We are IntechOpen,
the world's leading publisher of
Open Access books
Built by scientists, for scientists

4,800
Open access books available

122,000
International authors and editors

135M
Downloads

Our authors are among the

154
Countries delivered to

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Development of Capacitance Void Fraction Measurement Method for BWR Test

Hironori Watanabe[1], Hidesada Tamai[1],
Takashi Satoh[1], Mitsuhiko Shibata[1] and Toru Mitsutake[2]
[1]Japan Atomic Energy Agency, Tokai-mura, Ibarakiken
[2]Tosiba, Isogoku Yokohama-shi Kanagawaken
Japan

1. Introduction

In the study of two phase flow, void fraction (volume ratio of gas phase to total volume) in the flow channel is important physical value, so many measurements technique have been applied.

In the study of the atomic energy, X-ray, or γ-ray technique have been adopted for measure void fraction under high temperature and high pressure condition.

But in these techniques, real time measurement is difficult and measurement system is complex, therefore practical method have been expected.

In the measurement of the void fraction for BWR thermo- hydraulic test, following measurement under high pressure and high temperature conditions is necessary.

1.   Measurement is available for even though pure water
2.   Measurement is available
3.   Measurement is available for all void fraction regions
4.   Measurement is available in real time

Authors have developed capacitance measurement method (C method) that is electric void fraction measurement method to solve above theme.

Applying C method to BWR thermo-hydraulic test and Modified Light Water Reactor develop test had been performed at JAEA.

In former part of this article, we showed clarified measurement characteristic by C method to atmospheric condition, measurement effectiveness in pure water and measurement region can be expanded.

In latter part, we showed adopted electrode·signal cable for high pressure condition and attained measurement of void fraction on the condition of BWR.

To confirm propriety of C method, we compared measured datum by C method with datum by quick shut method, consequently characteristic function can apply to high pressure conditions.

Symbol

A_{X-s} :Projeited Area of Flow Channel [m²]
C :Capacitance[F]
C^* :Rasio of Capacitance[－]
$C(\alpha)$:Capacitance at Void Fractionα[F]
d :Inner Diameter of Pipe[m]:
I :Current[A]
j_g :Volume Flux of Gas Phase[m/s]
j_l :Volume Flux of Liquid Phase[m/s]
R :Resistance[Ω]
t :Time[s]
z :Coodinates in the Flow [m]
α :Void Fraction[－]
ρ :Density[kg/m³]
BWR   :Boiling Water Reactor
FBR   :Fast Breeder Reactor
SG   :Steam Genarator
QSV   :Quick Shut Valve

Attached letter

$\alpha=0, \ell$:Liquid Phase 100%
$\alpha=100, g$:Gas Phase 100%

2. C method of void fraction measurement (atmospheric condition)

2.1 Principle of measurement by C method

At first we measured resistance of two phase flow in the flow channel and confirmed that resistance has the relation of definite hyperbolic function (R method) to void fraction both in the atmospheric condition and high temperature and high pressure condition (7MPa). [1][2]

But there had been the theme that resistance measurement method (R method) do not fit for discontinuity of liquid phase because conductive pass is cut off at high void fraction region(more than 70%).

To solve disadvantage in R method, we developed C method, in C method high frequency AC power charged a pair of electrode.

In C method, it was experimentally confirmed that characteristic curve concluded to definite hyperbolic function, provided capacitance component in the two phase flow is separately measured making use of that phase is different between capacitance and resistance[3] [4]. C method has the advantage in measurement sensitivity compared R method as frequency of AC power changes to higher response current increase.

2.2 Test facility for void fraction measurement characteristics test

4x4 rod bundle simulating BWR fuel rod arrangement is installed in the Rectangular test section.

Fig.1 shows characteristic test facility for 4x4 rod bundle. Air-Bubble was introduced from lower nozzle through porous plate to gain uniform small bubble.

Void fraction was regulated by needle valve for inlet air. Void fraction was measured from the water volume in the test section between quick shut valves. Electrode is to measure impedance of two phase flow between a pair of electrode, we adopted different shape for most suitable shape for flow channel (faced plate, plate and rod, rod and rod).

In the test to charge high frequency AC to electrode installed inner wall of the test section, we adopted high frequency type impedance meter (LCR meter) and measured capacitance in the two phase flow.
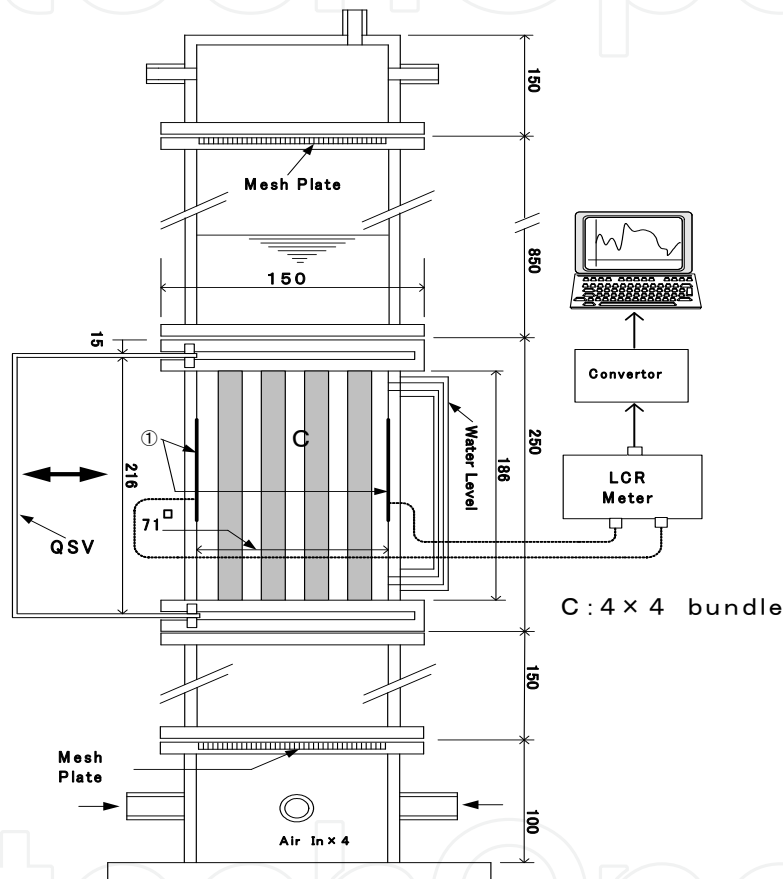

Fig. 1. Void fraction test facility with 4x4 bundle

2.3 Frequency response characteristic of test section

Fig.2 shows the frequency response characteristic of the test section by C method. In C method measurement sensitivity improved as the response current increase proportionally to $1/(\omega C)$.

On the other hand, more than definite frequency wide band, measured result (capacitance) becomes unstable due to resonance of AC current so 1MHz band was selected. Moreover multiple frequency of supplied AC (50Hz in this district) was avoided to prevent phasing interaction. So 1.01MHz was adopted as measurement frequency, consequently performed stable measurement.
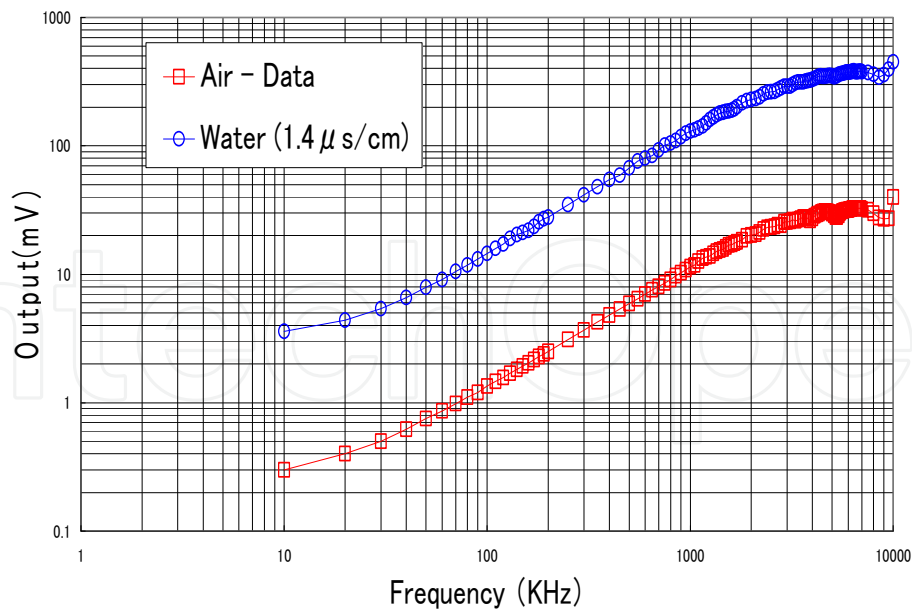
Fig. 2. Frequency characteristics

2.4 Void fraction measurement characteristic test result

Fig. 3 shows measurement result of C and R in the two phase flow with measurement characteristic function (hyperbolic curve).
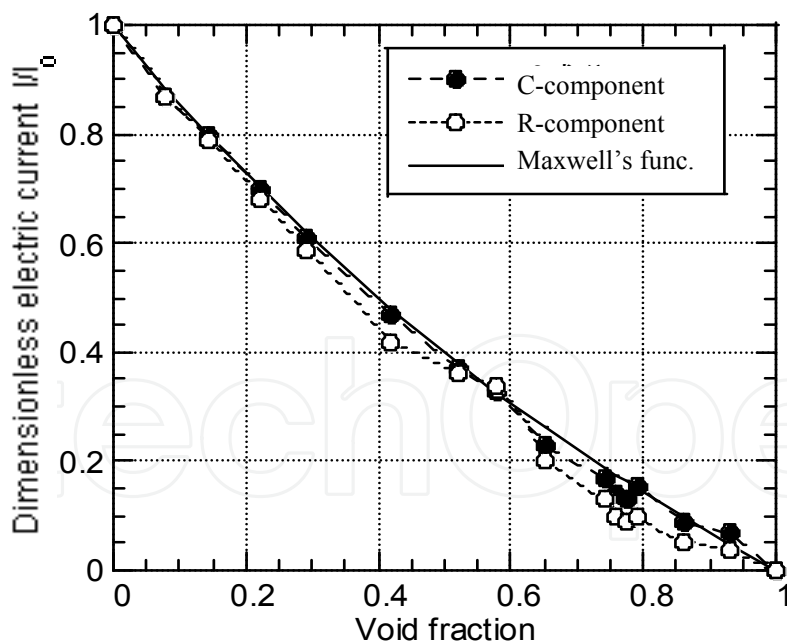

Fig. 3. Void fraction measurement of 4x4bundle (Atmospheric pressure)

This function introduced by Maxwell is expressed with solid curve, and both results agreed to this curve, especially, C measurement result agreed to over all regions, so Maxwell's function was adopted for measurement characteristic function trough tests.

Maxwell's formula[5] is shown in (1).

Formula (1) indicates that relation between current ratio of I (two phase flow) to Io (liquid phase flow) and void fraction is definite hyperbolic function while charging voltage kept constant.

Void fraction can obtain from formula (2) for R measurement and formula (3), (4) for C measurement respectively. Formula (2), (3) are transformed from (1).

$$\frac{I}{I_{\alpha=0}} = \frac{1-\alpha}{1+0.5\alpha} \text{ (Maxwell's formula)} \tag{1}$$

$$\alpha = \frac{R - R_{\alpha=0}}{R + 0.5R_{\alpha=0}} \text{ (R method)} \tag{2}$$

$$\alpha = \frac{1-C^*}{1+0.5C^*} \text{ (C method)} \tag{3}$$

$$C^* = \frac{C(\alpha)\text{-}C_{100}}{C_{\alpha=0} - C_{\alpha=100}} \tag{4}$$

3. Void fraction measurement test under high temperature and high pressure condition (7MPa)

With C method we performed void fraction measurement under high temperature and high pressure condition[6] [7] [8] by using measurement characteristic function showed at formula (3), (4) applying advanced BWR thermo-hydraulic test facility.

3.1 Advanced BWR thermo-hydraulic test facility

Advanced BWR (Tight-lattice Reduced Moderation Water Reactors) thermo-hydraulic test facility contains 37 e rods bundle in flow shroud made of ceramic. [9]A pair of opposite circular electrode made of stainless steel was attached to inner wall of ceramic flow shroud.

Fig.4 shows structure of test section and out line of the void fraction measurement system.

We measured capacitance between a pair of electrode in the two phase flow by LCR meter as described in 2.2.

3.1.1 Electrode

We developed Mineral insulator (MI) sheath type electrode to keep insulation and resistance to high temperature and high pressure condition [9].

Fig.5 shows over view and arrangement of MI sheath type electrode. Sensor part of electrode is circular SUS plates (6mm diameter, 1mm thickness). Sheath is SUS pipe filled with ceramic inside.

Electrodes were attached to the measurement nozzles of the test section at 3 different elevations with 2mm interval oppositely to another electrode.
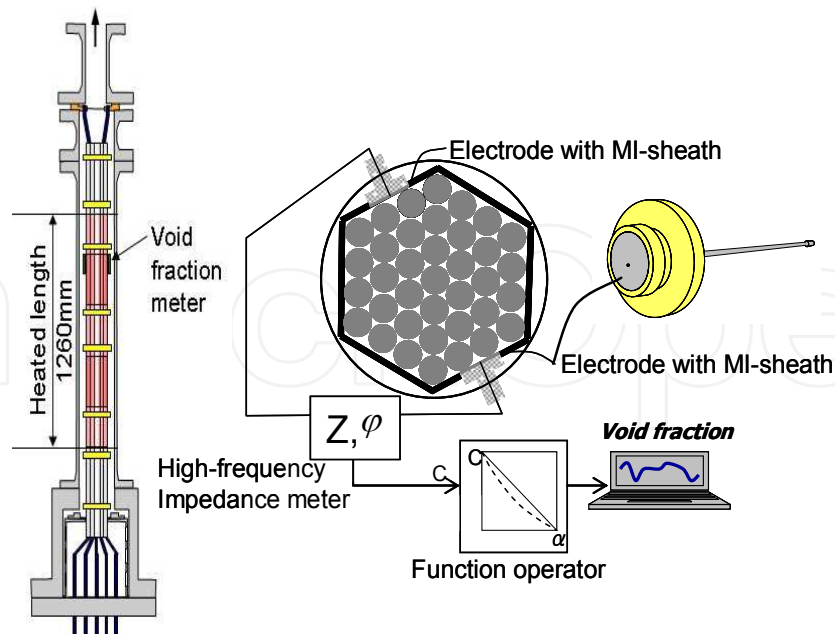
Fig. 4. 37 Bundle and measurement system

As to durability of electrode in the high temperature and high pressure condition, crack by the thermal stress was prevented as thermal expansion coefficient among composed materials are almost equal, consequently we could gain long life of MI sheath type electrode through autoclave test.

Signal cable was insulated from MI sheath to prevent leakage of measured signal current. Insulating points are following 3.

- Ceramic tip of cone shape was inserted between sheath and signal cable.
- Ceramic pipe was inserted in the half part of sheath (To cancel the capacitance by insulator between sheath and signal cable)
- In the welding of sheath and ceramic, intermediate material (Kovar-Alloy) was adopted as Kovar can be weld with sheath and ceramic.
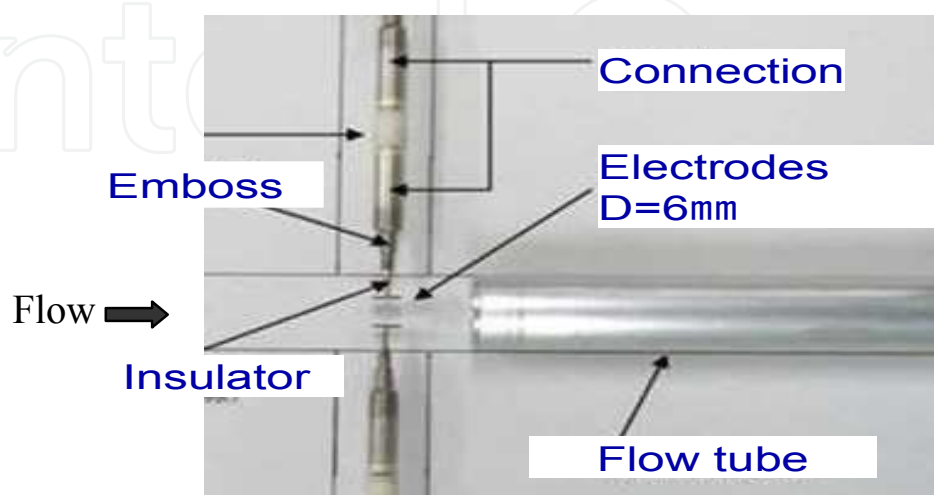

Fig. 5. MI sheath type electrode

3.1.2 Measurement Hi frequency of AC Power

In C method, measurement frequency of AC power should be optimized therefore we adopted 1MHz as stable frequency band as showed at 2.3.

3.1.3 Data acquisition of Liquid phase flow and Gas phase flow

In measurement initial capacitance data of liquid phase flow (Cl) and Gas phase flow (Cg) need to be input into signal conditioner as set up data.(Formula(4) claims Cl and Cg)

- C measurement of liquid phase (Cl)   C measurement of the liquid phase were performed at 2MPa，4MPa，and 7MPa as steady test conditions.

At transient condition of temperature measured C should be correct as C changes with temperature changes.

- C measurement of the gas phase (Cg) In practical measurement Cg means void fraction is 100% and inner wall of the flow channel is wet condition.

In calibration test, Cg condition was realized as follows. Water level dropped enough and electrode exposed by accumulating steam in the test section by shutting of out let valve. Cg condition was confirmed from measured ΔP.

3.2 Response test of void fraction measurement

The response signal characteristics of void fraction measurement system were obtained with the advanced BWR thermo-hydraulic test facility. The results are shown in Fig.6.

From Fig.6, it was known that the measured void fraction follows to power with good response under the transient conditions while heating power of rod bundle is increasing and flow rate of recirculation water is constant. Void fraction measured elevation are 1200mm , this elevation is top in the heating part (Void signal 1), and 900mm in the heating part (Void signal 2). From Fig.6, it was clarified that void fraction measurements can perform in real time way by C method.
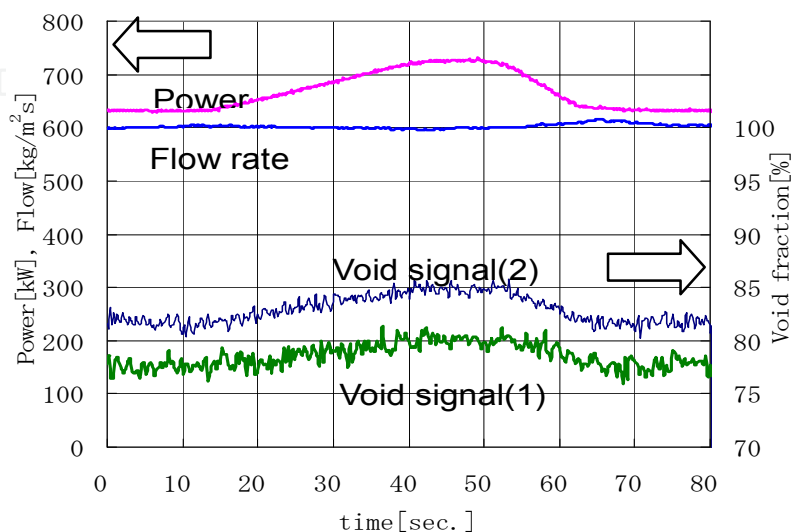

Fig. 6. Response of measurement system (7.2MPa pressure, 600kg/m²s mass velocity)

3.3 Void fraction measurement result

Pressure 2MPa, 7MPa

Void fractions were successfully measured applying C method to advanced BWR thermo-hydraulic test facility [10] [11] [12]. Fig.7 shows void fraction measurement result under heating power transiently controlled as to every mass flow rates of the recirculation water is constant at 2MPa pressure condition.
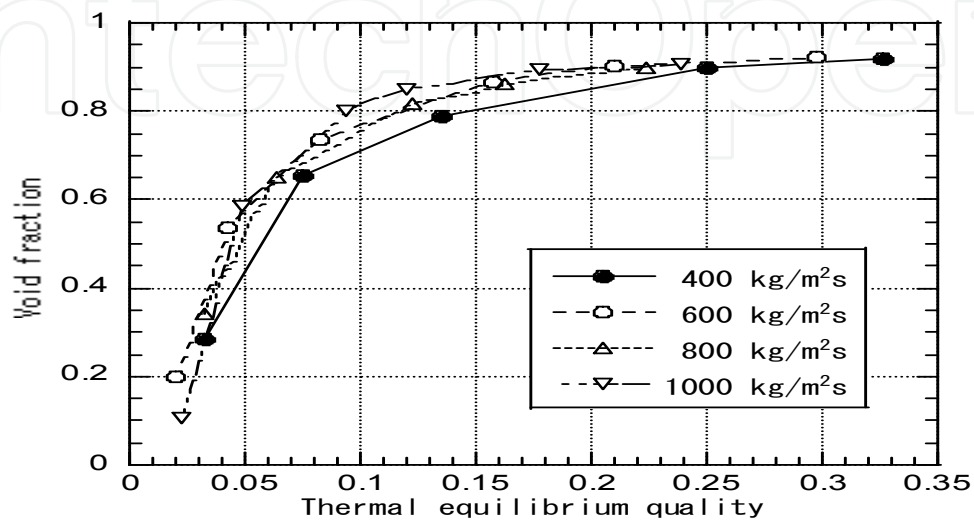

Fig. 7. Void fraction Measurement (2MPa pressure)

From measured result it were showed that with the increasing of mass flow rate of recirculation water 、 measured void fraction becomes decrease and this result agreed to the usual knowledge. In this test measured maximum void fraction is 92%. This result shows C method enable to measure large void fraction region with stability. Fig.8 shows void fraction measurement result, in the condition of pressure changed to 7.2MPa in former test. Result shows that with increasing quality void fraction following increase rationally.
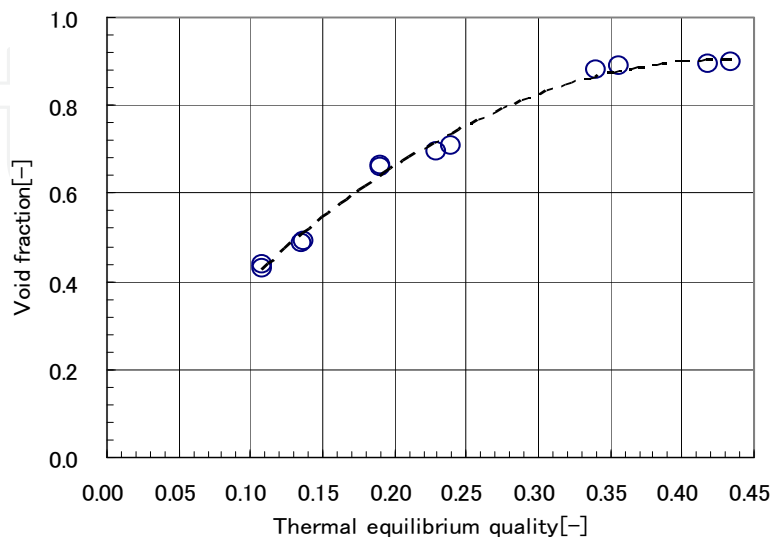

Fig. 8. Vo id fraction measurement (7.2 MPa pressure, 600 kg/m²s mass velocity)

4. Propriety of C method under high temperature (pressure 2MPa)

To confirm propriety of C method, we practically confirmed application of formula (3), (4) to high temperature and high pressure condition, we compared measured result by C method with measured result by quick shut method under the high pressure condition. At the result it was confirmed that C method is available for high temperature and high pressure conditions as well as atmospheric condition. Following is about calibration test for propriety. We adopted two type test section for calibration test. Test section for C method contains heating 37 rods bundle and test section for quick shut method contains non heating 19 rods bundle (Injected steam and water).

Comparison test was performed under 2MPa condition. Dimensions of the both test sections showed in the following.

Measurement method	C-method	Q.S. method
Number of rods	37	19
Outer rod diameter[mm]	13	12
Rod gap[mm]	1.3	
Hydraulic diameter[mm]	4.34	4.25

Configuration of 37 rods bundle is honeycomb 4 peripheries, and 19 rods bundle is honeycomb 3 peripheries respectively. Effect on the void fraction measurement due to the difference in the hydraulic diameter between 2 test sections was evaluated to be small though calculated result by Drift flux void fractional computing function.(Void fraction change is less than 1% provided quality is more than 5%)

But effect on the void fraction distribution due to heating form of the rod bundle was observed in the measured result.

4.1 Test facility for void fraction measurement by quick shut method

In the quick shut method two phase flow was instantly shut by Quick Shut Valve (QSV) and volume of the water in the test section is measured by differential pressure meter. For practical, Q.S.V is quick shut rotary disk installed to the shaft droved by high pressured air, synchronized actuate time is 0.05 second.

Fig.9 shows the structure of quick shut test section. Test section is composed of two sections to evaluate error of void fraction measurement, upper section is half length of lower section.

Correct void fraction was obtained from difference of the measured void fractions in the two sections, as void fractions correspond to gap between bundle and QSV was canceled.

4.2 Calibrated result of C method by Q.S method

Fig.10 shows measured result by C method and by Q.S method.

In Fig.12, measured void fraction by C method were showed with △ (solid line）, measured void fraction by Q.S method were showed with ○ (broken line) , and difference between C and Q.S approximated logarithmic function were showed with solid line for reference.
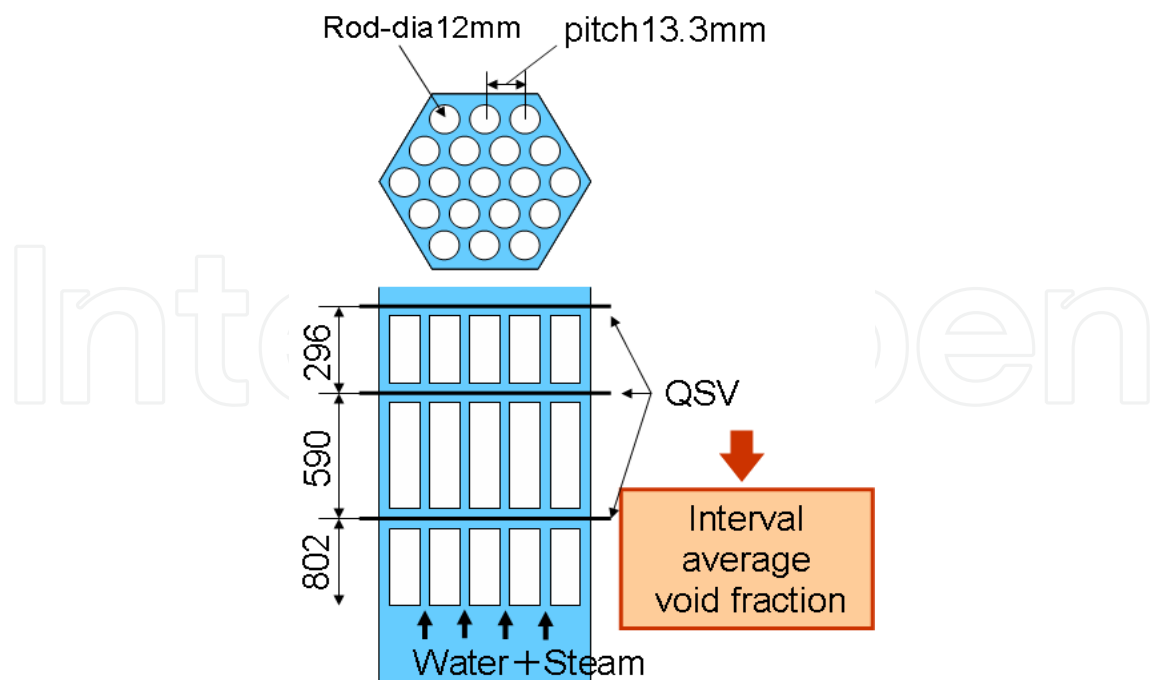
Fig. 9. Test section with quick-shut valve (QSV) for void fraction measurement

Moreover Fig.12 [10] shows that obtained two relational functions between void fraction and quality are equivalent function.

From minute view, measured void fraction by C method is a little larger than measured void fraction by Q.S method. Difference in the measured void fraction was largest at near 0.05 of the quality, difference becomes close up gradationally according to increasing in void fraction and range of difference was 4%~8%. The cause of the difference in the void fraction was considered that heating condition in the test section is different. 37 rods bundle is heating bundle and 19 rods bundle is non-heating bundle. In heating rods bundle it was observed that void fraction distribution was comparatively uniform. Contrary in non- heating rod bundle it was observed that void fraction distribution was large at the central flow channel and small at the near of the wall. With above reason, it is considered that measured void fraction by Q.S method is a little small than measured void fraction by C method under the region of less than 0.15 of quality. From calibration test C method is considered to be available in the condition of high temperature and high pressure as well as atmospheric condition in conclusion.

Moreover Fig.10 [13] shows that obtained two relational functions between void fraction and quality are equivalent function. From minute view, measured void fraction by C method is a little larger than measured void fraction by Q.S method. Difference in the measured void fraction was largest at near 0.05 of the quality, difference becomes close up gradationally according to increasing in void fraction and range of difference was 4%~8%. The cause of the difference in the void fraction was considered that heating condition in the test section is different. 37 rods bundle is heating bundle and 19 rods bundle is non-heating bundle. In heating rods bundle it was observed that void fraction distribution was comparatively uniform. Contrary in non- heating rod bundle it was observed that void fraction distribution was large at the central flow channel and small at the near of the wall. With above reason, it is considered that measured void fraction by Q.S method is a little small than measured void

fraction by C method under the region of less than 0.15 of quality. From calibration test C method is considered to be available in the condition of high temperature and high pressure as well as atmospheric condition in conclusion.
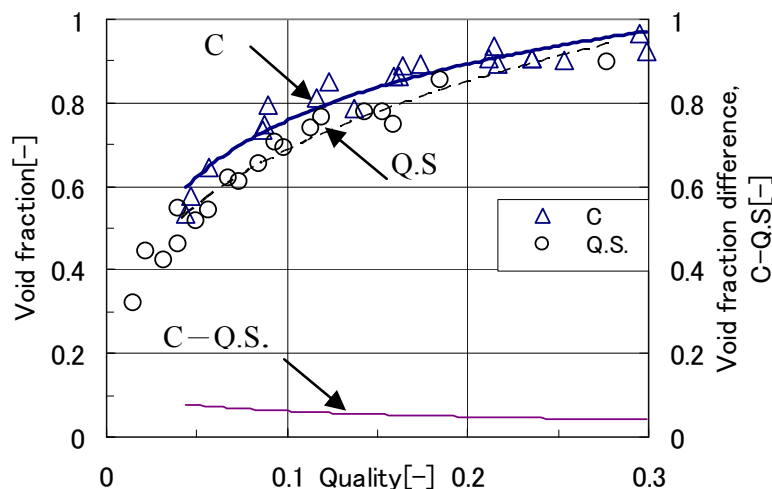

Fig. 10. Compared result between C and Quick-shut valve method void fraction method s (2MPa in pressure, 400~2000kg/m²s in mass flux) [10]

5. Conclusion

We developed C method for practical void fraction measurement, applied to the high temperature and high pressure condition and following results were obtained.

In C method measurement relational function between void fraction and capacitance in the two phase flow was confirmed to be definite hyperbolic function (Formula (3),(4)) through tests under different temperature and pressure conditions.

In C method void fraction measurement is available in the pure water as well as conductive water and measurement region is almost 0~100%.

In C method void fraction measurement under the condition of high temperature and high pressure up to 7MPa pressure was achieved by developed MI sheath type electrode. C method was applied following thermo-hydraulic tests.

BWR stability test, BWR Critical Heat Flux test, and Reactivity Initiated Accident test.

6. Acknowledgments

7. References

[1] Watanabe, H., Iguchi, T., Kimura, M. and Anoda, Y., Development of quick-response area averaged void fraction meter, *JAERI-Research 2000-043* (2000)・

[2] Watanabe, H., Iguchi, T. and Kimura, M. , Development of conductance-type void fraction meter, *JSME annual meeting*, No.4(2002), pp.233- 234・

[3] Watanabe, H., Mitsutake, T., Kakizaki, S. and Takase, K, Experimental study on feasibility of capacitance void fraction meter, *Transactions of the Japan Society of Mechanical Engineers*, *Series B*, Vol. 74, No.742 (2008), pp. 435-436

[4] Watanabe, H., Mitsutake, T., Kakizaki, S. and Akimoto, H, Electro-void fraction meter development and application to tight lattice rod assembly within reduced moderation water reactor, *Proceedings of the 9th National symposium of power and energy systems*(2004), pp.69-70・

[5] Maxwell, J.C., *A treatise on electricity and magnetism,*3rd ed・,(1954), Vol・1, Chapter 9, Article 314, Dover, New York

[6] Watanabe, H., Mitsutake, T., Kakizaki, S. and Akimoto, H, Electro-void fraction meter development and application to tight lattice rod assembly within reduced moderation water reactor, *Proceedings of the 9th National symposium of power and energy systems*(2004), pp.69-70・

[7] Watanabe, H., Mitsutake, T., Kakizaki, S. and Takase, K, Experimental Study on Capacitance Void Fraction Meters for High Temperature and High Pressure Conditions, *Transactions of the Japan Society of Mechanical Engineers*, *Series B*, Vol. 76, No.769 (2010), pp. 1379-1385

[8] Kureta, H., Yoshida, H., Tamai, H., Ohnuki, A. and Akimoto, H., Thermal-Hydraulic Estimation in Tight-Lattice Rod Bundles for Development of the Innovative Water Reactor for Flexible Fuel Cycle, *Progress in Multiphase Flow Research 3*, (2008), pp.99-109.

[9] Watanabe, H., Mitsutake, T., Kakizaki, S. and Takase, K, Experimental study on feasibility of capacitance void fraction meters, *Proceedings of the 13th National symposium of power and energy systems* (2007), pp.77-78・

[10] Kureta, H., Yoshida, H., Tamai, H., Ohnuki, A. and Akimoto, H.・Thermal-Hydraulic Estimation in Tight-Lattice Rod Bundles for Development of the Innovative Water Reactor for Flexible Fuel Cycle, *Progress in Multiphase Flow Research 3*, (2008), pp.99-109.

[11] Cimorelli, L and Evangelisti, R., The application of the capacitance method for void fraction measurement in bulk boiling conditions, *International Journal of Heat and Mass Transfer*, Vol・10(1967), pp・277-288・

[12] Inoue, A., Kurosu, T., Aoki, T., Yagi, M., Mitsutake, T. and Morooka, S., Void fraction distribution in BWR fuel assembly and evaluation of subchannel code, *Journal of Nuclear Science and Technology* Vo. 32, No.7(1995), pp.629-640.

[13] Tamai, S, Takase, K., Shibata, M. and Hayafune, H.・ Flow instability experiments on steam generator with straight double-walled heat transfer tube for FBR (2) Experimental Results under High Pressure Conditions, *2007 Fall Meeting of the Atomic Energy Society of Japan, K58,* (2007).
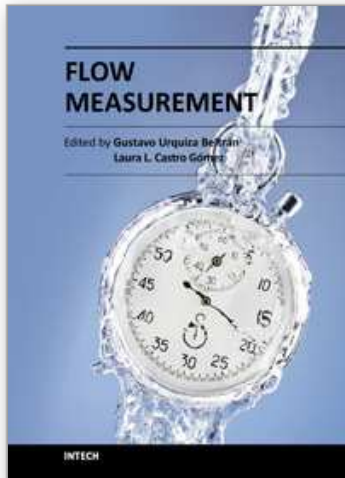
Flow Measurement

Edited by Dr. Gustavo Urquiza

The Flow Measurement book comprises different topics. The book is divided in four sections. The first section deals with the basic theories and application in microflows, including all the difficulties that such phenomenon implies. The second section includes topics related to the measurement of biphasic flows, such as separation of different phases to perform its individual measurement and other experimental methods. The third section deals with the development of various experiments and devices for gas flow, principally air and combustible gases. The last section presents 2 chapters on the theory and methods to perform flow measurements indirectly by means on pressure changes, applied on large and small flows.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Hironori Watanabe, Hidesada Tamai, Takashi Satoh, Mitsuhiko Shibata and Toru Mitsutake (2012). Development of Capacitance Void Fraction Measurement Method for BWR Test, Flow Measurement, Dr. Gustavo Urquiza (Ed.), ISBN: 978-953-51-0390-5, InTech, Available from: http://www.intechopen.com/books/flow-measurement/development-of-capacitance-void-fraction-measurement-method-for-bwr-test

INTECH
open science | open minds