TECHNICAL REPORT

Void Fraction and Pressure Drop in Liquid Metal Two-Phase Flow

Akimi SERIZAWA* and Itaru MIZUKOSHI

Department of Nuclear Engineering, Kyoto University

Received May 13, 1972

This paper describes a new correlation for predicting a two-phase frictional pressure drop multiplier, and discusses the pressure level effects and the mass velocity effects. This correlation predicts satisfactorily the frictional pressure drop not only for liquid metals but also for ordinary fluid two-phase flow in a wide range of flow variables.

The authors' void fraction correlation previously proposed is also compared with published data of void fraction for liquid metal two-phase flow, and is found to represent well the mass velocity effects. Wettability and magnetohydrodynamic effects are discussed briefly in relation to the hydrodynamic characteristics of liquid metal two-phase flow.

KEYWORDS: two phase flow, liquid metals, void fraction, pressure drop, mass velocity effect, pressure levels, effects flow pattern, magnetohydrodynamic effect, wettability effect, property index, accuracy

I. INTRODUCTION

A number of experimental studies have been undertaken in recent years with the view to clarifying the hydrodynamic characteristics—such as void fraction and two-phase friction multiplier—of steady-state liquid metal two-phase flow. But some of them, and in particular the earlier works—contain uncertainties attributable to their methods of measurement during high-temperature operation. Of the many correlations available for predicting the void fraction and the two-phase friction multipliers in liquid metal two-phase flow (e.g. of sodium, potassium and sodium-potassium), the Baroczy correlations for void fraction(1) and for pressure drop(2) appear to be the most valid, but even this method of data arrangement results in comparatively large discrepancies with measured data, in particular, with respect to the “mass velocity effect”, between his correlations and experimental data.

In the present report, we will survey the numerous available experimental data and derive new correlations applicable to the prediction of the void fraction, and two-phase friction multipliers to represent liquid metal and ordinary non-metallic two-phase flow. These correlations will include both the “mass velocity effect” and the “effect of fluid properties”. Furthermore, the magnetohydrodynamic and wettability effects on the void fraction of liquid metal flow will also be discussed briefly.

II. VOID FRACTION

Baroczy’s correlation(1), applicable to the liquid metal two-phase void fraction, has often been used for comparisons with experimental data, and similarly the Lockhart-Martinelli correlation(3). But these correlations, as mentioned already, does not always agree well with measured data. And this may be attributed to the fact that the mass velocity effect is not taken into account, whose existence has been indicated by detailed surveys of experimental data. The need is strongly felt for a more realistic correlation of void fraction...
applicable to the various conditions of two-phase flow.

Figure 1 shows a comparison between recent data on the sodium void fraction and the correlations by Lockhart-Martinelli and Baroczy, in which the liquid fraction \( R_l = 1 - \alpha \) is plotted against the Martinelli modulus \( X_{tt} \). Figure 2 similarly represents recent data on the potassium void fraction. If the mass velocity effect is ignored, both the Lockhart-Martinelli and Baroczy correlations agree comparatively well with the recent data, but poorly with the earlier ones, as reported by Baroczy\(^4\). And these data on liquid metal void fraction reveal tendencies very similar to those for ordinary fluid two-phase flow. Potassium data would be expected to fall into the same region of \( R_l \) vs. \( X_{tt} \) diagram as air-water two-phase data, since the hydrodynamic fluid properties of potassium are similar to those of water.

Here, using a previously reported void fraction correlation\(^5\) based on our experimental data for steam-water system, we will attempt to clarify mainly the mass velocity effect on the liquid metal two-phase flow characteristics, and we will also discuss briefly a few problems peculiar to the liquid metal.

1. Mass Velocity Effect

It is well established that the void fraction in ordinary non-metallic fluid systems—such as steam water or air-water—is influenced by the superficial liquid velocity \( V_0 \). This means that the void fraction \( \alpha \) increases with the velocity \( V_0 \). But this velocity effect is not very clearly revealed in experimental data of void fraction in such liquid metal two-phase flow systems as sodium and potassium. Baroczy\(^4\) and Aladyev et al.\(^6\)\(^7\) have reported that this effect could not be appreciably observed in their experiments. Actually the Baroczy correlation based on some data on liquid metal two-phase void fraction does not take account of this effect. Is this valid? Reviewing a number of representative experiments in liquid metal two-phase flow systems, we will examine this question, using the present authors' correlations.

\[
\alpha = 1 - \sqrt{\frac{1 - x^b}{1 + Kx}} \tag{1}
\]

\[
K = \varepsilon \left( \frac{\rho_l}{\rho_g} \right)^{\phi_{0.5}} \tag{2}
\]

\[
\varepsilon = \begin{cases} 
1.3 & \text{(for bubble flow)} \\
1.0 & \text{(for slug and annular flow)} 
\end{cases} \tag{3}
\]

where \( x \) is quality.

To compare various reported data for void fraction with Eq. (1), we can obtain the values \([K/(\rho_l/\rho_g)]\) for each data point as shown in Fig. 3, in which \([K/(\rho_l/\rho_g)]\) is plotted against the super-

Fig. 1 Liquid fraction vs. \( X_{tt} \) for sodium

Fig. 2 Liquid fraction vs. \( X_{tt} \) for potassium

Fig. 3 Mass velocity effect on liquid metal void fraction \([K/(\rho_l/\rho_g)] \) vs. \( V_0 \)
facial liquid velocity $V_0$. The solid and dotted lines represent Eq. (2) with $\varepsilon = 1.3$ and 1.4 respectively. This figure implies the existence of the mass velocity effect on void fraction explicitly in the liquid metal two-phase flow systems, with tendency qualitatively common with the case of ordinary non-metallic fluid systems.

Further, assuming Eqs. (1) and (2), we can easily obtain the value $\varepsilon$ for each data point. Figure 4 represents $\varepsilon$ as a function of the property index $[(\mu_l/\mu_p)^{0.2}/(\rho_l/\rho_p)]$ proposed by Baroczy. The data scatter around the value of 1.3 or 1.4. From these facts, it can be concluded that the mass velocity effect on void fraction for any single or two-component fluid can be determined from Eqs. (1) and (2) assuming 1.3 or 1.4 for $\varepsilon$.

Figure 5 shows a comparison of the correlating equations (1) and (2),—letting $\varepsilon = 1.3$—with recent data on void fraction obtained by Aladyev et al. and Baroczy for potassium. The calculated values agree within ±5% with the measured. Thus the authors’ void fraction correlation (Eqs. (1) and (2) with 1.3 for $\varepsilon$) is valid and can express very well the mass velocity effect not only for ordinary fluid flow but also for that of liquid metals, whether single or two-component.

2. Magnetohydrodynamic Effect

The effect of a magnetic field on the single phase flow characteristics of electrically conductive fluids, for instance mercury, has been widely studied, but seldom for two-phase flow systems. The experimental results of Thome for sodium-potassium-nitrogen two-phase flow constitute, at the present time, the only contribution to this interesting phenomenon.

The void fraction averaged over the cross section of the channel generally tends to decrease with increasing magnetic field strength. The local void fraction decreases in the center core region of the channel and increases near the wall, and thus its profile becomes flatter in the presence of a magnetic field. This may be due to the fact that the velocity profile of electrically conductive liquid phase is flattened by the magnetic field, and hence the slip velocity between gas and liquid phases may increase in the center region of the channel and decrease near the wall.

However the magnetohydrodynamic effect on two-phase flow has not yet been sufficiently examined, and it is a phenomenon that is important and interesting not only in the purely academic sense but also for the study of performance characteristics of MHD generators using liquid metal two-phase flow as working fluid.

3. Effect of Wettability

This effect becomes important for liquids that do not wet the wall. Mercury is one of such liquids. While wettability between fluid and the wall plays an important role in boiling heat transfer, present knowledge in the domain of two-phase flow dynamics is still very scanty. Comparison of experimental data on void fraction—obtained by Neal for mercury-nitrogen (non-wetted), Tamao for mercury-argon (non-wetted), and Smissaert for mercury-nitrogen (wetted)—is shown in Fig. 4. The data thus arranged
are suggestive, and appear to hold promising information, but it is premature to compare these data directly between them, since they were obtained with different measuring techniques under different flow conditions*. These data appear to indicate a higher void fraction for non-wetted system than for the wetted. (The two former experiments give void fractions of the same order.)

In addition, Neal and Tamao have reported in their papers the existence of large gas bubbles or slugs rising along the wall, while Smissaert did not observe such slugs. This fact indicates that two-phase flow patterns are, to some extent, sensitive to wettability. Large gas bubbles or slugs may induce counter flow or secondary flow of the liquid, and a correspondingly higher or lower slip velocity of the slugs. This change in slip velocity of the slugs directly leads to change in the average void fraction as mentioned in the previous section. This wettability problem requires to be solved, and further discussion in this domain is called for.

4. Flow Pattern

As generally known, the ordinary fluid two-phase flow presents an average void fraction that is related to the prevailing flow pattern. This should hold true also for liquid metal two-phase flow. Thus, knowledge of the flow pattern or of the flow map is quite essential in order to predict void fraction reliably. Yet almost no accurate and systematic information has so far been obtained on liquid metal two-phase flow. Now, we should naturally expect a different behavior of phases according to whether there is phase change or not, regardless of whether the flow is adiabatic or diabatic. Sodium flow, in which the liquid-to-vapor density ratio $\rho_l/\rho_g$ is much greater than that of steam-water flow, may develop into annular-dispersed flow immediately upon incipience of sodium boiling, since the volumetric change caused by boiling is very large, and hence bubbly and slug flows may possibly never occur, or at most occur under very limited conditions of flow (for example, in highly-subcooled flows). However, in the absence of phase change, for example, in the experiments by Neal on mercury-nitrogen, and Ochiai et al.(13) on sodium-argon, both bubbly and slug flow patterns are reported to have been observed. Further-more, Costa et al.(14) (sodium with heat addition), and Baroczy(8) (potassium without heat addition) have pointed out the possibility of slug flow, judging from the pressure trace and from the fluctuating output signals emitted by thermocouples or by flowmeters.

Visual observation of the flow pattern is difficult for liquid metal two-phase flow at high temperature, and hence we must utilize, in most cases, the fluctuating signals from void detectors, pressure transducers, thermocouples or flowmeters. But such indirect methods sometimes give inaccurate information and thus may lead to a false comprehension of the phenomena. Further developments in the dynamic analysis of fluctuating signals are therefore called for, particularly in their application to very complicated two-phase flow systems.

III. Frictional Pressure Drop

Experimental studies of two-phase frictional pressure drop have also been scanty in the past in respect of liquid metal systems. Many experimental difficulties connected with high-temperature liquid metal handling (in particular, alkali liquid metals) have restricted the availability of experimental data. Of the various correlations possible relative to frictional pressure drop, both the Lockhart-Martinelli(3) and Baroczy(2) correlations are the most utilized. It is to be recalled that the latter correlation in particular was obtained with application to liquid metals held in mind. The shortcomings of the Lockhart-Martinelli correlation for pressure drop are similar to those in the case of liquid fraction correlation; the correlation does not take into account the mass velocity and pressure level effects. On the other hand, the Baroczy correlation incorporates these effects, and it has been intended for appli-

---

*Smissaert utilized the mercury-wetted test section of a stainless steel tube (2" I.D.) plated with a 0.002" nickel coating after treatment by dilute hydrochloric acid. And the void fraction was measured by differential pressure method, backed up by $\gamma$-ray traversing technique.

Neal and Tamao used untreated stainless steel tubes of 1" I.D. and 27 mm I.D. (SUS 27), respectively. In both cases, the resistivity probe method was used.
cation to all fluids at various temperatures by embodying the property index previously described. This correlation provides for a diagrammatical representation of both the two-phase friction multiplier $\phi_{0l}^2$ (which is defined as the ratio of frictional pressure drop gradient between that for two-phase and that for all-liquid flow, and which is obtained as a function of the property index and the quality for a number of fluids with a constant mass velocity of $1 \times 10^6$ lb/hr*ft²) and the mass velocity correction factors for the multipliers obtained above (as a function of the property index and the quality at mass velocities of 0.25, 0.5, 2.0 and $3.0 \times 10^6$ lb/hr*ft²).

Detailed survey of liquid metal two-phase frictional pressure drop data yields differences in the mass velocity effect between Baroczy's correlation and experimental data obtained at values of mass velocity in the range $0.2 \times 10^6$ to $1 \times 10^6$ lb/hr*ft²: the experimental data reveal a trend, at constant quality, for the multiplier $\phi_{0l}^2$ to increase with mass velocity $G_0$.

A generalized correlation proposed here for predicting two-phase frictional pressure drop is derived on the basis of an approximate expression of the Lockhart-Martinelli correlation by using the experimental data of Baroczy (9) and Aladyev et al. (50) for potassium, Muscettola (CISE) (19) and Gaspari et al. (50) for steam-water*, and Inoue (51) and Serizawa et al. (52) for air-water.

1. Approximate Mathematical Expression of Lockhart-Martinelli Correlation

The Lockhart-Martinelli pressure drop correlation agree relatively well with the liquid metal data as cited earlier, but it has the shortcoming of not being expressed in the form of mathematical equations. Thus we will first try to derive its approximate expression.

The value $\phi_i$, which is defined as the square root of the ratio of two-phase to liquid single-phase frictional pressure drop gradient, is tabulated in Ref. (3) for the Lockhart-Martinelli modulus $X_{tt}$, where

$$X_{tt} = \left( \frac{W_1}{W_p} \right)^{0.9} \left( \frac{\rho_i}{\rho_p} \right)^{0.5} \left( \frac{\mu_e}{\mu_l} \right)^{0.1} \left( \frac{\mu_l}{\mu_e} \right)^{0.1}$$

From these tabulated values of $\phi_i$, we have obtained the approximate formula

$$\log \phi_i = -z + Vx^2 + 9.2$$

$$(4)$$

$$z = 2 \log X_{tt} + 0.176 X_{tt} + 0.382.$$

$$\text{(5)}$$

Figure 6 represents a comparison between these equations (solid line), the Lockhart-Martinelli correlation curve (dotted line), and also the approximate equation by Chisholm & Laird (53) (chain line). Equations (4) and (5) agree with the Lockhart-Martinelli curve within a few percent.

2. Derivation of Correlation

The variable $\phi_{0l}^2$ appears more comprehensive and more convenient for practical use than $\phi_i^2$. The relationship between $\phi_{0l}^2$ and $\phi_i^2$ is given as follows, provided that the single-phase friction factor $f$ is known.

Assuming $f = c \cdot Re^{-n'}$, we have

$$\phi_{0l}^2 = \phi_i^2 (1-x)^{2-n'}.$$  

$$(6)$$

When $n' = 0.2$,

$$\phi_{0l}^2 = \phi_i^2 (1-x)^{1.8}.\text{ (7')}$$

And when the quality $x \to 1$ (or $X_{tt} \to 0$), $\phi_i^2 \to + \infty$, and $\phi_{0l}^2 \to + \infty$ (reciprocal of the property index at $n' = 0.2$).

In consideration of these facts and recalling Eqs. (4) and (5), we introduce the following for-

* Muscettola (19) and Gaspari et al. (50) did not measure the void fraction, but they estimated the acceleration and hydrostatic terms, Muscettola with the aid of the momentum exchange model, and Gaspari using the CISE homogeneous flow model. Hence they reported that the two-phase frictional pressure drop could be evaluated with small error from the total pressure drop. Muscettola's data for frictional pressure drop indicate a significant mass velocity effect.
Formula for the two-phase friction multiplier $\phi_{f0}$:

$$\log \phi_{f0} = -\frac{z + \sqrt{z^2 + 0.2}}{4},$$  \hspace{1cm} (8)

$$x = 2 \log X_{it} + \frac{A}{X_{it} + C} + B X_{it} + D. \hspace{1cm} (8')$$

In the above equations, $A$, $B$, $C$ and $D$ are functions of the fluid properties, mass velocity $G_0$, the hydraulic diameter of the channel, etc. Here we determine their values as follows, based upon the experimental data listed in Table 1:

<table>
<thead>
<tr>
<th>Author</th>
<th>System</th>
<th>Flow variables</th>
<th>Method of void fraction measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aladyev et al.(^{(6)})</td>
<td>Potassium (adiabatic)</td>
<td>Vertical upflow((6.25, 6 \text{ mm} \phi))(T=1,028^\circ\sim1,109^\circ\text{K})(G_0=10.5\sim27.5 \text{ g/cm}^2\cdot\text{sec})(x=0.015\sim0.88)</td>
<td>Electrical resistivity</td>
</tr>
<tr>
<td>Baroczy(^{(8)})</td>
<td>Potassium (adiabatic)</td>
<td>Horizontal flow((0.62 \text{ in.} \phi))(T=1,377^\circ\sim1,466^\circ\text{F})(W_0=225\sim940 \text{ lb/hr})(x=0.01\sim0.094)</td>
<td>Orifice</td>
</tr>
<tr>
<td>Muscettola(^{(19)})</td>
<td>Steam-water</td>
<td>Vertical upflow((5.2, 8.2, 10.1 \text{ mm} \phi))(P=55.6, 70, \sim84.3 \text{ kg/cm}^2)(G_0=107\sim401 \text{ g/cm}^2\cdot\text{sec})(x=0.04\sim0.75)</td>
<td>Calculated by momentum exchange model</td>
</tr>
<tr>
<td>Gaspari et al.(^{(20)})</td>
<td>Steam-water</td>
<td>Vertical upflow((15.2 \text{ mm} \phi))(P=51.5, 71.3, 91 \text{ kg/cm}^2)(G_0=50, 75, 100, 125, 150 \text{ g/cm}^2\cdot\text{sec})(x=0.03\sim0.97)</td>
<td>Unmeasured (CISE homogeneous flow model)</td>
</tr>
<tr>
<td>Inoue(^{(21)})</td>
<td>Air-water</td>
<td>Vertical upflow((5, 9, 19, 28.8 \text{ mm} \phi))Annulus((21 \text{ mm O.D., 28.8 mm I.D.}))Rectangular duct((28.5 \times 14.2 \text{ mm}))Atmospheric pressure(V_1=0.19\sim2.68 \text{ m/sec})(x=0.008\sim0.128)</td>
<td>Quick-shut technique (with mechanical ball-valves)</td>
</tr>
<tr>
<td>Serizawa(^{(22)})</td>
<td>Air-water</td>
<td>Vertical upflow(Annulus((10 \text{ mm O.D., 28.5 mm I.D.}))P=1.05\sim1.2 \text{ kg/cm}^2)(V_1=0.8\sim1.5 \text{ m/sec})(x=0.0014\sim0.013)</td>
<td>Quick-shut technique (with electro-magnetic valves)</td>
</tr>
</tbody>
</table>
Function A: As shown in Fig. 7, plotted against the product of Reynolds and Froud numbers ($Re \cdot Fr$).

Function B: This Function is rewritten

$$B = 10^m(Re \cdot Fr)^n.$$ (8')

The exponents $m$ and $n$ are given in Fig. 8.

Function C: As shown in Fig. 9, plotted against $Re \cdot Fr$ with the property index $\xi$ as parameter, where

$$\xi = \left(\frac{\mu_{\text{eff}}}{\mu_{\text{g}}}\right)^{0.2}\left(\rho_{\text{f}} - \rho_{\text{g}}\right)$$ (8'')

Function D: $D = 7.75\xi^{0.536}$

Since the first term on the right-hand side of Eq. (8') becomes dominant for $X_{tt}$ below a certain value, where the function $z$ is negative, $\phi$ quickly increases in this range. In consequence, caution is required for applying Eqs. (8), (8'), (8''), and (8''') to liquid metal two-phase flow systems where the property index is relatively small. The limiting value of $X_{tt}$ for the applicability of these formulas may be estimated to be about 0.01 for potassium, subject to revision since, up to now, we have not yet obtained a sufficiently large number of pertinent experimental data for liquid metals. (This correlation cannot be defined at $x=1$, since $\log X_{tt}$ is not defined at $X_{tt}=0$.)

3. Comparison between Predicted and Experimental Values of Frictional Pressure Drop

Figures 10–15 represent comparisons of the predicted two-phase friction multiplier obtained with the present correlation using various experimental data by Aladyev et al. (6) and Baroczy (8) for potassium, Fauske et al. (24) for sodium, Thome (30) for sodium-potassium-nitrogen* and Serizawa et al. (22) for air-water*, Muscettola (29) for steam-water, Janssen et al. (32) and Moen (26) for steam-water, and Inoue (21) for air-water*, respectively. In each figure, the solid or dotted lines represent the curves predicted for each flow condition by the set of Eqs. (8)–(8''). Generally speaking, these figures show good coincidence between the proposed correlation and experimental data.

For steam-water systems, the correlation seems to predict slightly higher values for the friction multiplier than the experimental data obtained in the range of mass velocity below $0.5 \times 10^6$ lb/hr-ft$^2$ and steam quality beyond 0.6. This tendency concurs with what is indicated directly from a comparison with the data by Janssen et al. (1,000 psia, $G_0=0.5 \times 10^6$ lb/hr-ft$^2$, 0.25–1.75 ft rectangular channel). At higher mass velocities, better agreement is obtained than with the Baroczy

* In these cases, the conversion equation (7') is used.
Fig. 10 Correlative representation of experimental pressure drop data for potassium

Fig. 11 Correlative representation of experimental pressure drop data for sodium

Fig. 12 Correlative representation of experimental pressure drop data for sodium-potassium-nitrogen and air-water

Fig. 13 Correlative representation of experimental pressure drop data for steam-water

Fig. 14 Correlative representation of experimental pressure drop data for steam-water

Fig. 15 Correlative representation of experimental pressure drop data for air-water
correlation.

For liquid metal two-phase flow, overall agreement is satisfactory, and the trend shown by the predictions corresponds with the data. Both the experimental data of Aladyev et al. and of Baroczy for potassium and of Lurie(27) for sodium, which were restricted to a fairly small range of mass velocity, and the predicted values corresponding to these flow conditions reveal a trend for the two-phase friction multiplier $\phi_{10}$ to increase with mass velocity $G_0$. This corresponds to a negative value of the exponent $n$ for liquid metal, as shown in Fig. 8, (positive, on the other hand, for most of ordinary fluids). This trend of mass velocity effect indicates a marked difference in behavior between liquid metal and ordinary fluid flows. Nevertheless, as mentioned later, at higher mass velocities of the order of $10^6$ lb/hr-ft$^2$, this particular tendency gradually diminishes and reverses itself, and higher mass velocity is related to a lower friction multiplier $\phi_{10}$. The behavior thus becomes identical to that of ordinary fluid flow.

4. Pressure Level and Mass Velocity Effects on Liquid Metal Two-phase Flow

In respect of the pressure level and mass velocity effects upon liquid metal two-phase frictional pressure drop, accurate information is hardly available. Baroczy’s correlation appears the most valid, and it takes both effects into consideration by means of the property index and mass velocity correction factor, as described in detail earlier in this paper. But it cannot offer sufficient information for practical purposes. For this reason the two effects, as predicted by the present correlation, will be discussed briefly.

1. Pressure Level Effect

The effects of differences in temperature or pressure appear directly on the fluid properties such as the densities and viscosities of the two phases. One of the most possibly accurate and easily explainable parameters affecting the hydraulics of two-phase flow is the property index $\xi = (\mu/\mu_0)^{0.2}((\rho_1/\rho_0))$ proposed by Baroczy in Ref. (1).

The friction multipliers predicted by the present and Baroczy correlations at a mass velocity of $1 \times 10^6$ lb/hr-sqft and at temperatures of 1,200°, 1,300°, 1,400°, 1,600°, 1,700°F are represented for potassium in Fig. 16, and for sodium in Fig. 17. As a whole, the present correlation has a tendency to predict higher values of the friction multiplier compared with Baroczy’s. In the former case, the friction multiplier decreases consistently with increasing system temperature.
in a wide quality or \( X_{tt} \) range, while in the latter case, the predicted curves cross each other in the range of \( X_{tt} \) from 0.03 to 0.2.

(2) Mass Velocity Effect

This effect may be reduced to that based on the two-phase flow pattern. Careful examination of experimental data by Muscettola for steam-water at 70 kg/cm\(^2\) and Inoue for air-water under atmospheric pressure reveals no significant systematic effect of channel diameter or hydraulic-equivalent diameter upon the frictional pressure drop. This suggests that the proposed correlation should embody the mass velocity effect in the functions A, B and C as expressed by the parameter \( Re \cdot Fr \), and this product of the Reynolds and Froude numbers is proportional to \( G_0 \). Baroczy also takes this effect into consideration explicitly through incorporation of the mass velocity \( G_0 \).

The mass velocity effect predicted by the present correlation at a system temperature of 1,500°F and mass velocities of 0.25, 0.5, 1.0, 2.0, and \( 3.0 \times 10^6 \) lb/hr·ft\(^2\) is shown for potassium in Fig. 18, and for sodium in Fig. 19. In both figures, the predicted curves intersect each other in a complicated manner. These figures indicate the following two types of mass velocity effect according to the region of \( G_0 \) and \( X_{tt} \).

For \( 0.01 \leq X_{tt} \leq 0.5 \)

\[
G_0 \geq 0.5 \times 10^6 \text{ lb/hr·ft}^2
\]

The two-phase friction multiplier \( \phi_{tt}^2 \) increases with the mass velocity \( G_0 \). \( G_0 \geq 0.5 \times 10^6 \text{ lb/hr·ft}^2 \)

The two-phase friction multiplier \( \phi_{tt}^2 \) decreases with increasing mass velocity \( G_0 \).

This predicted trend is attributed to the negative value of the exponent \( n \) in the function B, and to the minimum values of function A and C at \( Re \cdot Fr = 2.5 \times 10^8 \) and \( 1 \times 10^8 \) respectively. Actually the bulk of the data exhibits the same trend.

For \( X_{tt} \geq 0.5 \), the prediction gives a large multiplier \( \phi_{tt}^2 \) for higher mass velocity, since the third term on the right-hand side of Eq. (8') overcomes the second term in this range of quality.

IV. CONCLUSIONS

(1) Detailed survey of recent data on liquid metal two-phase void fraction reveals a mass velocity effect similar to that observed in ordinary fluid two-phase flow: At constant quality, the experimental results already published represent a larger void fraction at higher mass velocity.

(2) Other effects peculiar to liquid metal two-phase flow, such as wettability and magnetohydrodynamic effects, must be studied further.
(3) The present semi-empirical correlation, Eqs. (1) and (2) with \( \varepsilon = 1.3 \), is applicable to calculations of the void fraction in liquid metal two-phase flow in a wide range of flow variables, as well as in ordinary fluid flow.

(4) Of various two-phase frictional pressure drop correlations, those of Lockhart-Martinelli and Baroczy give fairly good agreement with the experimental data, but they cannot always predict the mass velocity effect applicable to practical cases.

(5) Available data on liquid metal two-phase frictional pressure drop show a trend, in the range covered of the variables, for the friction multiplier to increase with the mass velocity. This trend is opposite to that seen in ordinary fluid systems.

(6) The present correlation, Eqs. (8), (8'), (8''), and (8'''), is proposed for prediction of liquid metal two-phase frictional pressure drop, which takes account of the pressure level effect and the mass velocity effect by means of the property index and the factor \( Re \cdot Fr \). This correlation has results in good agreement with a wide variety of data obtained for sodium, potassium, sodium-potassium-nitrogen, steam-water and air-water systems. Figures 16-19 represent the friction multiplier \( \phi_{108} \) predicted by the present correlation.

(7) Equations (4) and (5) are approximate expressions for the Lockhart-Martinelli pressure drop correlation.

--- References ---

(2) idem.: ibid., 62(64), 232 (1966).
(16) Balzhiser, R.E., et al.: AFAPL-TR-85, (1967), (Quoted from Ref. (4)).
(25) Janssen, E., Kervinen, T.A.: GEAP-416, (1964), (Quoted from Ref. (2)).