



encit 2020



18th Brazilian Congress of Thermal Sciences and Engineering
November 16-20, 2020, Online.

ENCIT2020-0321

FLUID MEASUREMENT IN BIPHASIC WATER - AIR USING ZHANG CORRELATION

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Abstract. *The measurement of flow is of paramount importance for the technological development and reliability of the industrial processes. Of the several quantities that are often measured, the flow is becoming more and more studied and researched, therefore, it needs several technological resources for its measurement. Currently, the technologies for the measurement of flows of single-phase fluids have great precision and repeatability and the phenomena that govern the interaction between fluid and meter are well understood. There are several flow meters for single phase flows, such as: orifice plate, nozzle, Venturi tube, ultrasonic, among others. In industries, especially in process and oil and gas industries, the flow model is typically multiphase, that is, there is the coexistence of two or more fluids within the piping that conditions it. The equipment used for multiphase flow flow measurement is quite complex and costly when compared to the one used in single phase flows. In this way, it is very interesting to adjust the typical single phase equipment to determine the flow rate. The measurement of flow from the generation of a differential pressure (depressions) is highly applied in the industries due to their low cost and applicability. In the present work, it was proposed the use of the correlation of Zhang et al. (1992) with the purpose of quantifying the value of the large flow in two-phase water-air flow. It was possible to observe the convergence between the values obtained with the Zhang correlation with the expected values.*

Keywords: *Flow measurement, Zhang correlation, Biphasic flow*

1. INTRODUCTION

Since the beginning of human evolution, the need and the importance of measuring different quantities have been realized, whether for simple marking of the contours of terrains to international trade and relations. The measurements are usually expressed as fractions or multiples of an internationally recognized standard unit, such as: meter, kilogram, according to others. The monitoring and control of the parameters that govern the functioning of a given phenomenon or process is the objective of interest in several areas of science and technology where the reliability of the processes or a given product is of paramount importance for the credibility and quality of the articles that will be products by industries and companies.

Among the various quantities that are frequently measured, the flow rate has become increasingly studied and researched, as it needs several technological resources for its measurement. The flow (Q) can be defined as the quantity of a certain liquid, vapor or gas that passes through a certain straight section of a pipe per unit of time. It should be noted that the flow can be measured in two ways, namely: volume or volumetric flow (Q_v) defined as the quantity in volume of a certain fluid that flows through a straight section of a pipe per unit of time, having as units m^3/s in the international system of units (SI); mass flow (\dot{m}) defined as the amount of mass of a given fluid that passes through a straight section of a pipe for the unit of time, having as units kg / s in the international system of units (SI).

When working with volume flow, especially when dealing with fluids that are compressible, such as gases, it is important to mention the conditions for specifying the volume to be measured, that is, the operating and reference pressure and temperature conditions. This happens because the volume of a given substance depends on the pressure and temperature under which it is inserted. When working in the operating condition, the volumetric flow is being characterized in the actual operating conditions of the system. When dealing with the reference condition, we work with pre-established base parameters, such as pressure and temperature of $0^\circ C$ and $760 mmHg$, respectively

Currently, the technologies for the measurement of flows of single-phase fluids have great precision and repeatability and the phenomena that govern the interaction between fluid and meter are well understood. There are several flow meters for single phase flows, such as: orifice plate, nozzle, Venturi tube, ultrasonic, among others. In industries, especially in process and oil and gas industries, the flow model is typically multiphase, that is, there is the coexistence of two or more fluids within the piping that conditions it.

Multiphase flows occur commonly in several areas of science and technology. The control and monitoring of the processes that govern the operation of the processing, food, energy conversion and fluid transport industries are of paramount importance for the quality of services and preventive actions regarding the weather that may come. happening, and with that, protecting the safety of workers and the efficiency of processes (SELLI, MF, 2007, p. 11).

It is important to emphasize that the term phase is not directly related to thermodynamic analysis, where the same substance can exist in more than one phase (solid, liquid and gas) but in the coexistence of two or more fluids that form a kind of "membrane" of separation between them, for example, the flow of water and oil, where they are immiscible with each other (PALADINO, 2005). It is of great importance to understand clearly and objectively the interaction of the multiphase flow and the measuring instrument for a better reliability of the results.

The equipment used for multiphase flow in measurement flow is quite complex and costly when compared to the one used in single phase flows. In this way, it is very interesting to adjust the typical single phase equipment to determine the flow rate. The measurement of flow from the generation of a differential pressure (depressions) is highly applied in the industries due to their low cost and applicability.

Among the various devices used in flow measurement, one of the most used is the orifice plate (PO). From a conceptual point of view, PO works by reducing the static pressure as the fluid passes through an orifice smaller than the space in which the fluid initially flows. Due to the losses that are generated in the flow, such as the loss of load and viscous effects, a portion of the energy is lost, resulting in a pressure differential (ΔP) and, depending on this, it is possible to quantify the flow.

The studies referring to the multiphase flows, in particular the biphasic one, have high importance for the scientific and technological development, mainly, in what concerns to the increment of new procedures able to replace others already existing.

In this work the study was focused on the biphasic flow of a liquid (water) and a gas (atmospheric air), where the water acts as a continuous phase, that is, uniformly distributed along the flow and the atmospheric air as a phase dispersed along the length of the pipe. Thus, we observed the effects generated in the pressure drop as a function of the orifice plate flow and compared the values obtained for the biphasic and single phase flow.

In the quantification of the biphasic flow rate, the homogeneous flow model was used and the Zhang correlation was used in the calculation of biphasic flow rates. Thus, it was possible to perceive the behavior of biphasic flow, water - air, in horizontal pipeline with fluid flow at low titer. The results suggest a reduction of the measured biphasic flow in comparison to the one-phase, which is in agreement with the expected, because the specific mass of the mixture is different and less than the flow with only water.

2. METHODOLOGY

For the experimental development of the liquid / gas system, water is used as a liquid phase initially stationary in a reservoir and atmospheric air as a gas. In order to detail the effects of the pressure difference generated in the flow of biphasic flow, water and air, when going through a reduction of area in a concentric orifice plate, and, therefore, the flow quantification from the measured pressure drop, it is proposed to evaluate from a variation of the water flow with nominal volumetric flow of 8000 liters per hour, and the air flow being controlled by a compressor that injects 9.00 liters per minute of air into the pipeline downstream of the bomb. The adopted physical model consisted of a bench with horizontal and vertical one-inch pipe sections, a reservoir, and a CAM W4 centrifugal pump. The following process flowchart, illustrated in figure 1, how the system was assembled in the facilities of the Fluid Mechanics Laboratory at the Federal University of Rio Grande do Norte.

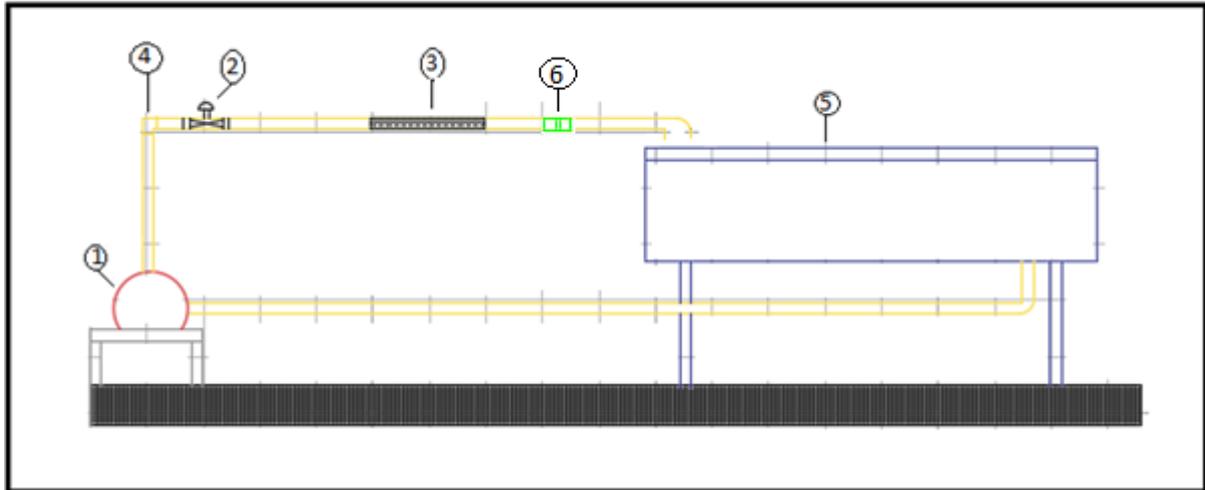


Figure 1. Schematic system of the basic components of the experimental bench (Software AutoCad 2015).
Available from: Own authorship, 2015.

The arrangement of the fluid pumping system sought to be as credible as possible, so the assembled system consisted of a set of tubes coupled to the pumping system (Dancor motor CV engine, 3500 rpm; centrifugal pump CAM-W4 providing a volumetric flow approximately 8m³ / h). For the implementation of the bench in the fluid mechanics laboratory, the thermoplastic, polyvinyl chloride (PVC) was used because it is widely used in the industrial environment, with an internal diameter of approximately 25.4 mm, as the pipe that will guide the flow of the biphasic mixture. Initially, only water, inside a reservoir, is sucked up by the pumping unit.

2.1 Acquisition of Single Phase Flows

The quantification of the mass flow of the single-phase flow was done in three ways, namely: measurement from the estimated time to fill a given volume pre-established, use of triangular spout and using the concentric orifice plate.

The calculation referring to this topic uses as basis the data obtained by the norm NBR 13225 in consonance with the norm NBR 5167-1. In order to perform the numerical value of the purely monophasic mass flow, that is, for the flow of liquid water, it was assumed that there was no heat exchange or to the system, so the average liquid water temperature was assumed to be the mean of the values provided by the thermocouples, thus, T_{med} = 20 ° C, as well as the flow regime is considered to be permanent. According to NBR 5167-1, the mass flow can be calculated from Equations 1 and 2, namely:

$$\dot{m} = \frac{C}{\sqrt{1-\beta^4}} \varepsilon_1 \frac{\pi}{4} d^2 \sqrt{2\Delta P \rho_1} \quad (1)$$

$$\dot{m} = \frac{C}{\sqrt{1-\beta^4}} \varepsilon_2 \frac{\pi}{4} d^2 \sqrt{2\Delta P \rho_2} \quad (2)$$

As observed in the above equations, the mass flow rate depends on certain parameters, such as discharge coefficient (C), relation between diameters (β), expansion factor (ε) and specific mass (ρ). The discharge coefficient was calculated using Equation 3 commonly known as the Stolz equation and used in the calculation of the discharge coefficient of concentric corner plates of live corner for type D and D/2 pressure sockets.

$$C = 0,5959 + 0,0312\beta^{2,1} - 0,1840\beta^3 + 0,0029\beta^{2,5} \left(\frac{10^6}{Re_D}\right)^{0,75} + 0,09L_1 \left(\frac{\beta^4}{1-\beta^4}\right) - 0,0337L_2\beta^3 \quad (3)$$

The values of L_1 and L_2 to be used in Equation 3, are obtained according to the standard NBR 5167-1 depending on the type of pressure taking used. The type of pressure taking used in this work is D and D/ 2, since it is the characteristic type that best suits the objectives of the experiment and the characteristics of the system, obeying the characteristics of this standard.

2.3 Acquisition of Biphasic Flows

The measurement of flow in typically single-phase flows is easy to analyze, since they have very widespread and accepted correlations. In the two - phase water - air flow measurement, the fluid dynamics effects are difficult to investigate and are not well understood. From the equation used to calculate the mass flow in single-phase equipment, it was made semi-empirical correlations for the measurement of flow rates in differential pressure meters, taking into account the presence of the biphasic mixture. According to Zhang (1992) quoted by Oliveira (2007), they propose a general formulation in Equation 4, where the factor, K_{1i} , to incorporate the generated effects of the biphasic flow.

$$\dot{m} = \frac{C_{D(Bi)} A_2 Y_{Bi} F_a}{\sqrt{1 - \beta^4}} K_{1i} \sqrt{2 \rho_l \Delta P_{Bi}} \quad (4)$$

where $C_{D(Bi)}$ represents the discharge coefficient for a two-phase flow. According to Zhang (1992), the discharge coefficient for securities of the order of one percent can be quantified as the same coefficient for the single-phase liquid flow for a given Reynolds, Re_l . The parameter Y_{Bi} is the biphasic expansion coefficient. Zhang (1992) defined the aforementioned parameter, such as:

$$Y_{Bi} = 1 - \alpha + \alpha Y \quad (5)$$

where Y is the monophasic expansion coefficient for the study gas (dimensionless) and α corresponds to the fraction in void measured as a function of the biphasic (dimensionless) flow.

3. RESULTS

The values of the mass flow using the triangular spout are provided explicitly by the equipment, thus not requiring calculations. According to the standard, for the pressure ports D and D / 2, the variables, L_1 and L_2 , are considered as preestablished parameters, assuming constant values, such as $L_1 = 1$ and $L_2 = 0,47$. In addition, the relationship between the diameters $\beta = d/D$, where $d = 12,035$ mm, corresponds to the diameter of the orifice or throat of the plate and $D = 25.4$ mm corresponds to the internal diameter of the system tubing, can be $\beta = d/D = 0,474$.

The Reynolds number (Re) is calculated for the internal diameter of the pipe. In this way, it was possible to calculate the discharge coefficient, $C = 0,06073$.

The expansion factor, ϵ and Y which works in order to correct the effects of gas compressibility (effect of the variation of specific mass as a function of pressure change), as previously observed, both water and gas (atmospheric air) have incompressible flow characteristics, the expansion factor will be equal to 1 for incompressible flow.

In this topic the results obtained for several important parameters in the calculation of the mass flow and the calculation of the same will be presented from the use of several empirical correlations used. It is worth mentioning that in the present work, we start from the premise of the hypothesis of homogeneous mixing, that is, the flow factor between the phases tends to unity and, thus, it is possible to calculate the title. So, $C_{Bi} = C = 0,6073$. The coefficient of thermal expansion of the orifice for the working temperature level, 20 ° C, is very close to the unit for several types of materials, as can be seen in Figure 2, for the present work $F_a = 1$.

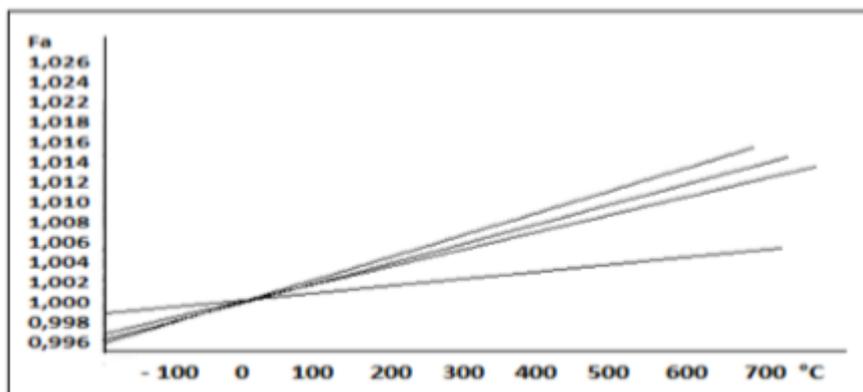


Figure 2. Coefficient of expansion for various materials.
 Available from: DELMÉE, 2003.

To identify the flow pattern found in this project, the model adopted by DUARTE, M, 2007 was used, where it uses a flow map where the ordinate is characterized by the volumetric flow of liquid, JL, in this case water, and gas, JG, as can be seen in figure 1. To calculate the volumetric flows, it was necessary, initially, to find the specific mass flows for liquids and gas using equation 6, where A, corresponds to the cross-sectional area of the flow, in this case, the section upstream of the PO, $A = 5,0671 \times 10^{-4} \text{ m}^2$ and mass flow rates for water and air, respectively $\dot{m}_w = 2.18 \text{ kg / s}$ and $\dot{m}_a = 1,815 \times 10^{-4} \text{ kg/s}$.

$$G = G_l + G_g = \frac{\dot{m}_l}{A} + \frac{\dot{m}_g}{A} \quad (6)$$

So it was possible to calculate the specific mass flow of water and air, respectively, $G_l = 4377.27 \text{ kg / m}$ and $G_g = 0.3582 \text{ kg / m}$. It is worth mentioning that, soon, the volumetric flow of water and gas was calculated, using equations 7 and 8 and the results obtained, respectively.

$$j_l = \frac{G_l}{\rho_l} = 4,386 \text{ m/s} \quad (7)$$

$$j_g = \frac{G_g}{\rho_g} = 0,296 \text{ m/s} \quad (8)$$

With the values obtained for the volumetric flows exposed by equations 7 and 8 we obtained or characterized the flow pattern using the flow map proposed by DUARTE, M, 2007, p. 15, as a flow of dispersed bubbles or dispersed bubbles, as illustrated by the black dot represented in figure 3.

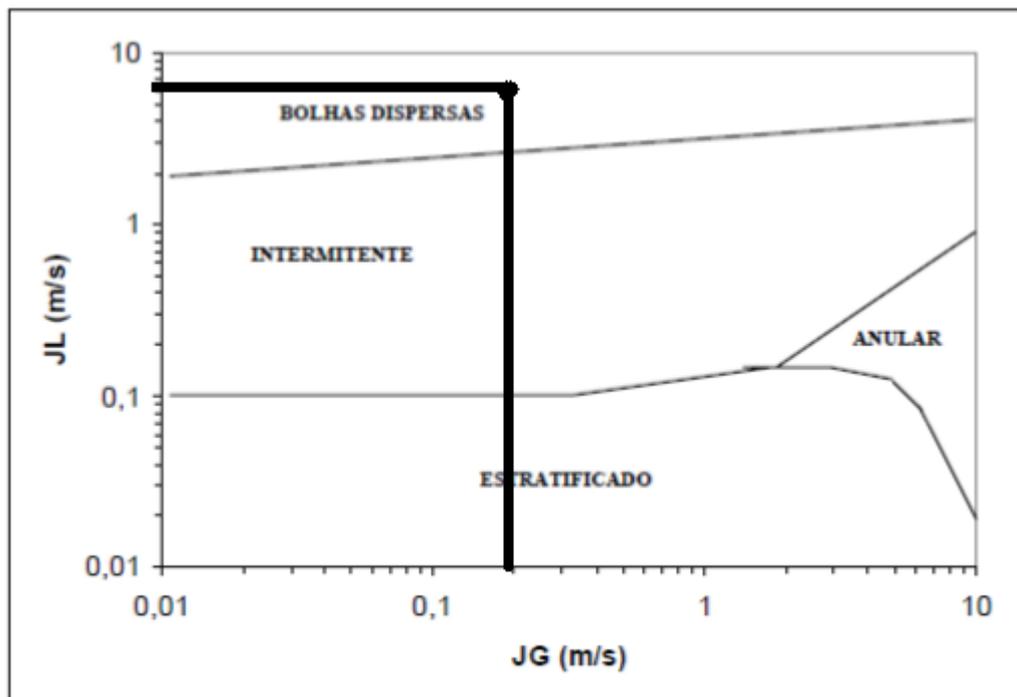


Figure 3. Flow pattern map proposed by DUARTE modified.
Available from: DUARTE, M., 2007, p.15.

Commonly, in this type of flow pattern, the dispersed air mass having a lower relative velocity when compared to the continuous phase, is characterized by the occupation of the upper part of the pipe according to the effects of the buoyant force. And if we compare the specific mass of air with water, we see that $\frac{\rho_a}{\rho_w} = 0,1212\%$, that is, $\rho_a \ll \rho_w$. It is important to take into account that there are several factors that contribute to variations in flow patterns, such as: surface tension, the occurrence of appreciable heat transmission, coalescence of molecules, among others. Thus, the characterization of the aforementioned flow pattern serves as a guide for the study, however, it must be borne in mind,

the influence of the factors mentioned above in the flow patterns, implies that the transition of such regimes are well defined and explained as seen in the pattern maps.

In this way, it was possible to find the mass flow values for the four valve opening conditions. Table 1 shows the resulting values for the various methods used to measure the mass flow of single phase flow.

Table 1. Parameters used and the result of the mass flow calculation for the four valve opening conditions.

β	C	ϵ	d	ΔP	ρ	Real Flow	Mass Flow	Mass Flor:Vertedor
0,474	0,6073	1	0,01204	100197,984	998,04	1,078	1,0026	1,0146
0,474	0,6073	1	0,01204	81221,630	998,04	0,907	0,9027	0,8816
0,474	0,6073	1	0,01204	70052,150	998,04	0,783	0,8383	0,7385
0,474	0,6073	1	0,01204	28254,701	998,04	0,677	0,5324	-

⁽¹⁾ measured at 25°C and using the international system of units.

In the quantification for the biphasic flow the void fraction was obtained from the calculation of the title,

$$x = \frac{m_g}{m_g + m_l} = 8,1824 \times 10^{-4}$$

and use of the graph presented by OLIVEIRA (2007) where it correlates the experimental values of the title and the values that would be obtained for the fraction in void, we find a mean value of fraction of void, $\alpha=0,2$, close to the one provided by Oliveira (2007) for the empty fraction. The table 2 shows the results found using the correlation of Zhang *et al* (1992).

Table 2. Shows the results obtained according to the correlation of Zhang *et al* (1992), for the calculation of mass flow rates for specific low masses.

	$\dot{m}_{Bi,Zhang}$	Kl	Ybi	Cbi	ρ_l	ΔP_{Bi}	A2	β
100%	0,829156653	0,955	1	0,6073	998,004	94934,85	0,00011376	0,474
75%	0,765981348	0,955	1	0,6073	998,004	80817,98	0,00011376	0,474
50%	0,666471973	0,955	1	0,6073	998,004	61885,14	0,00011376	0,474
25%	0,551845054	0,955	1	0,6073	998,004	40018,47	0,00011376	0,474

⁽¹⁾ measured at 25°C

Thus, we can observe a reduction in relation to the mass flow for the single-phase flow of the biphasic mass flow, which was already expected, because, due to the introduction of a second mass in the pipeline, both the loss of load increases and the specific mass decreases, which implies that, for a given amount of fluid volume, less mass passes in the unit of time.

4. SUGGESTIONS FOR FUTURE WORKS

For future work, the following proposals are considered:

- Comparison of the performance of the vacuum fraction measurement system with the use of sensors such as impedance or other techniques, such as, for example, ultrasound;
- Measurement of flow rates in two-phase flows from the system consisting of everything from Venturi or the orifice plate associated with the vacuum fraction sensor with electric field for jobs with high titers;
- Use of biphasic flow meters through the application of the cross correlation principle for two impedance void fraction sensors with rotating electric field.

5. ACKNOWLEDGEMENTS

I would like to thank the Coordination of Improvement of Higher Education Personnel (CAPES) and the Federal University of Rio Grande do Norte for all support.

6. REFERENCES

- Associação Brasileira de Normas Técnicas NBR - 13225. Medição de vazão de fluidos em condutos forçados, utilizando placas de orifícios e bocais em configurações especiais (com furos de dreno, em tubulações com diâmetros inferiores a 50 mm, como dispositivos de entrada e saída e outras configurações). Rio de Janeiro, 1994.
- Associação Brasileira de Normas Técnicas NBR - 5167. Medição de vazão de fluidos por meio de instrumentos de pressão – Parte: Placas de orifício, bocais e tubos de ventura instalados em seção transversal circular de condutos forçados. Rio de Janeiro, 1994.
- DELMÉE, G.J. Manual de Medição de Vazão. 3. ed. São Paulo: Editora Edgard Blucher LTDA, 2003.
- DUARTE, M. Influência da Viscosidade sobre o Escoamento gás-líquido horizontal intermitente. Dissertação (Mestre em Engenharia Mecânica). UNICAMP. São Paulo-SP, 2007.
- OLIVEIRA, J.L.G. Medição de Vazão de Escoamentos Bifásicos Utilizando Tubo de Venturi ou Placa de Orifício Associados a um Sensor de Fração de Vazio com Campo Elétrico Girante. 2007. 115 f. Dissertação (Mestrado em Engenharia Mecânica). Universidade Federal de Santa Catarina. 2007.
- PALADINO, E.E. Estudo do Escoamento Multifásico em Medidores de Vazão do Tipo Pressão Diferencial. 2005. 263 f. Tese (Doutorado em Engenharia Mecânica) – Universidade Federal de Santa Catarina. 2005.
- SELLI, M.F. Identificação de Padrões de Escoamento Horizontal Bifásico Gás – Líquido Através de Distribuição Tempo – Frequência e Redes Neurais.2007. 99 f. Tese (Doutorado em Engenharia Mecânica) – Escola de Engenharia de São Carlos da Universidade de São Paulo. Universidade de São Paulo. 2007.
- Zhang, H. J., Lu, S. J. e Yu, G. Z. An investigation of two-phase flow measurement with orifices for low-quality mixtures. International Journal of Multiphase Flow, v.18 (1), p.149-155. 1992.

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