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Inferring Rates from Wellhead Chokes during Multiphase Flow

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Abstract

This short technical discourse explores the relative merits of the use of thermodynamics based models with commonly used correlations to estimate flow rates of multiphase fluids through surface chokes. Seven different data sets gathered from laboratory and field settings, involving about 1,000 independent data points, constituted the essence of this study. The study found the importance of PVT data in any flow through choke calculations. Specifically, we found that changes in density and heat capacity of fluids with pressure and temperature should be part of any rigorous effort for computation of flow rates.

Background

In a flowing well, a wellhead choke has a two-fold purpose. The choke can be the primary means of controlling the flow rate and provide sufficient data for rate estimation. Flow rate estimation through chokes has been in use over six decades. To that end, dozens of empirical correlations have emerged since the pioneering study of Gilbert (1954). Subsequently, the thermodynamics-based models, introduced by Sachdeva et al. (1986) have shown the benefits of this modeling approach. Thereafter, Perkins (1993) suggested a new model, and by introducing phase slippage, Alsafran and Kelkar (2009) offered improvements to the Sachdeva et al. model. Similarly, Schüller et al. (2003, 2006) studied the flow of all three phases and offered appropriate modeling approach, including phase slippage.

Some of the early correlations of Gilbert (1954) and Ros (1960) and, others in the modern era, such as Al-Attar (2010) and Beiranvand and Khorzoughi (2011) have an inherent issue in that they do not delineate the critical/subcritical flow boundary. This flow differentiation becomes imperative because the downstream pressure is unaffected by rate during the critical flow, whereas the square root of pressure drop controls the subcritical flow rate. Surprisingly, Fortunati (1972) and Ashford and Pierce (1975) recognized the critical/subcritical flow boundary and offered appropriate correlations for both flow regimes.

Most recently, Zhou (2017) presented a study exploring relative merits of correlations and models based on a study of 1,000 data points, involving both laboratory and field data. The objectives of this study are to illuminate essential findings of that study and map out action items whenever production rates are inferred from choke flow measurements. For clarity of conveying the message, we use a somewhat unorthodox approach to a question and answer format.

Major Findings

We have posted several questions so that the most relevant messages can be conveyed succinctly. We discuss these items of interest in order of relative importance. First, we attempt to identify the variables of interest impacting the calculations of a choke model. Second, we try to understand the integrity of choke ID, vis-à-vis its response. Third, we try to address the debate about critical and subcritical flow. The third and fourth items involve discussions on slip velocity and discharge coefficient, and finally, we show which model works the best.

1. Which variables are essential in impacting measurement errors in model performance?

We selected a few variables that are likely to have the largest impact on the performance of a model or correlation. Specifically, we chose water cut, gas/oil ratio or GOR, upstream (p_u) and downstream (p_d) pressure across choke, and the choke size.

Fig. 1 shows that neither the GOR nor the water-cut materially impacts the performance of the Sachdeva et al. model (1986). But, the ±10% error in the upstream and downstream choke pressures may result above 20% error in rate estimation for a field data set containing 400 points. But, most importantly, the integrity of choke size has the most significant impact on the solution outcome.

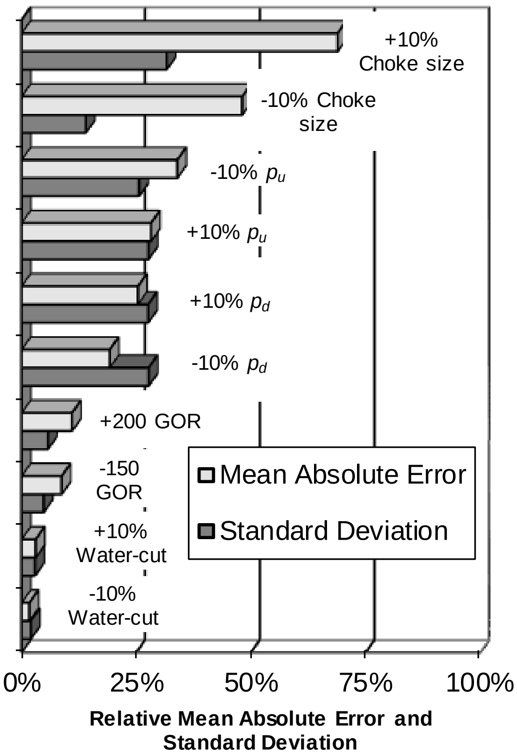


Fig. 1 – Sensitivity comparison relative to original results, 400 field data points.

2. So, how important is the choke integrity?

Graphing multirate tests in a dimensionless rate vs. pressure plot can be very revealing. First, it delineates the critical flow exemplified by the horizontal plateau segment of the test data from that in the curved section on the right, wherein subcritical flow sets in at lower rates. Second, issues with flow measurements arising from potential flow impediments become transparent. Fig. 2 shows such a plot for two sets of data from two wells. Whereas Fig. 2a suggests reasonable agreement of data with the overall theoretical choke curve, Fig. 2b exhibits an anomaly with the lowest choke setting at 40/64 in., wherein the largest flow rate occurs.

For the reported choke size, we obtained a rate of 2,950 STB/D. However, from the downhole spinner survey, this rate appears more in alignment with 3,400 STB/D. Therefore, to match this data point with the theoretical curve, a choke size adjustment of 43/64 in. becomes necessary. A potential cause of this discrepancy stems from the enlargement of the choke size arising from the production of sand. In other words, reaffirming the choke size before each test becomes an operational necessity.

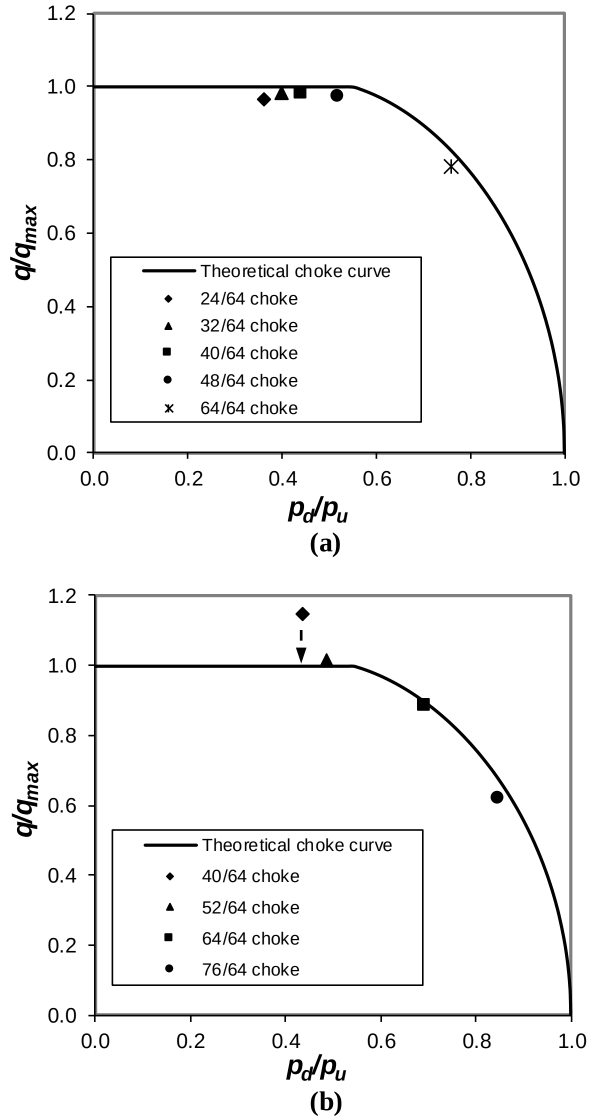


Fig. 2 – The theoretical choke curve helps identify data consistency (a), or lack thereof (b).

Fig. 3 also exhibits an issue wherein the rate reversal is indicated by the 14/64 and 20/64 in. responses. When data points do not provide a suitable match, some adjustments of input parameters or individual shifts in the right direction may be in order. Note that changing the upstream pressures shifts the data points diagonally, whereas changing the downstream pressure shifts the data horizontally. Changes in rate, fluid properties, and choke size trigger vertical movement. Obviously, these inconsistencies demand the need for accurate choke size and the upstream pressure before a well test and/or rate calculations occur.

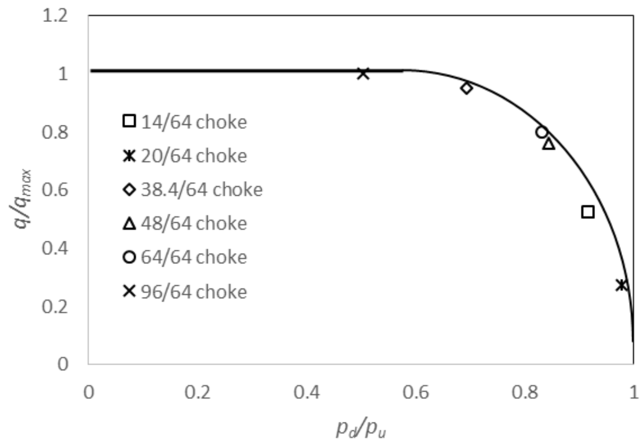


Fig. 3 – The theoretical choke curve identifies data inconsistency, as in 14/64 and 20/64 in. responses.

3. Are the models capable of handling critical and subcritical flows?

Yes, generally speaking, this is a settled issue in the context of all models. However, the error grows in the domain of subcritical flow. Fig. 4 demonstrates this point in a matured field exhibiting 440 data points. Evidently, the data points in the critical flow segment are better reproduced than those in the subcritical flow domain, although the overall response appears well within engineering accuracy. With reservoir depletion and declining flow rate in any field, more data points will be in the subcritical flow domain than its critical counterpart.

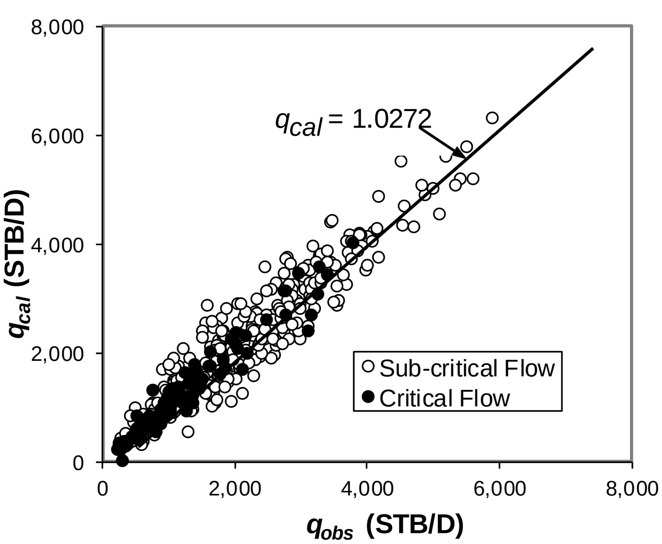
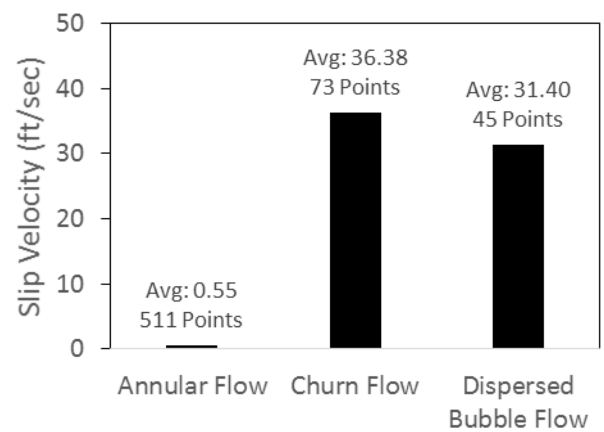


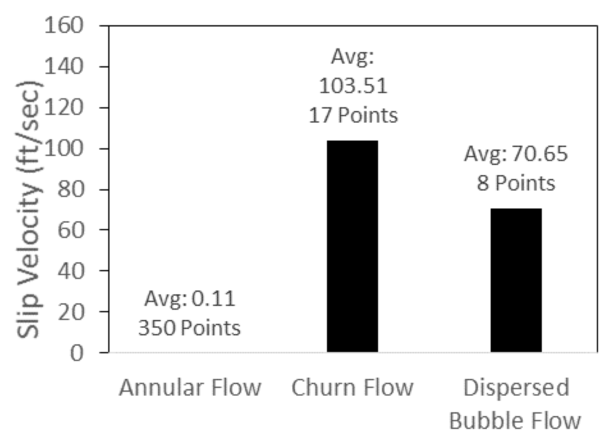
Fig. 4 – Sachdeva et al. model reproduces the results of a field in both critical and subcritical flow domains.

4. Can we afford to neglect the slip velocity in most model calculations?

The answer appears to be 'yes.' In simple terms, our general observation is that the inclusion of phase slippage improves a model's performance when dealing with laboratory data, but that improvement dissipates when field data are used. The physical explanation for this observation revolves around the fact that, in general terms, the phase velocities are much higher in a field setting compared to the laboratory environment. In other words, in the presence of annular flow, phase slippage disappears thereby favoring exclusion of phase slippage in a field operation. Fig. 5 illustrates this point by directly comparing the lab and field data sets.



(a)



(b)

Fig. 5 – Lab data show presence of slip velocity in about 19% of data points (a), but only in 6.7% of data points in field settings.

5. How important is the discharge coefficient? Can we assume a single value?

Although the choke discharge coefficient C_D involves Reynolds number, choke configuration, and fluid properties, but a simplified logarithmic relationship related to the liquid rate can be shown to work for simplicity. Fig. 6 illustrates this point for the data points shown earlier in Fig. 4. Therefore, the questions arise whether we should always develop this sort of correlation before using a model for rate estimation. Our experience suggests that a single value for C_D of 0.90 for the Sachdeva et al. model appears justified for both the laboratory and field data sets, although one can use the variable-C_D approach whenever a sufficient number of data points exists in a field setting.

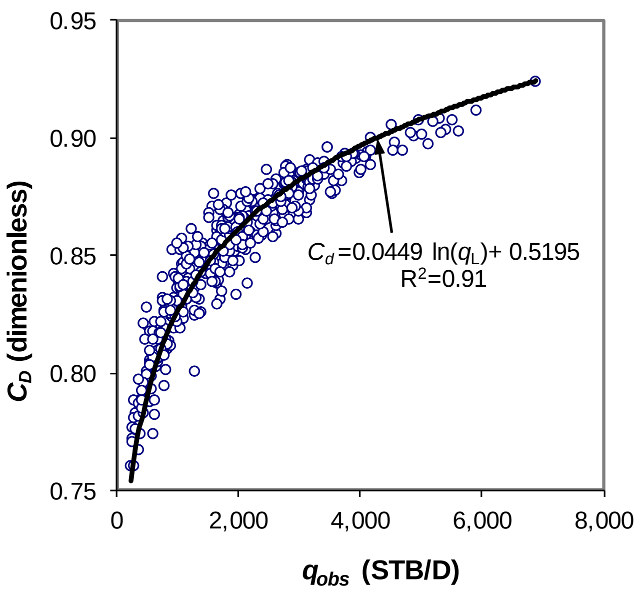


Fig. 6 — Choke discharge coefficient for the field rates correspond to those in Fig. 5.

6. So, which one is your preferred model?

Fig. 7 shows comparison of model performance involving field dataset. The figures show that the Sachdeva et al. model (1986) outperformed others considered in this study. No advantage of the inclusion of the slip velocity appears evident from either data set. Fig. 8 exhibits that the Fortunati correlation (1972), capable of determining flow boundary, showed the best performance among correlations. Comparing Figs. 7 and 8, one reaches the obvious conclusion that the models outperformed correlations for the combined field datasets used. Although not shown here, when the laboratory data sets are used the performance trends remain the same although absolute errors diminish.

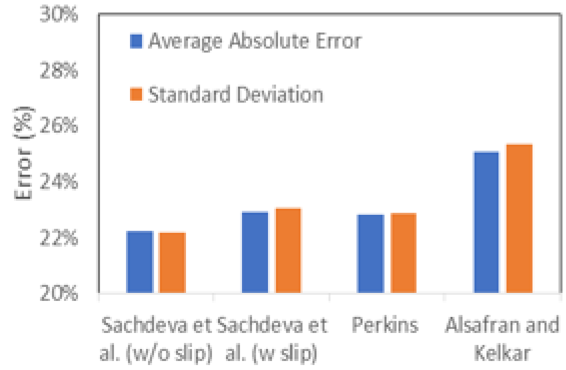


Fig. 7 – Model performance comparison of field data.

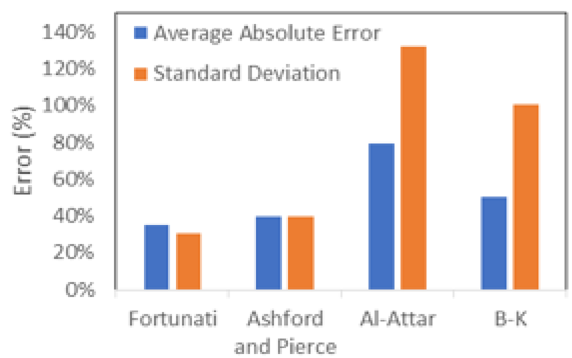


Fig. 8 – Correlation performance comparison of field data.

Conclusions

1. Models anchored in thermodynamic principles outperformed correlations, particularly those proposed in recent years. The Sachdeva et al. (1986) model, with minor modifications, showed some advantage over others. In contrast, the Fortunati (1972) correlation outperformed others. As expected, a field-specific correlation does not work well in other settings.

2. Given the dominance of annular flow in field settings, slip between the gas and liquid phases at the choke-throat condition appear unimportant for improving a model's performance.

3. Although a fixed value of C_D appears prudent, a rate-dependent C_D can be determined for any data set.

Nomenclature

C_D	discharge coefficient, dimensionless
p_d	downstream pressure, psia
p_u	upstream pressure, psia
q_{cal}	calculated flow rate, STB/D
q_{obs}	observed or measured flow rate, STB/D
q_{max}	maximum flow rate, STB/D

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