Proceedings World Geothermal Congress 2026, Calgary, Canada, June 8—11, 2026

# Void Fraction Correlations on Geothermal Two-Phase Flows

Alvin I. Remoroza
Energy Development Corporation, Pasig City, Metro Manila, Philippines 1610

## INTRODUCTION

Two-phase flow is the simultaneous flow of two distinct phases, i.e. liquid water and steam, which is the focus of this study.

Calculations for two-phase flows are more complicated than those of single-phase flows. Different techniques for analyzing two-phase flows include correlations, the phenomenological models, simple analytical model, and other methods such as integral analysis, differential analysis, computational fluid dynamics, and artificial neural network (Awad, 2012).

The general governing equations for two-phase flows require that (a) the fluids may be treated as continua and (b) the physical variables denoting the thermal and dynamic state of the fluid are well-defined. The area of research that takes the approach of solving the full conservation equations is generally referred to as Computational Fluid Dynamics (CFD) (Vij & Dun, 1996).

A comparison of the performance of 68 void fraction correlations based on unbiased data set covering wide range of parameters were done by (Woldesemayat & Ghajar, 2007). They classified the correlations into four categories (a) slip ratio, (b) KεH , (c) drift flux, and (d) general void fraction correlations. Slip ratio correlation are expressed as a function of the ratios between wetness fraction (1 - x) and x the "quality" or "dryness fraction", where x is defined as the ratio of gas flow rate to the total flow rate; the ratios of densities of the gas and liquid phase (ρG and ρL); and the ratios of the viscosities of the liquid and gas phase (μL and μG). KεH correlations are a constant or some functional multiple of the no-slip or homogeneous void fraction, pressure (P), the Froude number (Fr) based on the two-phase mixture velocity (UM), liquid input content (λ), or Reynolds number (Re). Drift flux correlations take into consideration the non uniformity in the flow captured by a distribution parameter (C0), and the drift velocity (UGM), defined as the difference between the gas phase velocity (UG) and the two-phase mixture velocity (UM).

In geothermal, the lip-pressure is the standard method of measuring flow of geothermal wells (Grant, James, & Bixley, 1982) (James, Factors Controlling Borehole Performance, 1970) (James, Maximum Steam Flow Through Pipes to Atmosphere, 1964) (James, Steam-Water Critical Flow through Pipes, 1962).

In 2000, (Zhao, Lee, & Freeston, 2000) derived a correlation from the analysis of two-phase flow velocity distribution using the Seventh Power Law where the average velocity of the equivalent single-phase flow is used to determine two-phase pressure drop.

In this paper, tracer fluid test (TFT) and/or bore output measurements (BOM) data from multiple wells will be used to analyze the performance or fitness of the different void fraction correlations from prior authors. Different relationships will be shown such as void fraction versus flow quality, discharge enthalpy, slip ratios, and other parameters.

## METHOD OF ANALYSIS

Taking off from the works of (Woldesemayat & Ghajar, 2007) which recommend correlations with good void fraction prediction for horizontal and upward inclined pipes regardless of flow regimes, this study will analyze the following correlations (a) Toshiba (Coddington & Macian, 2002), (b) Rouhani I (Rouhani & Axelsson, 1970), (c) Dix (Coddington & Macian, 2002), (d) Filiminov (Filimonov, Przhizhalovski, Dik, & Petrova, 1957).

Chisholm correlation (Chisholm, 1973) will also be included in the analysis because it is notable that it follows the thermodynamic limits such that when $x \rightarrow 0$, $S \rightarrow 1$, and as $x \rightarrow 1$, $S \rightarrow (\rho G / \rho L)^{1/2}$ (Thorne, 2016) .

In addition, a correlation based on the Seventh Power Law derived by (Zhao, Lee, & Freeston, 2000) is also included in the analysis.

TFT and/or BOM data of multiple wells of varying branchline sizes (10-18" nominal size diameter) from Energy Development Corporation's integrated database system were used in the analysis. The measurements were taken from 1997 up to 2018. The following information are available in the database for each TFT data set, (a) total mass flow, (b) water flow, (c) total discharge enthalpy, and (d) wellhead pressure. Using this data set, void fraction, steam flow quality, and other fluid properties were calculated.

## RESULTS AND DISCUSSIONS

Solving simultaneously multi-phase flow equations using TFT and/or BOM data will give the void/steam fraction of the two-phase flows as shown in Figure 1. Also in the figure are the experimental data from (Ralph Webster Pike, 1962) based on the adiabatic, evaporating, two-phase flow of steam and water in horizontal pipe. Pike use X-ray tube as a source of monoenergetic gamma radiation to measure void-fraction in two-phase water-steam flow. He concluded that assuming thermodynamic equilibrium is achieved; adiabatic, two-phase flow of steam-water can be described by annular flow equations. It can be seen that Pike's experimental data is consistent with the calculated void/steam fraction based TFT/BOM data.

Correlations by (Zhao, Lee, & Freeston, 2000), (Chisholm, 1973), and (Rouhani & Axelsson, 1970) give very good flow quality – void fraction R-squared values (better than 0.95). Correlations by (Filimonov, Przhizhalovski, Dik, & Petrova, 1957), Toshiba, and Dix show similar trends but with lower coefficient of determination or the data are more scattered. Overlapped histograms of calculated void fractions from different correlations showed that void fraction of geothermal fluid flows in two-phase lines are almost always greater than 0.60 (Fig 2).

Slip ratio calculations showed that Chisholm correlation gives the best coefficient of determination which can be used to indirectly measure the output of a well given any two of the void fraction, water/steam/mix velocities, mix densities, and/or the flow quality (Fig 3). The calculated void fraction of two-phase water-steam flow based on homogenous model has a very narrow range with high values at between 0.90 to 1. Calculated steam velocities based on different correlations showed similar values with average speeds of 19 to 20 m/s while the average water velocity is 1.6 - 2.6 m/s except for Filmonov correlation with an average of ~4.1 m/s. Based on the calculated slip ratios, most geothermal two-phase flows fall in the annular flow regime with thin liquid water layer flowing in the pipe wall.

Using a combination of gamma ray techniques and conditional orifice plate, void fraction and total mass flow can be indirectly measured, respectively. Discharge enthalpy can then be calculated using the void fraction correlation to complete production well output calculations. Alternatively, electrical capacitance volume tomography can be used to determine steam and brine velocities as well as the void fraction. These two methodologies were field tested in EDC geothermal wells and proven precise and accurate.

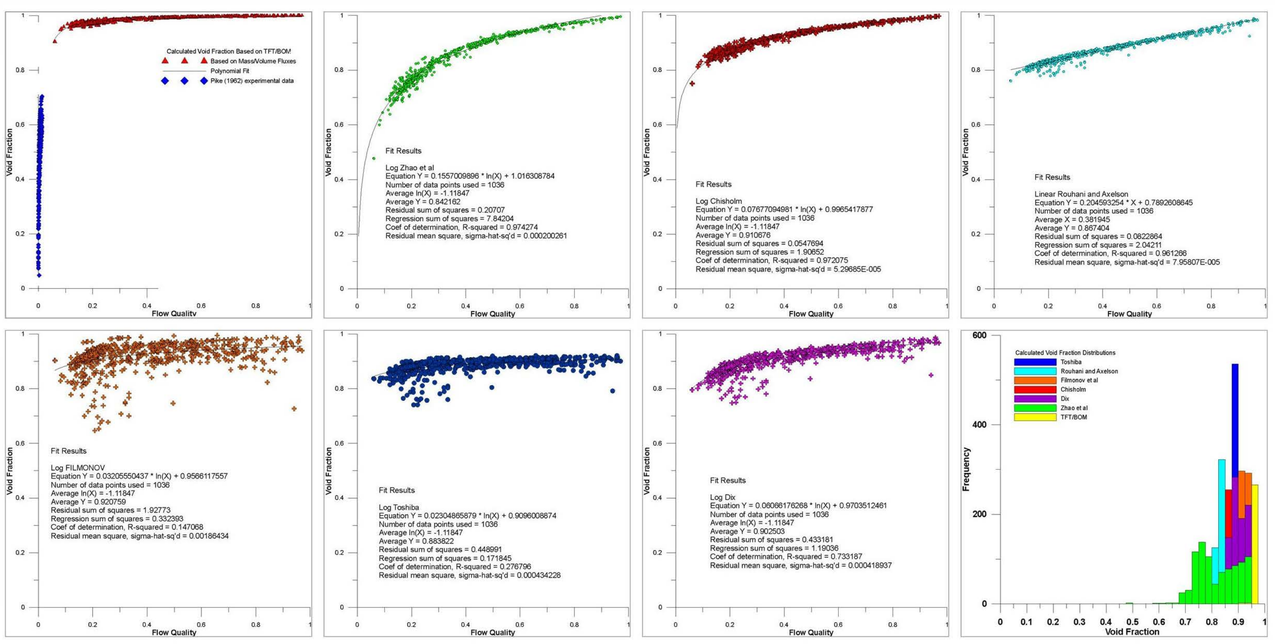



**Figure 1 Plot of calculated void fraction versus flow quality using different correlations and the histogram.**

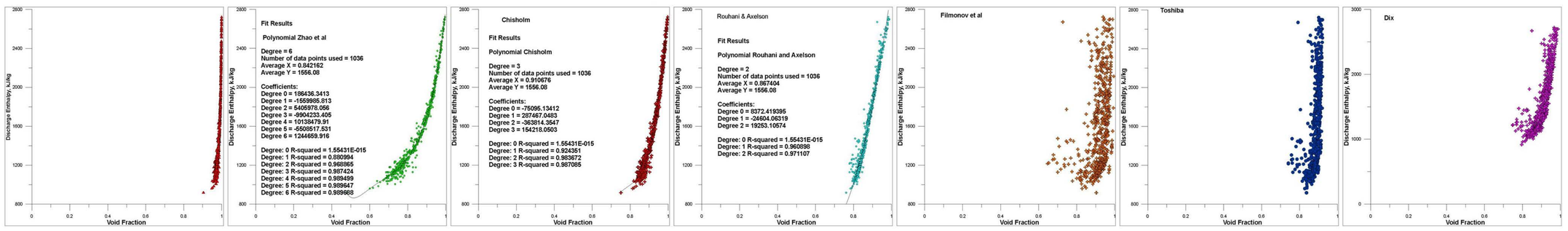



**Figure 2 Plot of well total discharge enthalpy versus void fraction using homogenous model and different correlations.**

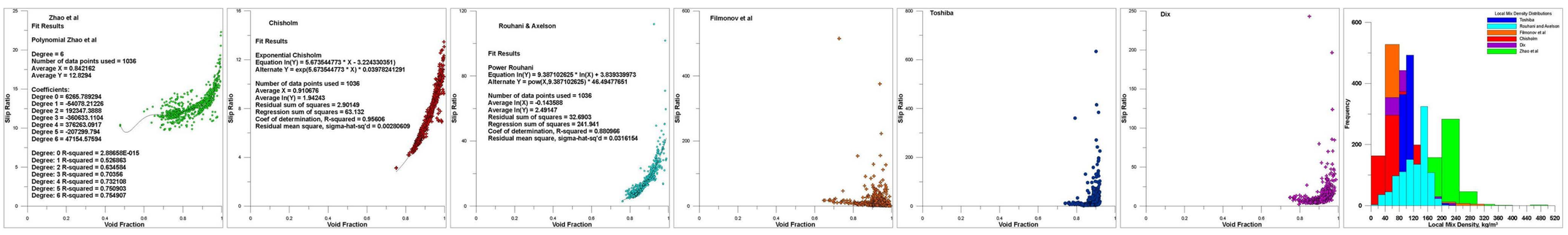



**Figure 3 Plot of slip ratio versus void fraction and local mix density distributions sing different correlations.**

## SUMMARY AND CONCLUSIONS

Void fractions of geothermal two-phase flows are higher than 0.6 while calculated slip ratios range from 2.6 to 12.2. Generally, the flow regime predicted is either annular or fully mixed mist flows. For fully mixed homogenous two-phase flow, the total mass flow can be measured indirectly using differential pressure meter (orifice, venture, etc.) assuming mix density is correlated to total discharge enthalpy while for separated flow, two-phase flow equations can be solved using any two of the following: water/steam phase velocities, total mass flow, void fraction, or steam flow quality. Void fraction and/or fluid mix density can be determined using gamma ray attenuation, fluid electrical capacitance/resistivity/inductivity measurements, ultrasonic, and/or vibration frequency.

**Acknowledgements**

Grateful to Energy Development Corporation for giving permission to publish and present this study.

## REFERENCES

Awad, M. (2012). Two-Phase Flow. In S. N. Kazi, An Overview of Heat Transfer Phenomena. IntechOpen.

Chisholm, D. (1973). Pressure gradients due to friction during the flow of evaporating two-phase mixtures in smooth tubes and channels. Int. J. Heat Mass Transfer , 347-358.

Coddington, P., & Macian, R. (2002). A study of the performance of void fraction correlations used in the context of drift-flux two-phase flow. Nuclear Engineering Design , 199-216.

Filimonov, A., Przhizhalovski, M., Dik, E., & Petrova, J. (1957). The driving head in pipes with a free interface in the pressure range. Teploenergetika 4 , 22-26.

Grant, M., James, R., & Bixley, P. (1982). A MODIFIED GAS CORRECTION FOR THE LIP-PRESSURE METHOD. Proceedings Eighth Workshop Geothermal Reservoir Engineering Stanford University (p. 133). Stanford, CA: Stanford University.

James, R. (1964). Maximum Steam Flow Through Pipes to the Atmosphere. Proc. Inst. Mech. Engrs., (p. 473).

James, R. (1962). Steam-Water Critical Flow through Pipes. Proc. Inst. Mech. Engrs., (p. 741).

Rouhani, S., & Axelsson, E. (1970). Calculation of void volume fraction in the sub cooled and quality boiling regions. Int. J. Heat Mass Transfer , 383-393.

Thorne, J. (2016). The Heat Transfer Engineering Book III. Lausanne, Switzerland: PP PUBLICO.

Vij, A. K., & Dun, W. E. (1996). Modeling of Two-Phase Flows in Horizontal Tubes. Urbana, IL: Air Conditioning and Refrigeration Center, University of Ilinois.

Woldesemayat, M., & Ghajar, A. (2007). Comparison of void fraction correlations for different flow patterns in horizontal and upward inclined pipes. International Journal of Multiphase Flow , 347-370.

Zhao, H., Lee, K., & Freeston, D. (2000). GEOTHERMAL TWO-PHASE FLOW IN HORIZONTAL PIPES. Proceedings World Geothermal Congress 2000, (pp. 3349-3353). Kyushu-Tohoku Japan