Int. J. Heat Mass Transfer. Vol. 10, pp. 277–288. Pergamon Press Ltd. 1967. Printed in Great Britain

THE APPLICATION OF THE CAPACITANCE METHOD FOR VOID FRACTION MEASUREMENT IN BULK BOILING CONDITIONS*

L. CIMORELLI and R. EVANGELISTI
Centro Studi Nucleari della Casaccia

(*Received* 23 *May* 1966 *and in revised form* 13 *July* 1966)

Abstract—In this article the application of the impedance method, developed as capacitive, to the study of bulk boiling at atmospheric pressure, is described. Corresponding to two values of mass flowrate, the calibration curves void fraction vs. relative capacitance are deduced, up to void fractions of about 85–90 per cent: as a void fraction standard value the response of the dilatometric method is chosen. Finally the differences between the experimental calibration curves and the Maxwell law are calculated and plotted.

NOMENCLATURE

C, two-phase mixture capacitance;
C_p, parasitic capacitance;
C_0, capacitance for all liquid;
c_p, specific heat of liquid;
h_{fg}, heat vaporization;
G, mass flow rate;
$l_v(l_0)$, level of the water in the expansion reservoir, with (without) voids in the test section;
L_c, condensing length of the condenser;
K, electrical conductivity;
R, electrical resistance;
S_e, cross-sectional area of the expansion reservoir;
S_c, cross-sectional area of the condenser;
T, temperature;
T_a, temperature at the inlet of pump;
T_e, temperature of the liquid in the expansion reservoir;
T_{TS}, mixture average temperature in the test section;
x, thermodynamic mass quality of two-phase mixture;
x_{in}, thermodynamic mass quality at the inlet of test section;
i.d., inner diameter;
o.d., outer diameter;
V_{TS}, volume of the test section;
V_c, volume of voids in the condenser;
V_m, measured volume of voids.

Greek symbols
α, gas volume fraction or void fraction;
ε, dielectrical constant;
ω, angular frequency;
ρ, density.

Subscripts
av, average;
c, capacitive;
m, mixture;
w, water;
v, vapour;
d, dilatation;
s, standard;
M, Maxwell;
e, expansion reservoir;
TS, test section.

INTRODUCTION

THE PROBLEM of predicting void volumes for the

* This work was performed in accordance with the provisions of 024-64-4 TEAI contract, sponsored by CNEN-Euratom Joint Research and Development Board.

flow of steam–water mixtures in vertical channels is very important for the designer of boiling nuclear reactors.

A knowledge of the void volume is needed for the determination of mean fluid density and acceleration, for the establishment of two-phase flow frictional pressure drop correlations, and for the computation of reactivity in water-cooled reactors.

Most of the voids measuring techniques which are based on the effects of nuclear reactions such as gamma attenuation [1–4] X-ray attenuation [5], beta attenuation [6], neutron diffusion or finally the (γ, n) reaction [7] are not applicable inside the reactor cores where intensive fields of all these nuclear radiations predominate.

Among the non-nuclear methods of voids measurement one of the most important is the impedance method [8, 9], which is based on the difference between liquid and vapour electrical conductivity and dielectric constant. This measuring method has been recently applied to determine the void fraction in subcooled boiling [10]. It is known that reliable measurements of the dynamic properties of the void fraction play an important role in the experimental determination of the boiling system stability and heat-transfer properties: the impedance technique for void fraction measurement is particularly suitable for local and dynamic measurements (statistical power spectral analyses, correlation analyses, transfer functions, etc.). However, the impedance method requires the knowledge of the effect of voids distribution on the relative admittance (admittance of the section with two-phase mixture referred to the admittance for all liquid at the temperature of the two-phase mixture supposed isothermal). Up to date it has been supposed that such an effect can be represented, depending upon the flow pattern, by the Maxwell law or by the slug flow law.

To check the validity of these assumptions and therefore the accuracy of the information obtained in bulk boiling conditions by such a measurement method, an experiment was planned with the aim of obtaining directly the calibration curve of the void fraction as a function of the relative admittance, measuring the void fraction by a dilatation technique and the admittance by an impedance method, developed as capacitive.

This paper presents the results obtained for mass flow rates 63 g/s and 78 g/s for inlet qualities ranging from 0 to 3·7 per cent, and for average value of void fraction in the test section ranging from 0 to 0·88.

1. IMPEDANCE METHOD AND RELATED PROBLEMS

This void fraction measurement technique is based upon the principle that the admittance between two electrodes immersed in a two-phase fluid changes when liquid is replaced by vapour: this change is caused by the difference between K_v and ε_v, K_w and ε_w.

When measuring with a.c. voltage and high frequencies, the disturbing effects of electrolysis and polarization are avoided and the admittance between the electrodes can be represented by the vector sum of two components, a conductance $(1/R)$ and a susceptance (ωC).

The dielectric constant of the liquid water is a well defined parameter [10] which is predominantly a function only of temperature, while the conductivity K_w is, among other things, dependent on the kind and concentration of ions present: on the contrary K_v and ε_v can be considered constant. To obtain a satisfactory degree of reproducibility of a conductivity measurement it would be necessary to control continuously the ions concentration in the fluid. Therefore it is obviously more easy and convenient to perform the void measurements by evaluating the variation of susceptance of the mixture rather than the conductance.

In the admittance measurement the conductance term $1/R$ can be neglected compared to the susceptance ωC when the following condition is satisfied

$$\left(\frac{\omega\varepsilon}{K}\right)^2 \gg 1 \tag{1}$$

whether for liquid or vapour phase. This aim is reached by using high frequencies for the a.c. measuring voltage, distilled water and construction materials for the loop, which show very little corrosion effects in water. When condition (1) is not satisfied, because of the geometry of the electrodes, it is still possible to employ the method as capacitive, provided that the parallel resistance is measured and taken into account during the calibration of the electronic C-meter circuit (Section 2b).

The major difficulty which limits the possibility of employing the capacitance method is represented by the parasitic capacitances due to connection cables, where these cannot be avoided or made small in comparison with the mixture capacitance. When performing the experiments with boiling channels of small loops, such a problem vanishes. The only source of uncertainty is in the evaluation of the void distribution effects on the relation between void fraction α and the relative capacitance C/C_0. Depending on the flow pattern and size of bubbles, the total dielectric constant of a two-phase mixture in forced convection boiling can be calculated as a function of the dielectric constants of the two media essentially by means of theoretical relations. One of these is the slug-flow law according to which the two slugs of vapour and water from an electrical viewpoint are in parallel between the electrodes. Therefore we have:

$$\alpha = \frac{1 - C/C_0}{1 - \varepsilon_v/\varepsilon_w}. \qquad (2)$$

Another possible method of relating α to the relative capacitance C/C_0 is the Maxwell law, which is derived, for small size bubbles dispersed in water matrix, from the approximate formula [11]

$$\frac{\varepsilon_m - \varepsilon_w}{\varepsilon_m + 2\varepsilon_w} = \alpha \frac{\varepsilon_v - \varepsilon_w}{\varepsilon_v + 2\varepsilon_w}. \qquad (3)$$

This formula only holds true if the particles of the body v in the matrix w are separated by distances large in comparison with their linear dimensions, and can therefore only be applied to small void fractions. Also in the case of annular flow regime it is possible to derive a function $\alpha = \alpha(C/C_0)$, by considering the liquid and vapour phases as capacitances in series. When the flow pattern corresponds to spray-flow regime, i.e. small liquid masses dispersed in a vapour matrix, another function $\alpha = \alpha(C/C_0)$ can be obtained by deriving the dielectric constant of the mixture ε_m by means of the Maxwell formula, applied for water droplets dispersed in a steam matrix.

$$\frac{\varepsilon_m - \varepsilon_v}{\varepsilon_m + 2\varepsilon_v} = (1 - \alpha) \frac{\varepsilon_w - \varepsilon_v}{\varepsilon_w + 2\varepsilon_v}. \qquad (4)$$

In Fig. 1 the curves $\alpha = \alpha(C/C_0)$ at $T_{sat} = 102°C$, corresponding to several void distributions, are plotted. This diagram indicates the great influence of the assumed flow pattern on the theoretical response of the capacitative method. The sensitivity $\partial(C/C_0)/\partial\alpha$ varies very much corresponding to the flow pattern considered. Calculations performed by us have shown that such a parameter on the contrary is practically unaffected by variations of temperature from 100 to 300°C.

The reliability of every mathematical approach to this problem is, in our opinion, very low; besides there is a lack of experimental data, in forced convection bulk boiling, regarding the trend of the function $\alpha = \alpha(C/C_0)$. The only data available [9] show that the discrepancies between the experimental results and the Maxwell law, applied for vapour particles dispersed in water, are lower than ± 2 per cent, for α ranging from 0·0 to 0·40. For this reason, we considered it interesting to set up an experiment to obtain a more reliable calibration curve $\alpha = \alpha(C/C_0)$, in a wider α-range. This aim has been achieved by comparing, in a defined steam qualities range, the values of α, measured with the capacitive method, with the void fraction measurements obtained with a high accuracy method, the dilatometric one, chosen as a standard.

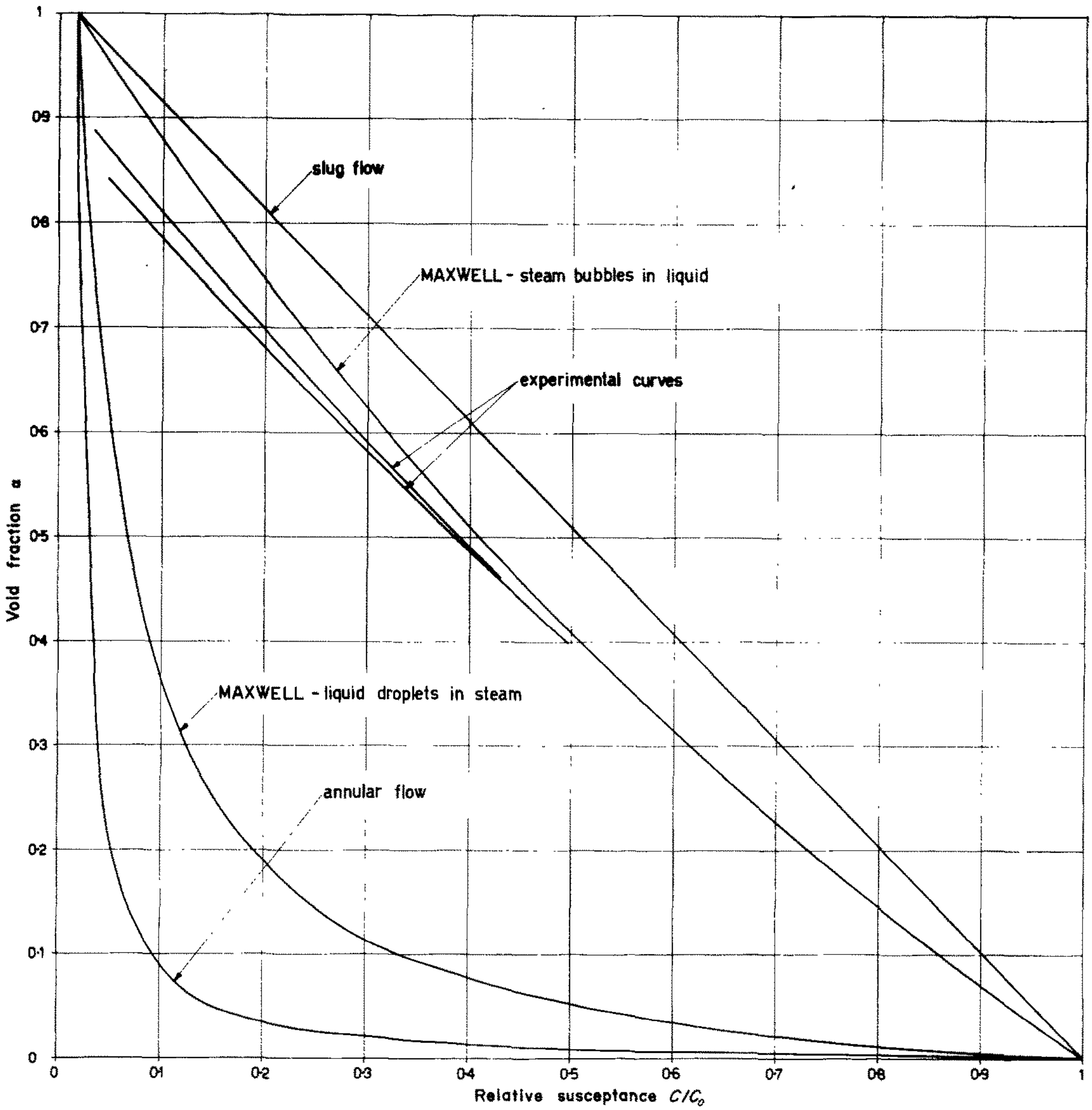

FIG. 1. Theoretical curves of α vs. relative susceptance (at $T_{sat} = 102°C$).

2. EXPERIMENTAL APPARATUS

(a) *Flow system and instrumentation*

For the experiment a small loop (CFP-5), built at C.S.N. Casaccia for the development of experimental techniques in the field of boiling heat transfer [12], was used. This loop is a closed circulating system comprising a pump, a turbo flow meter, a single-tube preheater (supplied by a 15-kW power controlled rectifier), a test section of annular cross-section (i.d. 18 mm, o.d. 30 mm) 1485-mm long, a compact condenser, a cooler and an expansion reservoir with a calibrated cylindrical burette. The loop is shown schematically in Fig. 2. For the condenser it was considered essential that the voids contained in it were less than 1–2 per cent of the

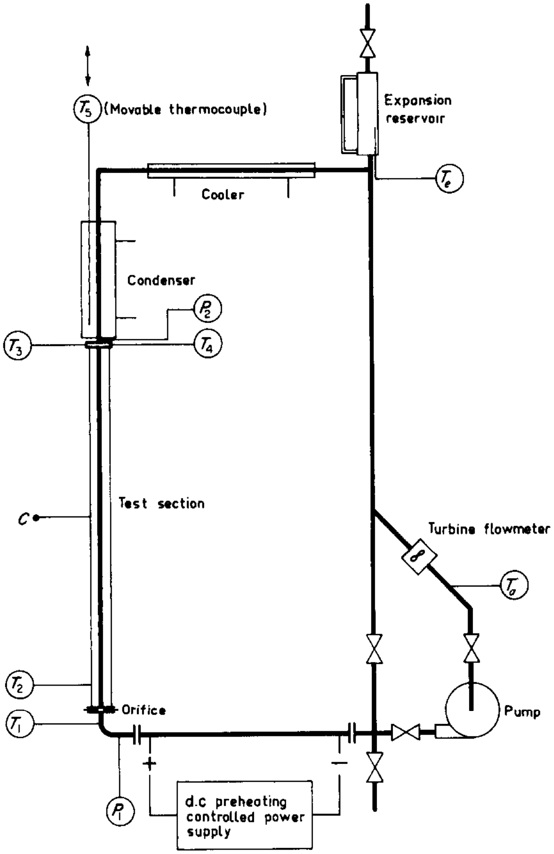

FIG. 2. Loop flow diagram.

voids in the test section. This was achieved by designing a thin annular condenser of very high effectiveness. Besides, design of the condenser was arranged to give the maximum temperature difference in the condensing space and therefore minimize the condensing length. A variable position $Cr - Al$ thermocouple probe (T_5) mounted inside the condenser gives the temperature profile and thereby the condensing length L_c. Between the preheater and the test section is placed an orifice which causes a drop in the delivery head of the pump of 2 kg/cmq, so that boiling by flashing is produced at the inlet of the test section. The inlet steam quality is evaluated by means of two thermocouples located before and after the orifice (T_1 and T_2): they indicate a temperature drop $\Delta t = T_1 - T_2$ which is related to the test section inlet quality by the equation:

$$x_{in} = \frac{c_p}{h_{fg}} \Delta t. \tag{5}$$

The thermocouple T_1 gives the reference voltage to a three actions control unit. Thermocouples T_3 and T_4 indicate the upper mixing chamber temperature: under adiabatic conditions (no heat flux to the text section). T_1, T_2, T_3 and T_4 may be used to obtain the average value of steam quality in the test section. The temperature of water in the expansion reservoir is indicated by the thermocouple T_e. The pump inlet temperature is measured by the thermocouple T_a, located after the flowmeter: the latter indicates the volumetric flow rate in the loop. A concentric pipe countercurrent heat exchanger reduces the temperature indicated by T_a to below 70–75°C. The power control system is one of the most important components of the experimental system. The response of the thermocouple T_1 gives the input to a three actions control unit which drives, by means of an operational amplifier chain, the preheating power so that T_1 is automatically controlled. Such a system enables one to perform both measurements, with dilatation technique and capacitance method, with constant inlet quality during a reasonable time period (in net boiling conditions $\Delta(\Delta t) = \pm 0{\cdot}1$ degC). In this way it is possible to employ in the C-meter suitable time constants to obtain a good read-out of the oscillating void fraction. Furthermore a high efficiency of this control minimizes the level oscillations of the liquid in the graduated burette of the expansion reservoir so that the accuracy of the void fraction dilatometric standard increases.

The dimensions of the test section were chosen taking into account the requirements of dilation technique and capacitance method to minimize the error: a maximum value of the volume for the one and a maximum value of the capacitance for the other. The calibration of the volume of test section has given

$$V_{TS} = 666 \pm 1 \text{ cm}^3$$

while for the expansion reservoir the number of cm^3 per division was 2·24 cm^3/mm.

(b) *Capacitance meter*

The capacitance method was applied to the CFP-5 circuit firstly for the measurement of subcooled voids [10]. In this work the capacitance between the electrodes, in the range 100–500 pF, was measured employing a high frequency (1 MHz) resonant circuit, in order to have a small conductance component $1/R$ with respect to the susceptance component ωC. In the present experiment the capacitance constituted by the two cylindrical tubes of the annular test section is in the range 500–11 000 pF, depending on the flow regimes. With these capacitance values it was very difficult designing a circuit, based on the resonance method and working at frequencies higher than 200 kHz: the elimination of the resistive term of the measured impedance was therefore necessary. The measurement of the capacitive parameter is then performed in two steps: firstly, at a frequency of about 200 Hz, the resistance between electrodes is measured by a comparison method, as schematically shown in the lower part of Fig. 3; secondly, the resistance measured with the potentiometer P (in the dotted lines) is placed in parallel with known, calibrated capacitances. These make it possible to calibrate the capacitance meter in the real measurement conditions: the resulting working frequency of the capacitance meter was 180 kHz. For each experimental point a calibration curve was necessary: a fitting calculation between calibration points was then performed by a 1620 IBM digital computer. By such a calculation it was possible to obtain the capacitance value corresponding to the considered experimental point. The overall accuracy of the employed capacitance measurement method was evaluated as $\pm 2{\cdot}5$ per cent.

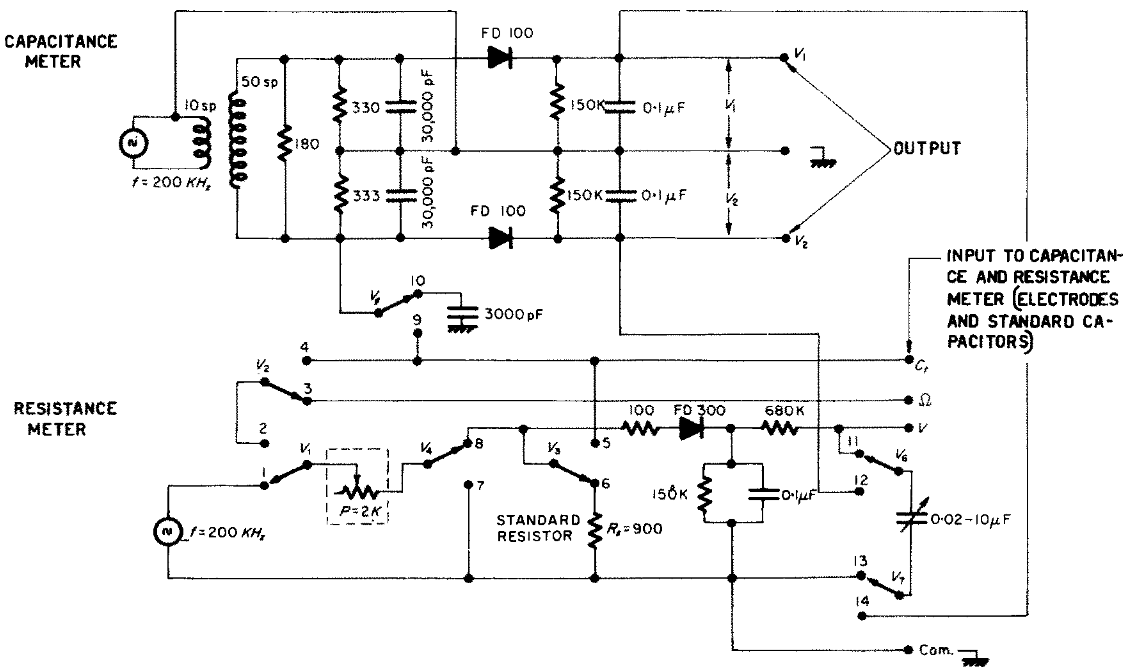

FIG. 3. Capacitance meter circuit.

3. CONSIDERATIONS ON THE EXPERIMENT AND RESULTS

The dilatation technique is based on the difference between the specific volumes of the water and the vapour. The accuracy of this method can be improved to better than ± 3–4 per cent [13–16]: therefore α_d has been chosen as a void fraction standard.

In principle this measuring system is very simple. A reference state is obtained with the loop completely filled with liquid. Liquid, which is displaced from the system when void is formed, is measured and this quantity of liquid is related to the void in the test section by determination of the water level in the graduated burette of the expansion reservoir. Obviously to derive from the experimental data the average value of the void fraction α in the test section the void fraction in the condenser cannot be neglected. Furthermore it is necessary to take into account the temperature difference between the reference (burette) and test states (test section). This quantity can be very important for the evaluation of the amount of liquid displaced, because of the variation of water density with temperature.

Assuming a linear trend of the voids in the condenser along the condensing length, the test section average α standard can be calculated by the formula

$$\alpha_d - \alpha_s = \frac{(l_v - l_0) \, . \, S_e}{V_{TS} + \frac{1}{2} S_c L_c} \cdot \frac{\rho_e}{\rho_{TS}} = \frac{V_m}{V_{TS} + V_c} \cdot \frac{\rho_e}{\rho_{TS}} \quad (6)$$

where the condensing length L_c is experimentally obtained from the temperature profile along the axis of the condenser. The justification of this relatively crude calculation is the small magnitude of the term V_c (in our experiment the highest value of V_c was lower than $0{\cdot}02 \, . \, V_{TS}$). For the cooler, preheater and the isothermal section between these components, in our loop the contributions to the mass balance equation, from which (6) is obtained, were very small and were therefore neglected in the data reduction.

The electrodes of the capacitative probe are the same two stainless-steel tubes which are the components of the annular test section and therefore the electrode configuration is cylindrical.

To minimize the parasitic capacitances due to other metallic masses present in the loop and to improve the electrical insulation, the test section has been connected to the loop by two thick flanges of lucite. Measuring with a bridge the capacitance of the test section in this condition without water in the loop, the correction due to the parasitic capacitance has been evaluated as $C_p = 32 \pm 2$ pF; the capacitance due to the connection leads, which are very short, can be neglected. This quantity can be considered constant in the course of the experiment. The aim of the capacitive method is essentially the achievement of the fundamental parameter C/C_0, where C represents the capacitance of steam–water mixture and C_0 the capacitance for all liquid, but at the same temperature of the mixture. Adopting such a configuration for the capacitive probe, the capacitance C is obviously related to the integrated void volume fraction in the whole test section. It is well known that C_0 can be expressed by

$$C_0(T) = g \, . \, \varepsilon(T) \quad (7)$$

where g is a quantity which depends only on the geometry of the capacitive probe. To avoid the uncertainty due to the evaluation of g, we have measured the capacitance of the test section filled with liquid water corresponding to several temperature levels $T_1, T_2 \ldots T_n$ in the range 65–85°C. Considering that the trend of the liquid water dielectric constant as a function of temperature is already experimentally well defined [10], we have obtained several values of g corresponding to the temperatures $T_1, T_2 \ldots T_n$. Since these values show a low scatter about the average value g_{av}, we have based calculations of C_0 on g_{av}. In this way to achieve the relative susceptance C/C_0, when the mixture is at the average temperature T_{TS}, we put

$$C_0(T_{TS}) = g_{av} \, . \, \varepsilon(T_{TS}). \quad (8)$$

The measurement of C_0 at several temperature levels was performed before beginning the experiment with two–phase flow.

The experimental measurements have been carried out on the small loop CFP-5 under the following conditions: forced convection; automatic regulation of T_1 by a three actions control unit; precision measurement with thermocouples of test section inlet and outlet temperatures; measurement of flow rate by a turbine meter; measurement of the absolute pressure before the orifice and at the outlet of test section. The experiments have been carried out at 1·15 kg/cm^2 pressure, for two values of flow rate and different value of quality, ranging from 0 to 3·7 per cent to preclude subcooled boiling in the preheater: about three hundred experimental points have been obtained.

The estimates of the errors involved in the measurements with the dilatation technique result in the following uncertainties:

$$\Delta x_{in} = \pm 0{\cdot}05 \text{ per cent}$$

$\Delta V_m / V_m = \pm\ 1{\cdot}8 \div 3{\cdot}3$ per cent (increases with α decreasing)

$$\frac{\Delta(V_{TS} + V_c)}{(V_{TS} + V_c)} = \pm 0{\cdot}2 \text{ per cent} \qquad (5)$$

$$\frac{\Delta \rho_e}{\rho_e} = 0{\cdot}1 \text{ per cent}$$

$$\frac{\Delta \rho_{TS}}{\rho_{TS}} = 0{\cdot}1 \text{ per cent.}$$

The total error of standard void fraction is

$$\frac{\Delta \alpha_s}{\alpha_s} = 2{\cdot}2 \div 3{\cdot}7 \text{ per cent.}$$

To evaluate approximately the accuracy of the results obtained with the capacitance method, we shall consider the void fraction to be a linear function of the relative susceptance, according to the slug flow law (2). Therefore

$$\frac{\Delta \alpha_c}{\alpha_c} = \frac{\Delta C}{C} + \frac{\Delta C_0}{C_0}$$

where

$$\frac{\Delta C}{C} = \pm 2{\cdot}5 \text{ per cent}$$

$$\frac{\Delta C_0}{C_0} = \pm \left(2{\cdot}5 \text{ per cent} + \frac{1}{C_0}\frac{\partial C_0}{\partial T}\Delta t\right)$$

$$= \pm\ 3{\cdot}5 \text{ per cent} \quad \frac{\Delta \alpha_c}{\alpha_c} = \pm 6 \text{ per cent.}$$

The mean scatter of the experimental points is in accord with this evaluation, especially at high void fractions. The calibration curves for α vs. relative susceptance C/C_0, experimentally obtained, are shown in Figs. 4 and 5: they enable one to evaluate the approximation degree of the Maxwell equation (3) in bulk boiling conditions. It must be noticed that, while the Maxwell relation is independent of the mass flowrate, our results indicate that, corresponding to high void fractions, the effect of the mass flow rate cannot be neglected. Furthermore the direct calibration of the capacitance method proves that for void fractions up to about 40 per cent the difference between the measured values and the values calculated by the Maxwell equation is less than 2 per cent void, as predicted by Wamsteker [9]. When boiling takes place in a channel at atmospheric pressure it is known [16] that the void fraction rises very rapidly with increasing quality, the initial slope of the quality curve being very high. Taking into account the relation (5), a very little variation of the temperature drop across the orifice, and therefore of the steam quality, causes a noticeable variation of the integrated void volume fraction inside the channel, that is of the standard void fraction. This fact increases the mean scatter of the experimental points in the region of the diagram $\alpha - C/C_0$ corresponding to low quality boiling conditions. The reliability of our results is therefore greater corresponding to the high values of void fraction.

In Figs. 4 and 5 the experimental points can

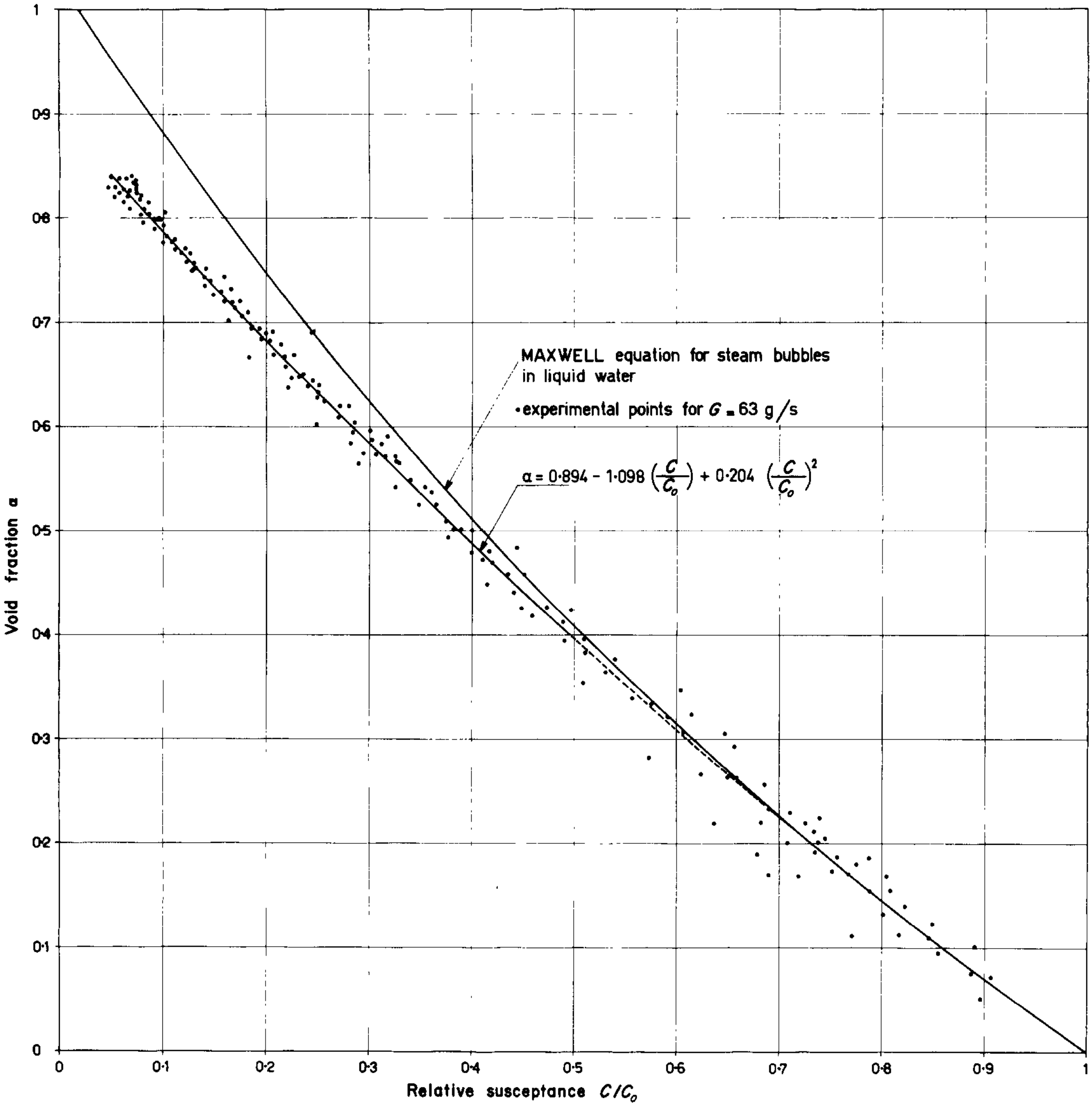

FIG. 4. Bulk boiling void fraction α vs. relative susceptance C/C_0.

be fitted by the equations:

$$\left.\begin{aligned} G_1 = 63\ \text{g/s} \qquad \alpha &= 0{\cdot}894 - 1{\cdot}098(C/C_0) \\ &\quad + 0{\cdot}204(C/C_0)^2 \\ G_2 = 78\ \text{g/s} \qquad \alpha_2 &= 0{\cdot}926 - 1{\cdot}202(C/C_0) \\ &\quad + 0{\cdot}276(C/C_0)^2 \end{aligned}\right\} \quad (9)$$

while the Maxwell equation (3) can be represented in α and C/C_0 coordinates as

$$\alpha_M = 1{\cdot}026 - 1{\cdot}519(C/C_0) + 0{\cdot}643(C/C_0)^2 - 0{\cdot}150(C/C_0)^3. \quad (10)$$

In Fig. 6 are plotted the differences $(\alpha_M - \alpha_1)$ and $(\alpha_M - \alpha_2)$ vs. α_M: these curves show the error which would affect the α measurement by the capacitance method in an annular duct

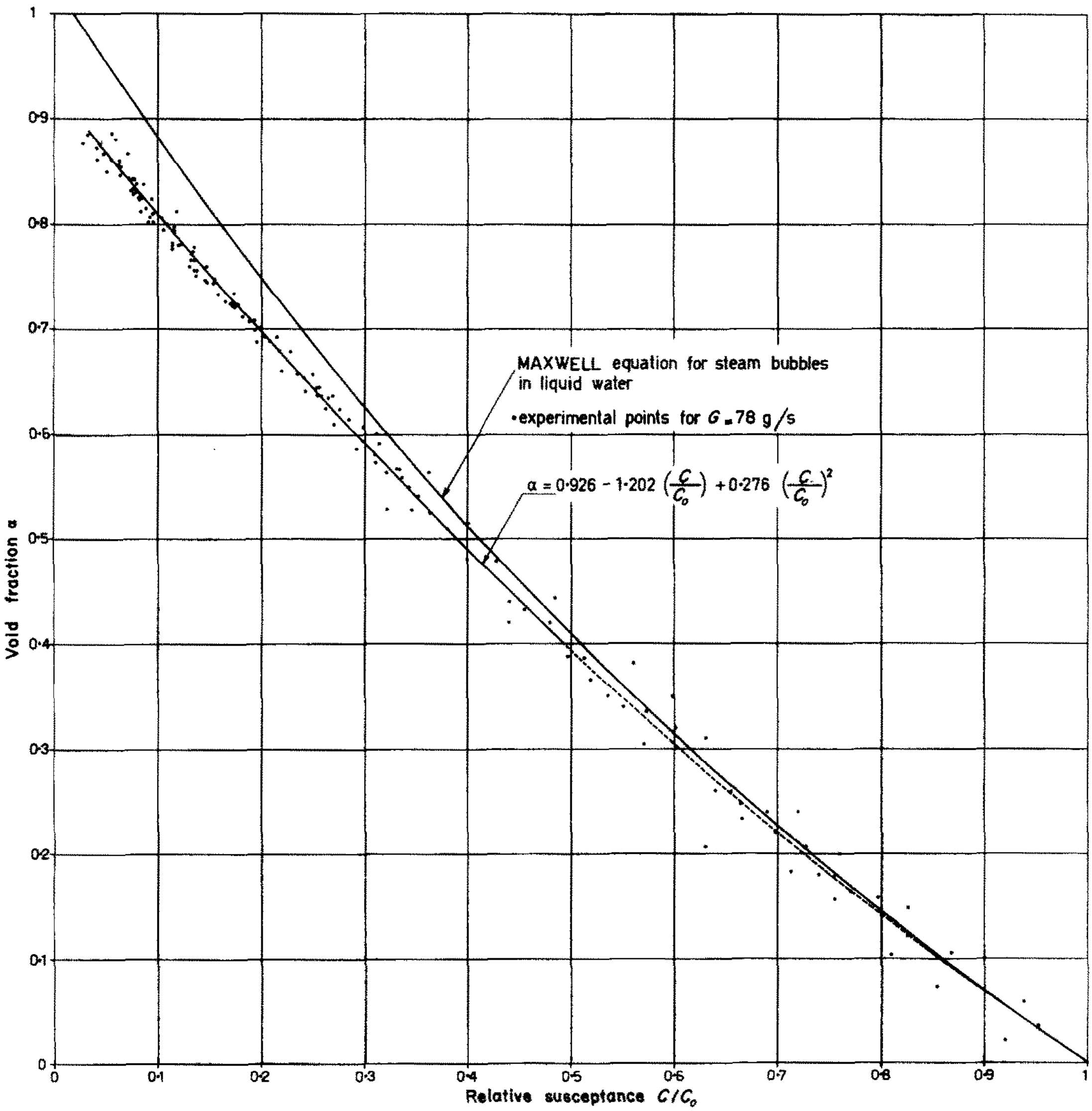

FIG 5. Bulk boiling void fraction α vs. relative susceptance C/C_0.

when the Maxwell equation is chosen to relate the void fraction to the relative admittance. It is to be noted however that the degree of approximation of the Maxwell equation improves with mass flow-rate increasing or with void fraction decreasing: for void fractions lower than 40 per cent, the difference ($\alpha_M - \alpha$) becomes much smaller than 0·02. From Fig. 1 the Maxwell curve of steam bubbles in liquid matrix appears to be the best among the existing theoretical curves, especially for application to subcooled voids [10].

Our experiment shows that the impedance method is quite suitable and useful for experimental studies of net boiling voids, but it is convenient to calibrate directly the gauge in the

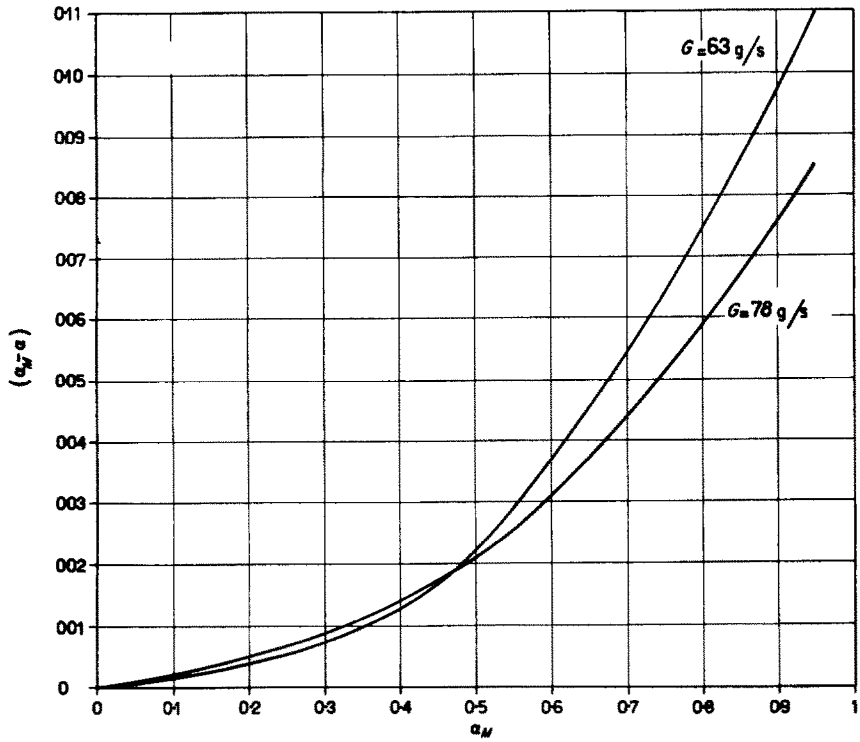

FIG. 6. Difference between the Maxwell α values (α_M) Hand the experimental ones (α) vs. the void fraction (α_M).

region $\alpha > 40$ per cent to avoid the uncertainty due to the choice of a theoretical calibration curve. Corresponding to two values of mass flow-rate and an annular geometrical configuration equations relating the void fraction to the relative susceptance are indicated: they are very reliable for $\alpha > 40$ per cent. In the region $0 < \alpha < 40$ per cent the Maxwell equation (3) appears to be the most reliable.

ACKNOWLEDGEMENTS

The authors are grateful to Mr. G. F. Canti and Mr. C. Chiesa for their helpful assistance in carrying out the experimental measurements.

REFERENCES

1. H. H. HOOKER and G. F. POPPER, A gamma-ray attenuation method for void fraction determination in experimental boiling heat transfer facilities, ANL-5766 (1965).
2. W. J. BARAN and P. LUPOLI, Misura della frazione volumetrica di vapore col metodo della attenuazione gamma 0 *X* parte 1ª e 2ª, Doc. DI TE. TR 12, C.N.E.N. (1963).
3. P. LUPOLI Misura della frazione volumetrica di vapore col metodo della attenuazione γ, Progress Report to 30 June 1965, Doc. Int. TR 29; C.N.E.N., C.S.N. Casaccia (1965).
4. R. FESTOSO and P. LUPOLI, Misura della frazione volumetrica di vapore col metodo della attenuazione γ, Progress Report to 30 September 1965, Doc. Int. TR 30; C.N.E.N., C.S.N. Casaccia (1965).
5. G. E. MARTIN and E. W. GROSHE, X-ray absorption measurement of steam voids in water at high pressures, *Adv. X-ray Analysis* **4**, 319–334 (1961).
6. H. C. PERKINS, Z. L. YUSUF and R. I. LEPPERT, A void measurement technique for local boiling, *Nucl. Sci. Engng* **11**, 304–311 (1961).
7. S. ZIA ROUHANI, Void measurement by the (γ, n) reaction, *Nucl. Sci. Engng* **14**, 414–419 (1962).
8. I. ORBECK, The impedence void-meter, *Symposium on In-core Instrumentation*, Oslo, 15–19 June 1964, Paper D-8.
9. A. J. WAMSTEKER, H. F. VAN VLAARDINGEN and C. L. SPIGT, The application of the impedance method for transient void fraction measurement and comparison with the γ-ray attenuation technique, *Symposium on*

In-core Instrumentation, Oslo, 15–19 June 1964, Paper D-2.
10. L. CIMORELLI and A. PREMOLI, Measurement of void fraction with impedance gauge technique, *Energia Nucl.* **13**, 1 (1966).
11. L. MAXWELL, *A Treatise on Electricity and Magnetism*. Oxford University Press, Oxford (1873).
12. L. CORNAGGIA, M. DI BARTOLOMEO, E. GILARDI and A. PREMOLI, Circuito sperimentale ad acqua da 25 kW, C.N.E.N.—RT/Ing. 1 (1964).
13. V. E. SCHROCK, G. ANGELINO, G. POSSA and J. B. VAN ERP, Density measurement in a boiling channel, *Energia Nucl.* **10**, 525–535 (1963).
14. S. M. ZIVI, Kinetic studies of heterogeneous water reactors, RWD-RL-167 (1960).
15. E. E. DUKE and V. E. SCHROCK, Void volume, site density and bubbles size for subcooled nucleate pool boiling, *Proc.* 1961 *Heat Transfer Fluid Mech. Inst.*, p. 130. Stanford University Press (1961).
16. R. EVANGELISTI and A. PREMOLI, Misure di vuoti in un canale bollente verticale in condizioni adiabatiche, *Calore* **2**, 1 (1965).

Résumé—On décrit ici l'application de la méthode de l'impédance capacitive à l'étude de l'ébullition globale à la pression atmosphérique. Les courbes d'étalonnage de la fraction de vides en fonction de la capacitance relative, correspondant à deux valeurs du débit massique, sont obtenues jusqu'à des fractions de vides d'environ 85 à 90%. On choisit l'indication de la méthode dilatométrique comme valeur étalon de la fraction de vides. Enfin, les différences entre les courbes d'étalonnage expérimentales et la loi de Maxwell sont calculées et portées sur un graphique.

Zusammenfassung—Es wird die Anwendung der Impedanzmethode, in kapazitiver Entwicklung, auf die Untersuchung des Siedens bei Atmosphärendruck beschrieben. Für zwei Werte des Stoffstroms werden Eichkurven für den Dampfanteil über der relativen Kapazität abgeleitet, für Dampfanteile bis zu 85–90 Prozent. Als Normal für den Dampfanteil wird eine Beobachtung nach der Ausdehnungsmethode gewählt. Die Unterschiede zwischen den Kurven der Versuchseichung und der Maxwellverteilung sind berechnet und aufgezeichnet.

Аннотация—В данной статье описано применение разработанного емкостного варианта метода электрического сопротивления к исследованию объемного кипения при атмосферном давлении. Для двух значений массового расхода представлены калибровочные кривые зависимости относительного объемного паросодержания от относительной ёмкости для значений относительного объемного паросодержания, доходящих примерно до 85–90%. Стандартное значение относительного объёмного паросодержания определялось по дилатометрическому методу. Наконец, рассчитаны и представлены в виде графиков расхождения между экспериментальными калибровочными кривыми и законом Максвелла.