Comparison of simplified models in the prediction of two phase flow in pipelines.

M. Jerez-Carrizales¹*, J. E. Jaramillo², D. Fuentes³
¹-²-³ Escuela de Ingeniería Mecánica, Universidad Industrial de Santander, Carrera 27 Calle 9, Bucaramanga, Santander, Colombia
E-mail: manuel.jerez@correo.uis.edu.co

Abstract. Prediction of two phase flow in pipelines is a common task in engineering. It is a complex phenomenon and many models have been developed to find an approximate solution to the problem. Some old models, such as the Hagedorn & Brown (HB) model, have been highlighted by many authors to give very good performance. Furthermore, many modifications have been applied to this method to improve its predictions. In this work two simplified models which are based on empiricism (HB and Mukherjee and Brill, MB) are considered. One mechanistic model which is based on the physics of the phenomenon (AN ) and it still needs some correlations called closure relations is also used. Moreover, a drift flux model defined in steady state that is flow pattern dependent (HK model) is implemented. The implementation of these methods was tested using published data in the scientific literature for vertical upward flows. Furthermore, a comparison of the predictive performance of the four models is done against a well from Campo Escuela Colorado. Difference among four models is smaller than difference with experimental data from the well in Campo Escuela Colorado.

1. Introduction
The two phase flow is a complex phenomena. Interactions between two fluids generates structures commonly known as flow patterns. These flow patterns made the two phase flow more difficult to model than the single phase flow [1, 2].

Wells in Campo Escuela Colorado (Santander, Colombia) suffer from wax and asphaltene deposition in the pipelines. For this reason, a project to deal with this problem was started. The main objective of that project is to develop some computational tools. It is expected that software predict material deposition rate in a section of the pipe. The prediction of the wax and asphaltene deposition is going to be developed by two steps as shown in the figure 1. First, a model to predict conditions in every point of the pipe, second, a model to predict deposition at certain conditions of composition, pressure, temperature and velocity, besides others.

*To whom any correspondence should be addressed.
This work is focused in the first part. In order to check prediction of the pressure drop in a pipe a comparison between four models is done with a point of Campo Escuela Colorado. The goal in the two phase flow models in pipelines is to determine the pressure, temperature and volumetric flow profiles along it. In the oil industry, the total pressure drop allows a linkage between models for the reservoir and the pressure in the well head. Also, the volumetric flux is necessary to know the amount of liquid and gas produced by the well.

2. Models

The first model to predict two phase flow in vertical wellbores was developed by Poettmann & Carpenter [3] in 1952. Since then, several models have been published in the scientific literature. However, any model is not able to predict accurately the pressure drop for all conditions in the oil industry. In this work, three generally used models are selected and a new one too.

The equation to predict pressure drop in the pipe is shown in (1). The total pressure drop is the sum of the pressure drop due to gravity, friction and acceleration.

\[(dp/dz)_T = (dp/dz)_F + (dp/dz)_H + (dp/dz)_A\]  

(1)

2.1. Hagedorn & Brown (HB) model

This model was published in 1965 and in spite of time elapsed, it was recommended by Ansari[4] in 1994. The HB model is flow pattern independent.

The original HB model [5] uses three graphs to calculate the viscosity number coefficient \( N_{lc} \), the secondary correction factor \( \psi \) and the liquid holdup \( h_l \). The holdup is determined as \( h_l = \psi f(N_{lc},...) \).

Two modifications to the original method are here implemented:

- Since the method was coded in C++, the regression proposed by Guo et al [6] was used to replace the three graphs.
- The studied configurations are for vertical upward flow; therefore, the holdup must be greater than the non slip holdup.

2.2. Mukherjee & Brill (MB) model

The Mukherjee & Brill method [7] is a simplified model that is flow pattern dependent, and it can be used in deviated wells. The MB model is partly based on the adimensional numbers of Duns & Ros [8]. Furthermore, it defines new ones to predict transitions in the flow pattern as shown in the figure 2.
This method uses an exponential equation to get the holdup. This equation depends on a group of coefficients; coefficients are selected whether flux is upward, stratified downward or other downward.

2.3. Ansari (AN) et al model
The Ansari et al [4, 1994] model is a mechanistic model based on the flow pattern map of Taitel et al and Barnea et al [9, 10]. The AN model shows a force balance for every flow pattern used.

The AN model includes many iterative subroutines, so, it demands more operations than the HB, MB and HK models to get the holdup and the pressure gradient.

2.4. Hasan et al (HK) model
The Hasan et al [11] model is based on the drift flux approach (2) for steady state conditions.

\[ u_D = C_0 u_M + u_D \]  

(2)

The values for \( u_D \) and \( C_0 \) for (2) are selected from the table 1. They proposed an interpolation method for these values near a flow pattern transition.

Figure 2. Algorithm to select flow pattern from MB model.

Liquid velocity number \( N_{lv} \)
Gas velocity number \( N_{gv} \)
Pipe diameter number \( N_d \)
Liquid viscosity number \( N_l \)
Liquid velocity number transition from bubble to slug flow \( N_{lvB/S} \)
Gas velocity number transition from slug to mist flow \( N_{gvS/M} \)
Transition from slug to stratified downflow \( N_{vS/T} \)
Table 1. Values from the drift flux parameters by Hasan et al.

| Flow pattern | $C_0$ | $u_p$ |
|--------------|-------|-------|
| Bubble       | 1.2   | 2     | 1.2 $V_{nb}$ |
| Slug         | 1.15  | 1.15  | 1.12 $V_=$ |
| Semianular   | 1.15  | 1.15  | 1.12 $V_=$ |
| Anular       | 1     | 1     | 1 $0$ |

3. Methodology

In this work, the models are implemented using the C++ object oriented programming philosophy. Correct models implementation should be validated. Therefore, models are compared with experimental data available in the literature [12, 13]. The general procedure is shown in the figure 3.

It is necessary to calculate physical, thermal, and chemical properties, flow pattern, holdup and pressure gradient at different points in the pipe for every data, as shown in figure 4. The validation step shows that results are influenced by the method applied to estimate fluid properties. Three correlations were analyzed, Standing, Al Marhoun and Vazquez & Beggs [2]. The properties that were calculated with these correlations were gas solubility and oil formation volume factor.

4. Results

4.1. Validation

4.1.1. Influence of properties. The table 2 shows the influence of the selected correlation applied to calculate fluid properties on the pressure drop. It is noted that mean error value is small; however, there are some points with a high error.

Table 2. Influence of methods to calculate properties

| Method            | Value | HK  | MB  | HB  | AN  |
|-------------------|-------|-----|-----|-----|-----|
|                   | [-]   | [%] | [%] | [%] | [%] |
| Al Marhoun-Standing | Mean  | 3.64| 3.45| 2.52| 3.03|
|                   | σ     | 4.60| 3.44| 4.84| 4.46|
|                   | Max   | 17.26| 14.47| 16.31| 17.17|
| Vazquez-Standing  | Mean  | 1.76| 1.86| 3.25| 1.92|
|                   | σ     | 2.23| 2.61| 5.49| 2.43|
|                   | Max   | 8.12| 10.37| 21.25| 9.76|
| Al Marhoun - Vazquez| Mean | 3.86| 3.88| 2.60| 3.82|
|                   | σ     | 4.73| 4.47| 3.92| 4.62|
|                   | Max   | 15.41| 15.92| 15.22| 15.84|
4.1.2. **Pressure drop calculation.** Four models with the same fluid properties were compared against experimental data to check implementation of the models. Results are shown in figure 5. The nearest to the central line the best the results.

![Figure 3. General procedure](image1)

![Figure 4. Procedure for every test](image2)

![Figure 5. Comparison of measured pressure drop against values predicted by the Ansari et al, Mukherjee & Brill, Hagedorn & Brown and Hasan et al models.](image3)
Finally, a regression of data in figure 5 to test numerically the best model is made. This is shown in table 3. The best model has an $m$ value and a determination coefficient $R^2$ near to 1.

| Model | $m$ [-] | $b$ [psi] | $R^2$[-] | $\sigma_{\text{error}}$ [psi] |
|-------|---------|-----------|----------|-------------------------------|
| AN    | 0.9713  | 53.1976   | 0.9521   | 266                           |
| MB    | 0.9076  | 186.3821  | 0.9538   | 244                           |
| HB    | 0.7594  | 42.6434   | 0.8584   | 377                           |
| HK    | 0.9898  | 185.3421  | 0.9306   | 330                           |

The best models are the Ansari et al model and the Hasan et al model.

4.2. Comparison with Well 37 from Campo Escuela Colorado

Experimental data selected for comparison purposes are those from [14]. The values are measured in the well number 37 at Campo Escuela Colorado. Two different tests were done by the ICP (Instituto Colombiano del Petróleo) in January 30 of 2008, a mechanical state and a PVT (pressure-volume-temperature) analysis. Data measured were pressure and temperature from wellhead, reservoir and bottomhole. Furthermore, oil flow, gas flow, water flow, API gravity, gas components, tubing diameter and length of the pipe were determined.

In figure 6 variation of predicted pressure for each model with depth is presented together with experimental data at the bottom of the well 37 (grey diamond). As it can be seen all models overpredict results. The difference between the predicted and measured pressure at the well bottom is around 30%, and all models predict a similar value: $%\text{error}_{\text{AN}}=33$, $%\text{error}_{\text{MB}}=30$, $%\text{error}_{\text{HB}}=30$, $%\text{error}_{\text{HK}}=33$. Moreover, holdup predicted by the four models is presented in figure 7. This graph shows throughout the well two phase flow is present due to holdup never reach the value of one that indicates a single phase is achieved.
5. Conclusions

1. It has been observed that fluid properties (correlations used) has an influence in the total pressure drop that was a 3% in average, but that can be as high as 20%.
2. The best performance was presented by the Ansari et al and the Hasan et al model in the validation process. Furthermore, the first one is simpler than the second one method, and it does not need internal iterative routines.
3. When the models were compared with data from the well 37 of Campo Escuela Colorado all models exhibited a difference of about 30%. Therefore, it should be made a deeper analysis to better understand the source of these differences for this case.

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