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A Study on the Measurement of Local Void Fraction

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수직사각 유로내에서의 국부적 기포계수 측정에 관한 연구

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Abstract

The importance of the study of two phase flow phenomena has increased for both fuel performance and safety analysis of nuclear power plants. In the analysis of two phase flow system, an accurate prediction of local void fractions is very important. In this study, a vertical rectangular subchannel having 4 electrically heated rods is constructed for the measurement of local void fraction under two phase flow. The measurement has been conducted by electrical conductivity probes and signal processing circuit which are known to be adequate to measuring local void fraction. Also experiments are performed with varying the inlet flow rate to search for radial void fraction profile accordingly to the different flow rate even with the same averaged void fraction. From the result of experiments, the validity of electrical conductivity probe and electrical circuit is confirmed.

요　　약

이상유동 현상의 해석은 원자력 발전소의 각계통과 가압경수형 원자로의 안전성 분석, 각종 열수력학적 현상의 해석 그리고 타 산업체의 필요성에 의해 그 연구의 중대성이 커지고 있다. 이러한 이상유동의 현상 해석에 있어서 국부적 영역에서의 기포계수 결정은 매우 중요하다.

본 연구에서는 이러한 이상유동시 국부적 기포계수의 측정을 위하여 원자로내 부수로를 모사한 수직사각 유로를 제작하였다. 또한 국부적 영역에서의 기포계수 측정에 적합한 것으로 알려진 전기탐침 및 그 부가회로를 제작하였으며, 완성된 탐침을 이용하여 실제 비등이 발생하는 실험용 유로내에서 국부적 기포계수의 측정을 시도 하였다. 실험 결과 제작된 전기탐침 및 그 부가회로의 타당성을 확인 할 수 있었다.

1. Introduction

Two phase flow phenomena has been studied for various systems (e.g. pressurizer, heat exchanger, reactor subchannel, etc.) in nuclear power plant and for related industries with many theoredtical and experimental methods. In particular, the accurate prediction of void fraction in the subchannel under two phase flow condition is of great importance to model the behavior of flow in fuel assemblies. The void fraction in a boiling channel with subcooled inlet is a complex function of various design parameters and operating conditions.

Thus is this work, the measurement of local void fractions in boiling rectangular subchannel has been conducted with electrical conductivity probe method[2, 7, 8]. It is well-known to be adequate to the measurement of local void fraction in conducting media such as water, mercury, etc. This method was developed by Neal(1963) for the measurements in mercury-nitrogen flow[4]. and Nassos(1963) for those in air water mixture [1] . Also a number of investigators have reported the use of such a kind of probe for the measurement of local properties in gas-liquid flow. Measurements of void fraction were performed previously by Malnes(1966), Neal & Bankoff(1963)[4], and Serizawa(1975). Of them, Neal and Bankoff and Serizawa have used two probes in series to measure bubble size and velocity[5]. Most of such previous measurements have performed for air-water mixture and/or cylindrical tube geometry. However, the two-phase flow in the real reactor subchannel is affected by complicated geometrical and boiling effects.

In this study, we performed the measurements in a vertical rectangular subchannel having 4 heating rods which simulates the subchannel of pressurized water reactor. Also the appropriate electrical circuit as well as electrical conductivity probes have been made for signal processing.

Finally, the void distributions in test section of subchannel were obtained and visualized by three dimensional graphic package from subcooled boiling to bulk boiling under various flow conditions.

2. Conductivity Probe Techniques

2.1. Measuring Principle

The principle of two phase flow measurement by the conductivity probe is based upon the electrical resistance difference between the vapour and the liquid phases. In a vapour-water flow, the vapour phase can be considered as electrically insulated, whereas the liquid phase as electrically conducted. When the conductivity probe contacts with the continuous liquid, the circuit is closed. Morever a vapour will break the circuit. Thus the probe works like a switch, yielding a two-state signal. Such a signal shows a nearly immediate response to water contact with the probe tip but a delayed response to vapour contact, due to the required dewetting time of probe tip. To calculate the accurate void fraction, this delay effect must be minimized. Minimization of this delay is obtained by the proper design of the probe tip and treatment of signal.

2.2 Probe Design

The requirements for probe design to be used for measurement in boiling loops are as follows ;

1) the probe should not be deformed and damaged in high temperature
2) flow disturbance may be minimized in the test section
3) probe vibration is not permitted in two phase flow conditions

The schematic configuration of designed probe is showen in Figure 1. It consists of a probe tip, free insulated enamel wire with 0.1 mm diameter, stainless steel tube with 0.4 mm diameter to protect the wire from flow conditions and high temperature, and stainless steel tube with 1.6 mm diameter which holds the probe against channel wall. The probe tip has to be sharpened in order to minimize dewetting time.

2.3. Signal Processing

2.3.1. Bridge Amplifier Circuit

In order to maximize the voltage of signal output for resistsance difference between liquid and vapour phases, a bridge amplifier circuit is designed and showed in Figure 2. The circuit improves the bridge circuit which is used in the strain gauge for measuimg pressure[18, 19]. In this research the output voltage of bridge amplifier circuit is four times as strong as that of bridge circuit. The ouput voltage from circuit is given by

$$Vo = [\Delta R/(R+R_1)] \times E$$

where

Vo=output voltage (v)
ΔR=resist difference between phases (Ω)
R=resist of liquid phase (Ω)
R_1=fixed resist (Ω)
E=applied voltage to circuit (v)

Finally, the manufactured probes and electrical circuit are used in experiments after calibrated in the air–water pyrex tube.

2.3.2. Triggering Circuit

To calculate local void fraction from measured data, the cutoff level which is boundrary between liquid and vapour phase is determined. The triggering circuit is designed for the transformation of raw output signals produced from bridge amplifier circuit into rectangular forms. This circuit is used in the consistent calculation of local void fraction. The signal produced from triggering circuit has hysteresis effect. But this technique has a disadvantage of losing raw data produced from bridge amplifier circuit.

2.3.3 Programmable Triggering

Triggering circuit can be replaced by computer program of data acquisition system. If the cutoff level of raw data is determined by analysis, computer program transform the signal above the level into binary 1 and that below into binary 0. The transformed signal using this technique is shown in Figure 3. The advantages of this technique are as follows.

- hysteresis effect without destruction of raw data produced from bridge amplifier circuit
- filtering effect of electrical noise

2.4. Data Acquisition System

Figure 4 shows the flow chart of signal processing from probes to the computer software. Analog to digital converter used in this experiments has 12 bit resolution and its maximun conversion rate is 100 khz.

3. Calculation of Local Void Fraction

3.1. Local Void Fraction

The local void fraction, which is measured by the conductivity probe, is defined as a time average of the concentration, f(x,y,t), by

$$\alpha(x,y) = \frac{1}{T}\int_{O}^{T}[1-f(x,y,t)]\ dt$$

in which f(x,y,t) equals zero if the phase at the *probe tip is vapour and one if the probe liquid* phase.

3.2. Determination of Cutoff Level

The pulsed signal could not sharply break the circuit due to probe wetting when the probe tip pierced the vapour. Thus the probe tip should be designed sharply so that this effect can be minimized. However the determination of cutoff level is very difficult becaues the interfacial boundary between two phases is not clear even with the sharp tip. In this study, methods for determination of the cutoff level have been studied as follows.

The raw data produced from birdge amplifier circuit are converted into discrete integer from −2048 to 2047 by 12 bit analog to digital converter and stored in IBM PC. The ideal signal output is rectangular form, so analysis is performed using rectangular signal produced from function generator. Figure 5 shows a rectangular signal produced from function generator and Figure 6 shows sampling number and cumulative sampling number of Figure 5. In Figure 6, x–axis is digital number and y–axis of Figure 6–1 is sampling number and y–axis of Figure 6–2 is cumulative sampling number. The digital number corresponding to liquid signal abruptly increases in Figure 6–1, so cutoff level exists above that. Figure 7 shows measured signal in the test loop for calibration and Figure 8 shows cutoff level of actual signal. In Figure 8 cutoff level exists just past the peak of Figure 8–1 and the starting point of slope variation of Figure 8–2. The use of triggering circuit or programmable triggering technique make it easy to calculate void fraction. In the respective result of above mentioned methods, void fraction is almost the same.

4. Test Loop

Figure 9 shows a schematic diagram of the test loop. Experimental apparatus consists of subchannel test section having 4 heating rods, preheater, flow meter, by–pass line, pump, stroage tank, and secondary loop.

The test channel is designed to be vertical rectangular geometry to simulate nuclear reactor system. The overall length of test channel is 202.8 cm, the channel cross section having four heating rods is 5 cm×5 cm and its hydraulic diameter is 1.847 cm. Two sides (front and rear sides) of the channel was made of transparent glasses to visualize the void behavior during experiments.

4 cylindrical heating rods with outer diameter 1.5 cm are electrically heated and fixed by two grids. The total heat capacity of four heaters is 40 kw. And the preheater consists of five U–shaped electrical heaters and located at subchannel entrance for inflow of the preheated water into the subchannel. Its total heat capacity is 50 kw and the inlet temperature is controlled by digital temperature controller. In this experiment, the liquid mass flow rate is measured by two orifice type flowmeters with wide range and narrow range, which are installed between preheater and stroage tank. The wide range flowmeter is used for the measurement of flow rate above 4.2 m^3/hr and narrow range flowmeter is used for below that. Flow rate is controlled by by–pass line. Storage tank is composed of water reservoir tank and secondary loop for cooling down of tank water before it flowing into pump. The volume of stroage tank is about 300 liter and secondary loop is made of wrinkled stainless steel tube.

5. Measurement and Discussion

Measured parameters in experiments are temperature, system pressure, pressure difference, liquid flow rate and local void fraction. Thermocouples are located at the inlet and outlet of the test channel. The system pressure is measured in channel inlet and pressure difference is measured at 10 cm above and 10 cm below the conductivity probes. Local void fractions are measured at 13 points of channel cross section by traversing 4 probes and their axial measuring position is 164.5 cm above from the bottom of the test channel. Cross section of the rectangular subchannel is symmetrized 1/8 by mirror effect and then measuring points for local void fraction are determined by this effect. Figure 10 shows the measuring points in the subchannel cross section. Measurements are performed under the various flow rate from 4.2 m^3/hr to 2.0 m^3/hr and heat flux of the main heating rod is maintained to be constant during the experiments but the temperature of the inflow water varied by preheater. The measuring time interval should be sufficiently large so that a statistically reasonable average can be obtained at that point. In our expriment measurement, time interval at each measuring point is 18 seconds and it is accepted to be reasionable by auxilarily experiments.

5.1 Void Distribution Under Varying Flow Rate

Measured data are visualized by 3 dimensional computer graphic package. Figure 11 shows the variation of boiling patterns from subcooled boiling to bulk boiling under varying inlet flow rates. Figure 11–a,b,c,d are for subcooled boiling and Fugure 11–e,f are for bulk boiling. As shown in Figure 11–a, most of the voids exist near the heating rod and the peak of the void fraction exists but it is relatively low compared with that of surrounding. Figure 11–b,c,d, shows the trend that void fraction decreased smoothly from heating rod to channel center, but the increase of flow rate brings the decrease of void fractions at channel center. Figure 11–e,f show well developed bulk boiling (flow pattern is churn turbulent flow) but void distributions are irrgular due to irregular energy transfer between void and liquid.

5.2. Void Distribution of Similiar Void Fractions

Figure 12 shows void distribution of similar channel averaged void fraction (α_{avg}=0.1643, 0.1857) under different flow conditions and enthalpies. In case of high mass flow rate, the void fraction at channel center is lower that in case of low flow rate because pressure difference between channel wall and center is higher than the case in fluid of low mass flow rate. In further investigation, this effect will be studied.

6. Conclusions and Discussion

In this study, electrical conductivity probes and additional circuit for measurements of local void fraction in the boiling loop are developed and used to obtain void fraction distributions in the range of subcooled to bulk boiling in the rectangular subchannel. From the result of measurements, the validity of electrical conductivity probe and electrical circuit is confirmed. The experimental results show that the increase of flow rate bring the more decrease of void fraction at channel center relation to neighborhoods of heating rods. In the reasult of this experiments, some improvements and further studies are needed as follows

(1) Bridge amplifier circuit is apt to conductivity probe method because its signal characteristic using it is low nosie and signal to noise ratio is very good.
(2) Measurements in boiling loop using developed electrical conductivity probe and circuit are confirmed under various flow conditions.
(3) Further study on the determination of cutoff level is needed
(4) The study on the determination of flow pattern by analysis of output signal is recommended.
(5) Two–probe method for measurement of distribution of vapour velocity is recommended.

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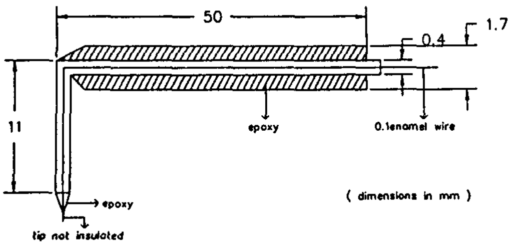


Fig. 1. Electrical Conductivity Probe

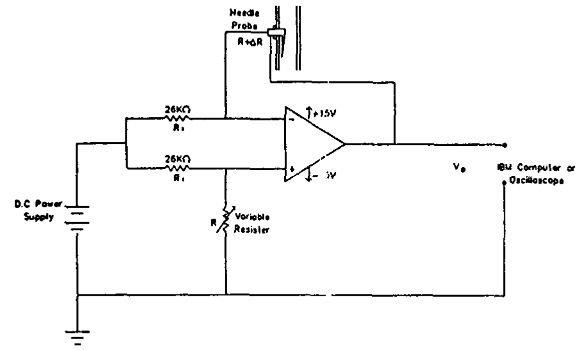


Fig. 2. Sketch of Bridge Amplifier Circuit

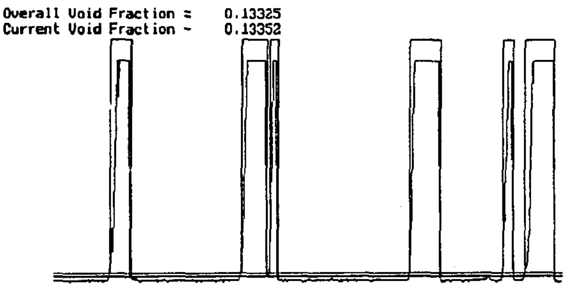


Fig. 3. Signal Treament by Programmable Triggering

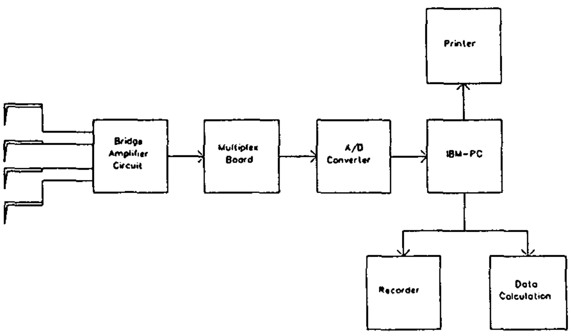


Fig. 4. Flowchart of Signal Treatement

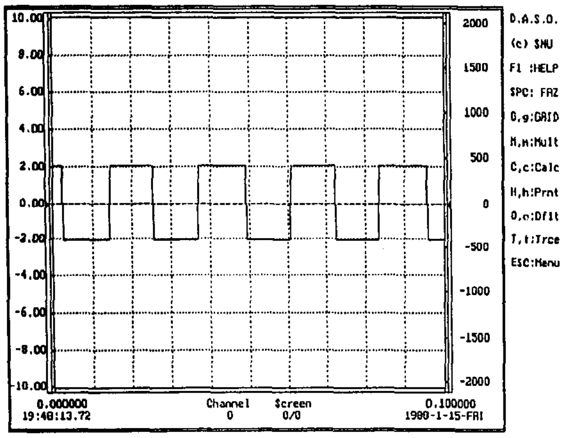


Fig. 5. Rectangular Signal Created by Function Generator

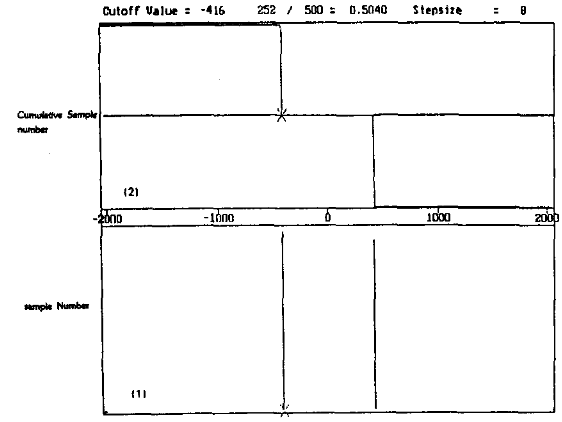


Fig. 6. Sampling & Cumulative Numbers of Fig. 5

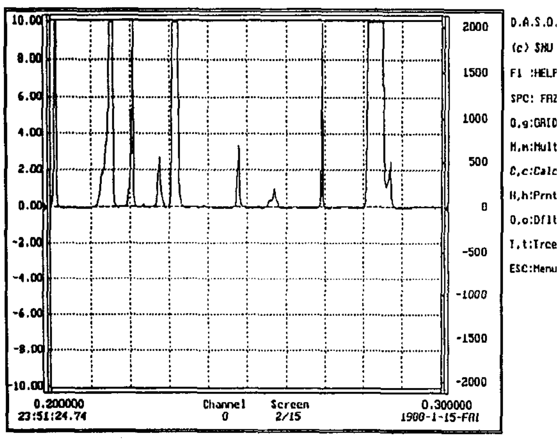


Fig. 7. Measured Signal in Subchannel

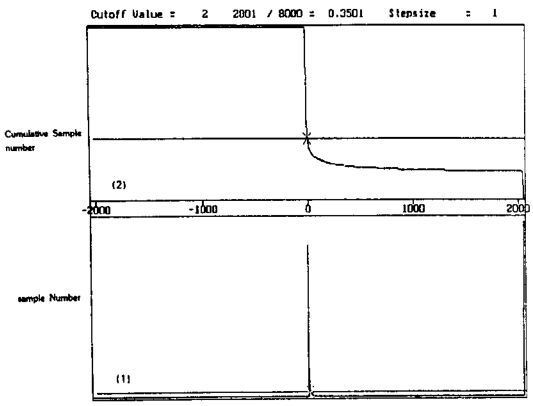


Fig. 8. Sampling & Cumulative Sampling Numbers

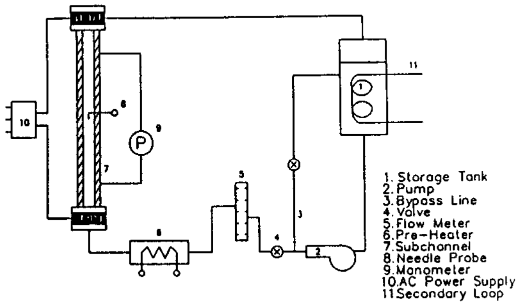


Fig. 9. Schematic Diagram of Test Loop

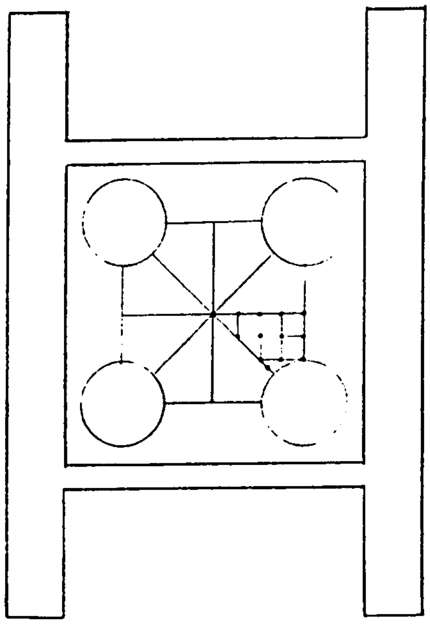
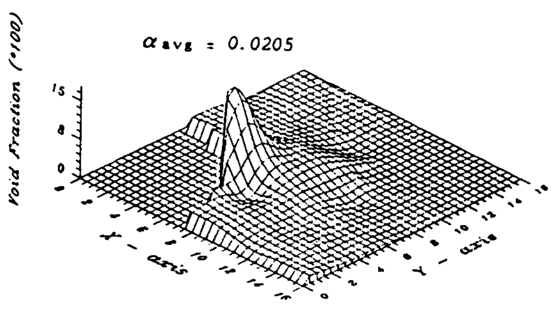
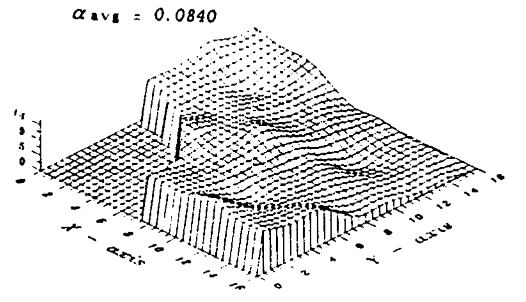


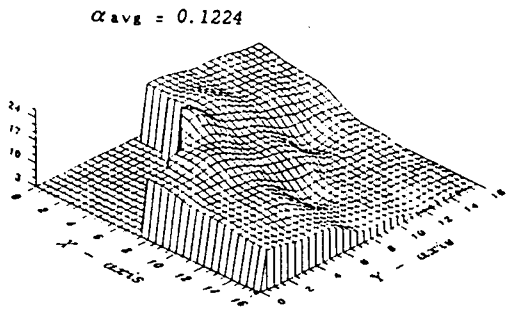
Fig. 10. Measuring Points in Subchannel



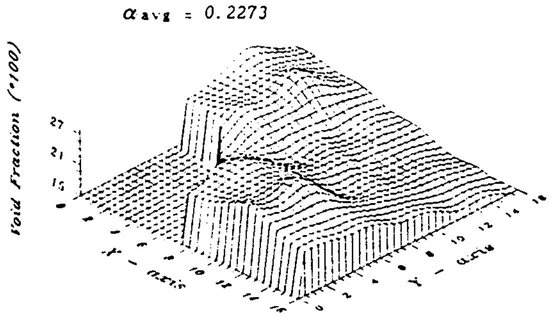
a. Void Distribution (*100) : Q = 4.2 m**3/hr



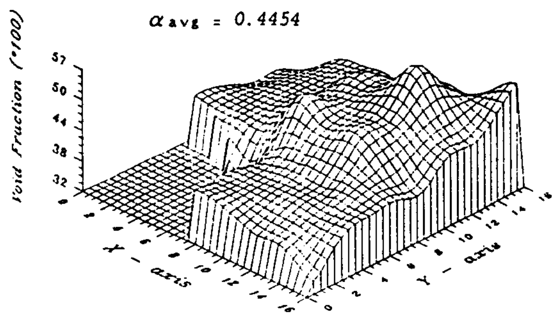
b. Void Distribution(*100): Q=3.8m**3/hr



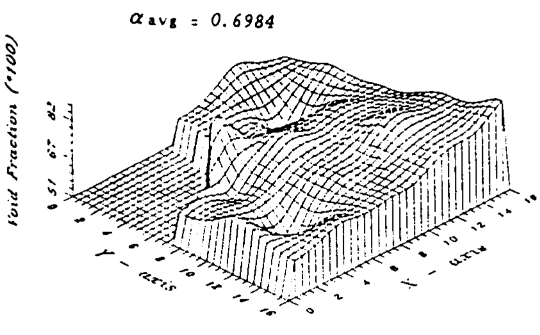
c. Void Distribution(*100): Q=3.4m**3/hr



d. Void Distribution (*100) : Q = 2.9 m**3/hr



e. Void Distribution (*100) : Q = 2.5 m**3/hr



f. Void Distribution (*100) : Q = 2.0 m**3/hr

Fig. 11. Void Distribution Varying Flow Rate–a,b,c,d,e

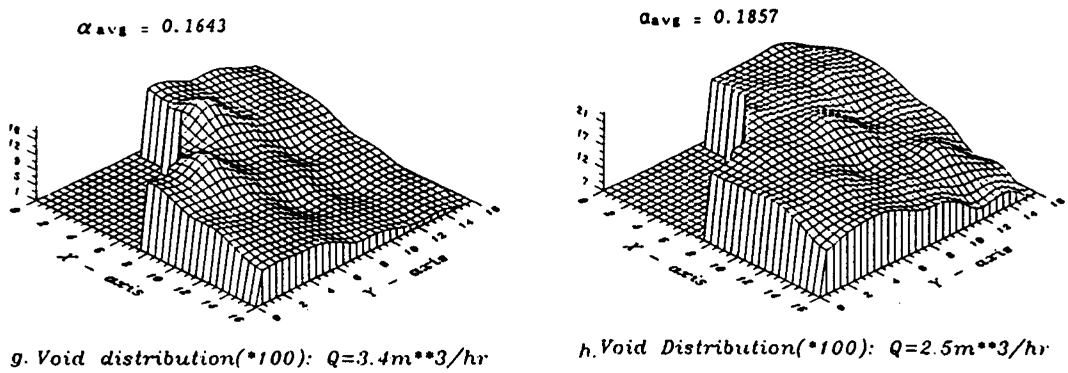


Fig. 12. Void Distribution of Similiar Average Void Fraction–g,h