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MULTIPHASE FLOW CORRELATIONS (PART 1) : DEVELOPMENT AND APPLICATIONS

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ABSTRACT

In the petroleum industry, multiphase flow correlations were developed in order to generate pressure traverse data along the production string and wellbore, to select correct tubing sizes for new production and infill wells, and also to design artificial lift installation at some later date. A simulation program is normally required to perform those tasks due to the repetitive step like nature of the calculation of the multiphase flow correlations.

INTRODUCTION

Multiphase flow which can be defined as the concurrent movement of free gases and liquids in pipes, occurs throughout industry, in situations as diverse as chemical processing plants, geothermal power stations, nuclear reactors and in oil and gas industries.

The presence of an infinite number of flow structures is the prominent characteristic of multiphase flow, which can be grouped into a number of classes known as flow patterns (also known as flow regimes).

Flow regimes in vertical sections which can be found in (Govier and Aziz, 1972), are generally axi-symmetrical because the effect of gravitational forces is parallel in the direction of flow. Whilst the flow patterns in horizontal sections which are shown in (Alves, 1954), exhibit a non-symmetrical distribution.

Flow regimes in the deviated pipes resemble those found in vertical and horizontal sections. Generally, sections with large angle of inclinations show similar flow regimes to those found in the horizontal sections. Whilst small angle of inclinations are close to those found in vertical multiphase flow.

GENERALISED VERTICAL MULTIPHASE FLOW CORRELATIONS

The computation of pressure drop for multiphase flow in vertical pipes is a complex problem due to the presence of free gas and a liquid which may be oil and/or water. Much work has been performed in order to achieve a satisfactory solution of the problem, and Table 1.0 depics those correlations that have contributed with varying degrees of success to a solution of the vertical multiphase flow problems (Brown, 1977).

The generalised multhiphase flow correlations such as the modified Hagedorn and Brown (Hagedorn and Brown, 1965), Duns and Ros (Duns and Ros, 1963), Orkiszewski (Orkiszewski, 1967), Beggs and Brill (Beggs and Brill, 1973) and others, require an identification of the flow regimes before .

Date	Author(s)	Type of work	Pipe sizes	Fluids	Comments
1914	Davis & Weidner	Laboratory experimental	1½"	Air-water	Holdup and friction had to be separated. Obtained minimum pressure traverse by injecting gas. Showed method of air entry of no consequence. Showed pipe roughness to be a factor.
1932	Versluys	Mathematical analysis			No practical value.
1931	Versluys	Theoretical			Discussed flow patterns. No practical value.
1929	Donoghue	Field experimental	5", 3", 2½", 2", 1½"	Oil	Showed that a minimum velocity of 5 ft/sec was necessary to keep a well flowing.
1947	Shaw	Laboratory experimental	1", 1¼", 2", 2½"	Air-water	Showed effect of diameter, length of pipe, and submergence on flow rates and gas requirements.
1952	Poettmann & Carpenter	Semi-empirical method using field data	2", 2½", 3"	Oil, water, gas	Developed practical solution for 2", 2½", and 3" tubing. For G/L ratios less than 1,500 scf/bbl and for rates > 420 bpd.
1962	Winkler & Smith	Practical	1" through 3½"	Oil, water, gas	Prepared working curves from Poettmann and Carpenter correlation.
1960	U.S. Industries	Practical	1" through 4½"	Oil, water, gas	Prepared working curves from Poettmann and Carpenter correlation.
1954	Gilbert	Field data for practical use	2", 2½", 3"	Oil, water, gas	Presented set of vertical multiphase flow traverses.
1958	Govier & Short	Laboratory experimental	Small pipe	Air-water	Presented a correlation for calculating pressure losses but has not been extended to practical use.
1961	Tek	Semi-empirical	2", 2½", 3"	Oil, water, gas	Used Poettmann and Carpenter data to prepare another correlation. Has not been used in practice.
1961	Baxendall	Field data by Poettmann & Carpenter method	2½", 3½"	Oil, gas	Used Lake Maracaibo field data and prepared correlation similar to Poettmann & Carpenter (good correlation for that area).
1961	Ros	Laboratory experimental plus field data	All	All	Good correlation for all ranges of flow.
1961	Duns & Ros	Laboratory experimental plus field data	All	All	Good correlation for all ranges of flow. Easier to understand than original work of Ros.
1961	Griffith & Wallis	Laboratory experimental	Small	Air, water	Good results in slug flow region. Used by other investigators to improve their correlations.
1962	Griffith	Laboratory experimental	Small	Air, water	Used to improve other correlation in plug flow regime.
1961	Hughmark & Pressburg	Laboratory experimental	Small	Air, water	Presented holdup correlation used by Dukler in horizontal flow.
1963	Fancher & Brown	Field experimental	2"	Gas, water	Collected data to extend correlation of Poettmann and Carpenter to accurately predict pressure losses at low flow rates and high G/L's.
1963	Gaither, Winkler & Kirkpatrick	Field experimental (1,000' pipe)	1", 1½"	Gas, water	Developed correlation for pipe sizes used in test. Has not been extended to practical field use.
1963	Hagedorn & Brown	Field experimental (1,500' tube)	1¼"	Air, crude	Developed correlation specifically to handle viscosity effects in 1¼" tubing.
1965	Hagedorn & Brown	Field experimental	1" through 4"	Oil, water, gas	Developed generalized correlation to handle all ranges of multiphase flow.
1967	Orkiszewski	Review of all methods plus own correlation	All	Oil, water, gas	Utilized work by Ros, and Griffith & Wallis to prepare own general correlation to predict pressure losses for all ranges of flow.
1972	Aziz & Govier	Laboratory & field data	All	All	Presented correlations developed mechanistically, tested against field data.
1972	Sanchez	Field data	Annular Flow	All	Checked present day correlations for ability to handle annular flow.
1973	Beggs & Brill	Laboratory	1", 1½"	Air, water	Developed generalized correlation to handle all ranges of multiphase flow and for any pipe angle.
1973	Chierici, Civecci & Scrocchi		All		Presented modification of Orkiszewski method for slug flow pattern, tested with field data.
1973	Cornish	Field data	Annular Flow	Oil & gas	Field correlation for very high flow rate wells in one area.

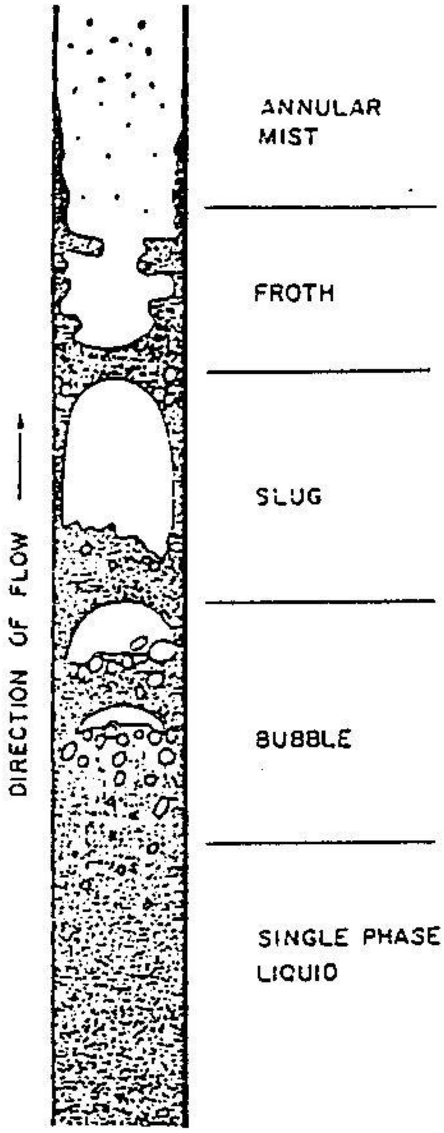

Figure 1.0 : Typical Flow Patterns for Vertical Flow of Gas-Liquid Mixtures (Aziz, Govier and Fogarasi, 1972)

proper equations can be defined for calculating the flowing pressure gradient in the incremental pipe length under investigation. The flow regimes for vertical flow of gas-liquid mixtures as depicted in Figure 1.0 emphasises the need for proper flow regimes identification (Aziz, Govier and Fogarasi, 1972). Thus if the flow regimes cannot be accurately determined, the calculated pressure loss will be in error and discontinuities in the slope of the flowing pressure gradient curves may be apparent.

All generalised multiphase flow correlations utilise the basic total pressure drop equation which comprises of three important terms, namely the hydrostatic pressure gradient, friction pressure gradient and acceleration pressure gradient. In that relationship as shown in equation (1), the effects of chemical reactions between phases are neglected. However, factors like viscosity, density etc are included (Production Dept. of America Petroleum Institute, 1984).

$$\left(\frac{dp}{dh}\right)_{total} = \left(\frac{dp}{dh}\right)_{static} + \left(\frac{dp}{dh}\right)_{fric.} + \left(\frac{dp}{dh}\right)_{acc.} \quad \text{..........(1)}$$

The four generalised correlations mentioned earlier were developed either from large experimental data base or field data with little or no regard given to the flow mechanism. Consequently, this makes extrapolation to different flow conditions becomes inaccurate because such correlations are usually influenced by the field or experimental conditions and type of fluid systems. Nevertheless, special attention should be given to the Aziz, Govier and Fogarasi method because it is found that this method has taken the flow mechanism phenomenon into consideration, so that different correlations can be proposed for different flow regimes (Aziz, Govier and Fogarasi, 1972). It was revealed that the Aziz et al correlation performed with an accuracy comparable to the Orkiszewski method (Vohra, Robinson and Brill, 1973).

GENERALISED DIRECTIONAL MULTIPHASE FLOW CORRELATIONS

In an offshore field, all producing wells are drilled directionally to reach different subsurface locations in order to drain the reservoir effectively. Some of the wells may have deviations as much as 60^{o} from the vertical. The main problem at present is that no proven multiphase flow correlation is available which can adequately solves the problems associated with all angles of flow. Brown discovered that the standard vertical multiphase flow correlations gave fairly good results for directionally drilled wells with deviations not exceeding $15\text{-}20^{o}$ from the vertical. Beggs, however, has proposed a correlation for directional flow but it still requires some modification in order to improve its accuracy (Brown, 1977).

So far the directional well problems were solved by modifying the standard vertical multiphase flow correlation. This can be achieved via the addition of sin θ to the static gradient term of equation (1) as shown below : -

$$\left(\frac{dp}{dh}\right)_{total} = \left(\frac{dp}{dh}\right)_{static} + \left(\frac{dp}{dh}\right)_{fric.} + \left(\frac{dp}{dh}\right)_{acc.}$$

$$= \left(\frac{g}{g_c}\right) m \, \text{Sin}\,\theta + \left(\frac{f v^2}{2 g_c d}\right) + \left(\frac{v \, dv}{g_c \, dv}\right) \quad \text{...............(2)}$$

Equation (2) allows friction and acceleration terms to be taken over the total tubing length, but density to be taken over the vertical length only. Nevertheless, the inherent error in this method is that a holdup correlation for vertical multiphase flow is used, where at some angles the holdup may exceed that for vertical flow (Brown, 1977).

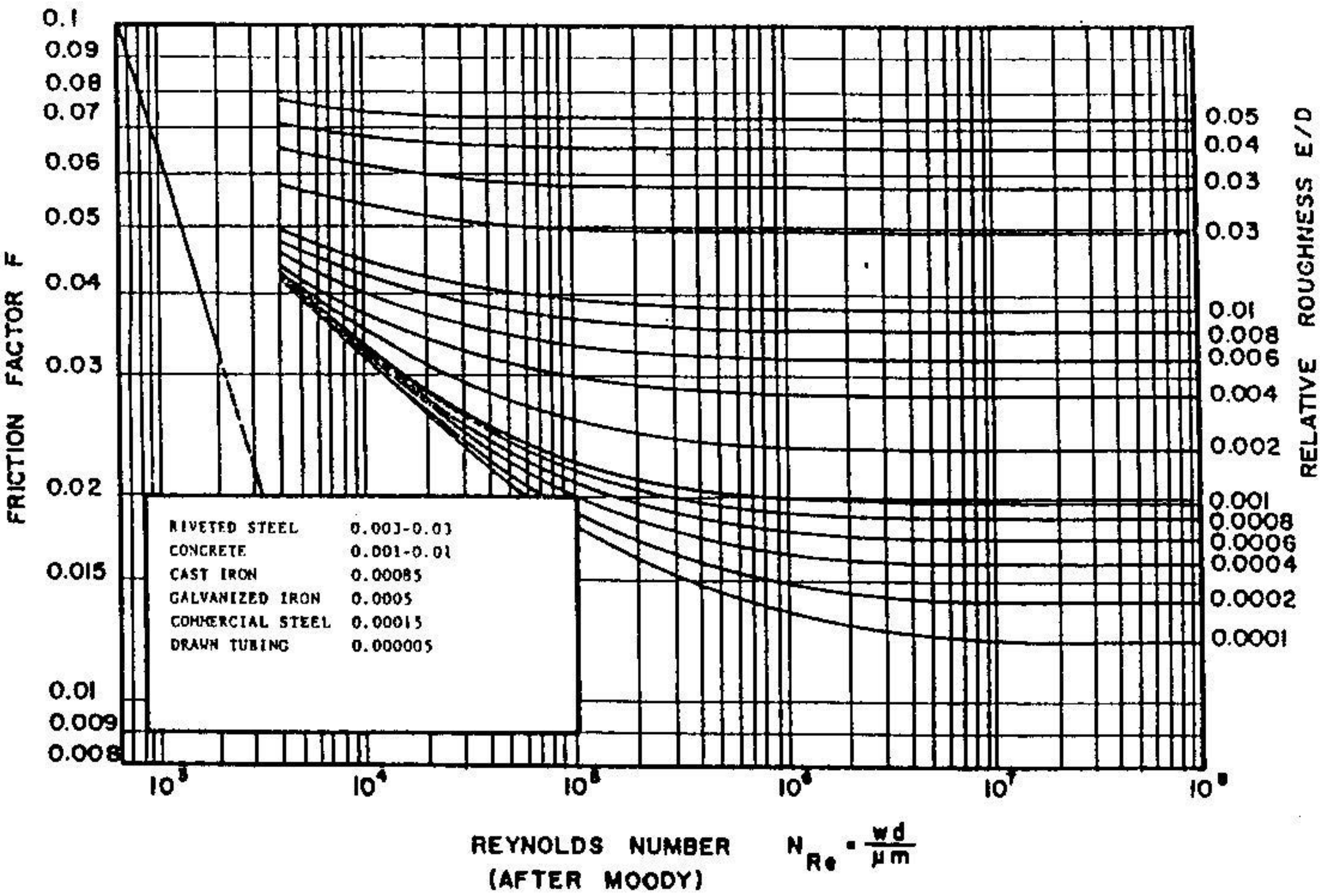

Figure 2.0 : Friction Factor Curve (Moody, 1944)

MULTIPHASE FLOW CORRELATIONS APPLICATIONS

Multiphase flow correlations are very important to production engineers. Generally, a most suitable vertical/directional multiphase flow correlation has to be determined first prior to performing any of the following tasks : -

o Selection of tubing sizes for new production and infill wells.

o Selection of insert strings for mature wells.

o Analysing/predicting flowing bottomhole pressures.

o Generate pressure traverse data along the production string and wellbore.

o Determination of maximum flowrates.

o Determination of productivity indices of wells.

o Designing artificial lift installation at some later date.

Due to the repetitive step like nature of the calculation of a multiphase flow correlation, a simulation program is normally required to compute the tedious flowing pressure along production conduit and wellbore. Given the wellhead pressure and the depth of interest, the program can compute flowing pressure along the string until it reaches the flowing bottomhole pressure, or vice versa.

It should be noted that apart form tubing flow, the previously discussed correlations can also be used for annular flow with the general substitution for hydraulic diameter. The estimation of roughness for tubing flow may not give any problems because it can be readily determined from Figure 2.0. For annular flow, however, roughness of the inside of the casing string and the outside of the tubing string must be taken into account (Brown, 1977).

CONCLUSION

1. All generalised multiphase flow correlations utilise three important terms, namely the hydrostatic pressure gradient, friction pressure gradient and acceleration pressure gradient.

2. Sin θ has to be added to the static gradient term before a generalised multiphase flow correlation can be used to solve the directional well problems.

3. Attention should also be given to the Aziz, Govier and Fogarasi method because it has some theoretical justification.

4. A simulation program is usually required to compute the tedious flowing pressure along the production conduit and wellbore.

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