0.0144	0.00	9.53	10.83	12.03
7-9	0.0053	0.0053	0.00	5.44	5.83	6.79
8-9	0.0047	0.0047	0.00	4.53	4.00	13.26

Since the Beggs-Brill correlation is used to predict two-phase pressure gradient which indicates that mass flow rates of each phase have certain values, it means that each phase has their own superficial velocity. As it is assumed that the liquid mass flow rate is 0 in a gas flow, therefore, the liquid superficial velocity will be 0, or the void fraction gives 1. In the other hand, in a two-phase flow, the volumetric ratio of the liquid on a pipe segment when the liquid and gases are moving in a same velocity, namely no-slip liquid holdup, is betwen 0 to 1. A single-phase liquid flow indicates no-slip liquid of 1 whereas a gas flow gives 0. Furthermore, a normalized density used to predict the pressure gradient in the analysis model will become the gas density.

4. Concluding Remarks

A simulation involving a certain case was elaborated. A certain value of demanded flow rate was set up followed by some certain values of loaded demands. From the results, convergence of iteration is achieved by 160 iterations, where the convergence of the mass flow rates occurs before the pressure gradients. The mass flow rate is obtain in the deviation up to 0.4 % between the Beggs-Brill correlation and Darcy-Weisbach equation. On the other hand, the pressure gradients deviation is achieved on a higher value.

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