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Experimental Investigation on Air-Distribution in a Water Flowing through a 61-Rod Bundle with Helical Spacers

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Abstract

The object of this study was to obtain data on air-distributions in two-phase up flow in vertical rod-bundle test-section. The test-section in this study was a hexagonal shaped 61-rod bundle where each rod was wrapped with helical spacers. The variables were flow rates of air and water and air inlet positions.

Experimental data were obtained at the outlet of the test-section. The experiments were performed in two parts. Firstly, data were taken at increasing flow rates of air keeping water flow rates constant, and secondly, at simultaneous increase of air and water flow rates. At each flow condition, air supply position could be changed to 4 different positions. Data obtained by electrical void-needle technique were analyed and are presented here in graphical forms for comparison.

The results of this study demonstrate qualitatively that air-distribution tends to be more uniform as water flow rates are increased. The air supply positions have noticeable effects on the pattern of air-distribution.

요 약

본 연구의 목적은 수직 연료봉 집합체에서 물—공기 2상 유동일 경우 공기분포현상에 관한 실험적 데이타를 얻는데 있다. test-section은 6각형, 61개의 연료봉 집합체로 구성되며, 각 연료봉은 helical spacers로 감겨져 있고, 사용되는 유체는 공기와 물이다.

실험은 크게 2부분으로 나누어서 물의 유량을 일정하게 하고 공기의 유량을 증가시킬 경우와 물과 공기의 유량을 동시에 증가시킬 경우의 공기분포현상에 관해 실시하였다. 공기는 4구멍을 통해 각각 주입시켰다. 보이드율의 측정은 전기적 Void-needle 방법을 적용하였으며 그 결과는 도표를 통해 보여주고 있다.

이 실험의 결과로써 물의 유량을 증가시킬 수록 공기분포는 균일하게 되며, 공기 공급 위치는 공기분포에 큰 영향을 미치고 있음이 입증되었다.

1. Introduction

The study of air-distribution is of interest for a basic understanding of thermal hydraulic phenomena in reactor coolant channel as well as insight to cross flow induced mixing phenomena, particularly in liquid metal cooled fast breeder reactors.

In the operation of nuclear reactor, some kinds of gases, such as argon, may be introduced at the inlet of the coolant-channel through different sources, namely, through coolant circulating pumps, and thus the resulting mixture-flow proceeds to the outlet section with, probably, different distributions of either phases in different sub-channels. Introduction of this gas-phase in coolant-flow

a) may expulse some volume of coolant from the coolant-channel, resulting in increase of coolant-temperature, and

b) may contact the heated surfaces of the fuel-elements resulting in decreaset of heat transfer coefficient between flowing coolant and heated fuel-surfaces.

In addition to the hydro and thermodynamic changes of the coolant, the presence of gas-phase changes the reactivity of the reactor fuel core also. This situation, therefore, demands for proper investigation to be carried out relative to air distribution determination from sub-channel to sub-channel in order to find out, from thermal hydraulic point of view, the severely affected regions of air-content. So far, no predictive theoritical study or exprimental investigation for air-distribution in multi-rod bundle flow channel have appeared in the literature; although much works have been performed in two-phase mixtures flow in geometries of single-tube or rectangular flow-channel. Therefore, an experimental study has been carried out and reported here to determine air-distribution in the outlet of a 61-rod bundle test-section with wire wrap spacers in order to find qualitatively the tendency of the distribution pattern taking into account the variations of flow-rates (both air and water) and air-inlet positions upstream the simulated test section.

2. Statement of the problem and Theory

In two-phase flow, subchannel flow distribution across any section depends on many factors. The dominating factors may be fluid properties, flow velocities, geometries of flow-channel and flow regimes. Theoretical attempts in determining the void-profile considering these dominating factors have resulted in complicated expressions. Fortunately, simple expressions are also available if the flow pattern is assumed to be equilibrium homogeneous in all respects.[1]

Homogeneous flow theory provides easier technique for analysing two-phase flow. Suitable average properties are determined and the mixture is treated as pseudofluid that obeys the usual equations of single-component flow. All of the standard methods of fluid-mechanics can then be applied.

Differences in velocity, temperature and chemical potential between the phases will promote mutual momentum, heat and mass transfer. Often these processes proceed very rapidly, particularly when one phase is finely dispersed in the other, and it can be assumed that equilibrium is reached. In this case, the average values of velocity, temperature and chemical potential are the same as the values for each component and we have homogeneous equilibrium flow. The resulting equations are simple and easy to use, but it is often advisable to check the validity of the equilibrium assumptions by using more accurate theories. However, as a first step of investigation of air-distribution phenomena, the theory of homogeneous flow may be applied to a good approximation. Thus, the theoretical model, which is used here for calculations of void-fractions, is based on assumptions that the mixture-flow is isothermal, steady and homogeneous equilibrium[2,3,4,5]

For homogeneous steady flow with velocity equilibrium, the void-fraction at any point of the flow cross-section, assuming further time-averaged values may be expressed as:

$$\text{Av. Void-fraction}=\frac{\text{air volume flow rate}}{\text{air volume flow rate}+\text{water volume flow rate}}$$

$$\text{or: } \alpha=\frac{V_g}{V_g+V_l}$$

Now, in multirod-bundle fluid channel, where each rod in turn is wrapped with helical wire spacer for better heat transfer, it is reported that cross-flow of coolant takes place to a certain extent from sub-channel to sub-channel[6].

Therefore it is logical to expect that the void-distribution across such a flow-channel will be somewhat different from that of plain rod-bundles without wire spacers. Since no direct theoretical expression for void fraction-distribution in multirod bunble flow geometry with helical spacers is available, the only recourse here is to determine the same by experiment.

In order to measure void fraction or air-distribution across outlet of the test-section, there are several void-measuring techniques available now-a-days.[7,8] Of these electrical veid-needle technique seems to be suitable in the present experimental void-measurement due to its simplicity in use.

When void-needle is placed in flow-channel, it can send signals as it touches the surface of any air-bubble. These signals can be, through proper instrumentation, recorded on paper. The size/width of the recorded signal depends on contact time with each bubble, in other words, with length of the bubble making contact with tip of the needle. So contact-period for bubbles for a certain sampling time can be counted.

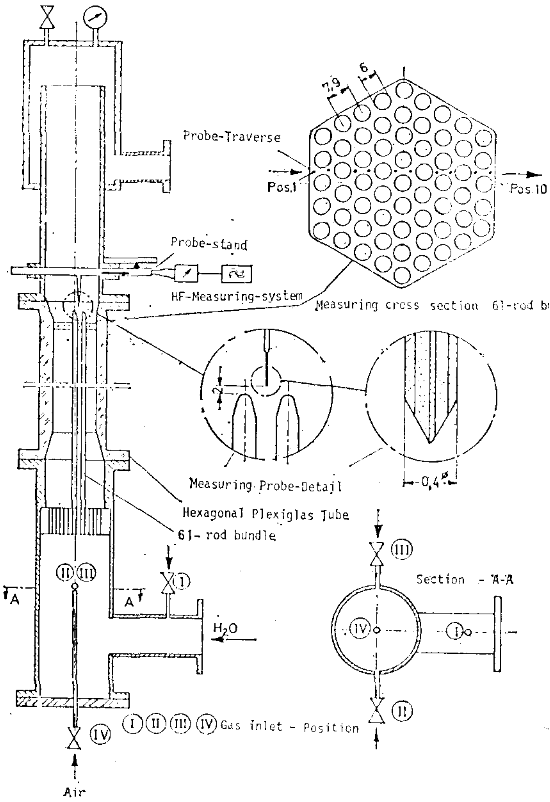

Fig. 1. Test section with measuring-probe and gas inlet-position.

Table 1. Geometries and dimensions of 61-rod bundles for studies on air-distribution with hexagonal rod arrangement

Type of spacer		Helical wire
Rod diameter (D)	mm	6
Rod Pitch (P)	mm	7.9
P/D ratio	—	1.32
Support length of rods in bundle	mm	300 100* and 200*
Helical lead	mm	300 100* and 200*
Minimum rod distance	mm	1.9
Wire diameter	mm	1.9
Tube wall thickness	mm	0.4
Rod length	mm	1500

* These configurations are also possible

3. Experimental Apparatus

The experimental apparatus consisted of a vertically mounted test section, equipped with a 61-rod bundle (Fig. 1). Each rod in the bundle was wrapped with helical wire spacer and then the rods were arranged hexagonally. The bundle was placed inside a hexagonal-shaped plexiglass shroud, through which visual observation was possible during actual test-condition.

Necessary dimensions of the test section are shown in table 1. The test section was connected with sub-cooled water inlet feeder-pipe throught an inlet-header. The water from the test-section passed through outlet feeder-pipe to an outlet-header. A by-pass line was connected in parallel with the test section for fine controlling of water flow-rates. Water from outlet-header passed into the air-separator tank placed at the top of the test section-assembly and water from this tank was recirculated to the inlet-header through a centrifugal pump. At the inlet to the test section a rotameter-type flow-meter device was connected in order to measure volume flow rate of water. A pressure gauge device was mounted at the outlet of the test section for measurement of outlet pressure. An ordinary mercury thermometer was used in the air-separator tank for recording water temperature at each test run condition.

To perform the air-distribution experiment using the test section described above, measured quantities of air at nearly constant temperature (20°C) was supplied to the inlet of the test section through a Fischer & Porter type flow-meter device. Normal flow rate calibration of this device was made based on 760mm Hg and 20°C temperature condition. So actual air flow-rates were obtained by applying a correction method taking into account of changes of

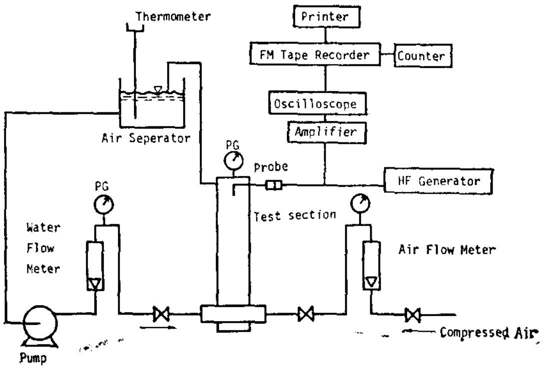

Fig. 2. Line diagram of Test rigs and measuring system

pressure and temperature. For measurement of inlet air pressure, a pressure-gauge was mounted in between flow meter and inlet to the test section. During all test-runs, temperature of air remained practically constant. From the flow meter device, air was supplied to inlet of the test section. 2 drills to air-flow-connections were made at the same plane of water inlet to the test section spaced at 180° angular distance around circumference. Two other air-connections were made respectively at centre of the bottom section of the test bundle and in the water inlet tube (Fig. 1).

A simplified line-diagram of measuring system is shown in Fig. 2.

4. Measuring device and its instrumentations

In order to measure void fraction in specified number of sub-channels across outlet of test section, the technique of electrical void-needle was used. A coaxial conductor which is sharpened at the tip is pulsed by a high-frequent voltage. The capacity of the probe is strongly changed whenever the tip of the probe enters the liquid phase, which happens when bubbles or droplets are passing the probe. The change in the capcity results in a related alteration ofthe pontential. This variation of the potential can be observed. Real signals observed by using a probe is shown in Fig. 3. In paper[10] the detailed principles of the techniques was given. The tip of the probe was made to traverse across outlet section by a traversing-mechanism The probe encountered 10 subchannels while passing through central region of the cross-section. A simplified schematic of the probe-traversing mechanism and position of the probe in each sub-channel can be seen in Fig. 1.

The circuit of the electrical-probe was completed incorporations of necessary electronics. Pulses or signals from a particular sub-channel detected by the probe placed in it, were fed into oscilloscope through amplifier for visual observation. Whenever tip of the measuring probe made contact with an air-bubble, it sent a pules, whose shape and size depend on the shape and size of the detected bubble. Further, connection was made from oscilloscope to FM tape recorder in order to record all pulses detected by the probe. Thus, for a definite sampling time, all the signals detected by the probe placed in a sub-channel could be recorded each time in test run condition. There was a clear difference of air-level and water-level in the recorded paper. By considering the time dependency of the signal one roughly can assess the void fraction in the subchannel. At first the signals are processed to the modified square-wave signals (Fig. 3) applying a suitable trigger level. Simplified schematic of the void measuring instrumentation has been shown in Fig. 2.

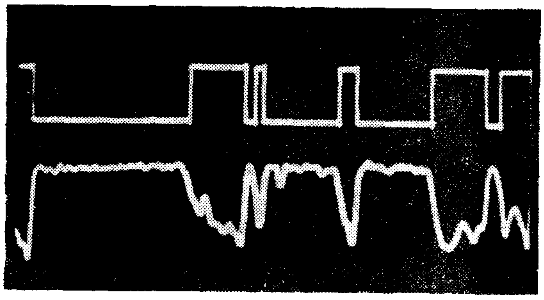

Fig. 3. Showing typical signals detected measuring-probe

5. Experimental procedure

After checking all loop-connections in proper position, water circulating-pump was started first and flow was allowed to continue for few minutes in order to obtain steady flow condition. Next, air-supply valves at main supply line and at inlet to the test section were opened. Finaly, air-supply control valve through air-flow meter was opened. This precautionary steps for supplying of air to the test section were taken in order to prevent any flash-back of water from test section. Then the two phase flow, i. e. mixtures of air and water, was again allowed to continue for few minutes with a view to achieve stabilisation of the whole system flow.

The regulating valves, situated at both water and air flowmeters, were properly adjusted to read desired flow-rates for each experimental test condition. Inlet and outlet pressures from the pressure-gauges were recorded at same time. Temperature of water was taken in each test run using mercury thermometer placed in the air-separator tank.

All electrical connections of the electronics for the void-measuring probe were checked and put on. Few minutes were allowed to elapse before start of actual measurement. The void-probe was placed in sub-channel no. 1 using the probe-traversing mechanism. The position of the probe in each sub-channel was determined by measuring the gap between two adjustable nuts on the traversing-mechanism. For this purpose, a distance-calibration-chart for the probe-traverse across outlet of test section was prepared beforehand.

When all the steps, as described above, were completed properly, singnals from the measuring probe in sub-channel no. 1 were recorded via amplifier, oscilloscope on FM tape recorder. Similar recordings were made for all other sub-channel positions.

The same procedure was repeated with other test runs.

6. Analysis of recorded data

The presence of an air-bubble in any sub-channel was detected by the electrical probe, placed there as a signal whenever bubble made contact with tip of the probe. Thus the magnitude of the signal dected represented the size of the bubble. So the recorded pulses from the detected signal represented both numbers and sizes of bubbles making contact with the detector across outlet of cross-section in a given sampling time.

Now, for a particular flow condition, length of a bubble is proportional to time of contact of that bubble with the bubble-detector. So time of contact, or rather duration of contact, is related with width of recorded pulse. Thus measuring the widths of all pulses in bubble-phase-level one can determine the total contact time of bubbles, which is also representative of total bubble-lengths. It is to be noted here that, in the recorded paper, the air and water-phases are recorded in two seperate levels.

Namely, the number of the modified square-wave signals from the probe, which corresponds to the number of bubbles arriving at the measuring subchannel for a given sampling time, was counted by a digital counter. Void fractions determined in this way were summarized and thses and shown in Fig. 4-9.

7. Results and discussion

Sub-channel averaged void-fractions at outlet of test section, determined from the present experiment were plotted against sub-channel positions for 3 different flow conditions and for 4 different air-supply positions.

For the test runs of set A, the inlet flow rates of water were $8.5m^3/h$, and air 0.17, 0.44 and $0.63m^3/h$ (based on standard pressure and temperature). For test runs of set B, the inlet flow rates of water and air were respectively 10.0, 20.0 and $30m^3/h$ and 1.44, 2.27 and $2.92m^3/h$ (based on actual pressure and temperature). The air-supply positions were arranged respectively through: water inlet (I), centre of inlet section (IV) and two side inlets at 180° apart (II and III).

Graphical representations of the experimental results were arranged in such a way so as to observe the effects of flow rates and air supply positions at inlet on air-distribution at outlet of the test section (Fig. 4-9). Examination of the evaluated results (plottings of void-fractions versus sub-channel positions) reveals the following global statements:

1) For a particular air supply position, when air flow rate alone is increased keeping water flow rate constant, the pattern of air-distribution in outlet sub-channels, evaluated at increasing air flow rates similar tendency, the air content in the outlet of cross section is not homogenouesly distributed. There are sub-channels showing no air, others showing much more than in the homogenouesly distributed case (up to 4 times higher) (Fig. 4, 5).
2) For the same particular air-suply position, when both air and water flow rates are increased, the distribution pattern show also similar tendency. In this case, fluctuation in

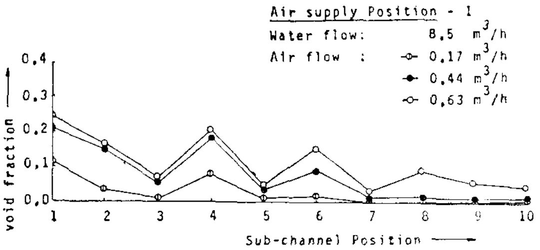

Fig. 4. Measured void fraction as a function of sub-channel Position in 61-rod-bundle with helical Spacer

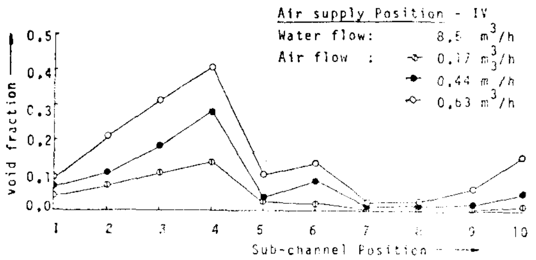

Fig. 5. Measured void fraction as a function of sub-channel Position in 61-rod bundle with helical spacer

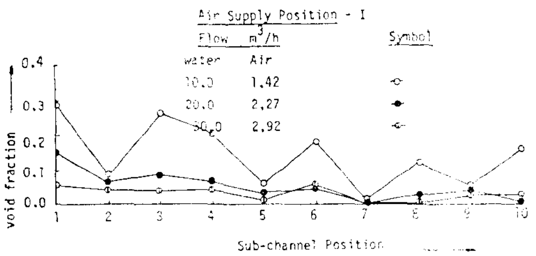

Fig. 6. Measured void fraction of sub-channel Position in 61-rod bundle with helical spacer

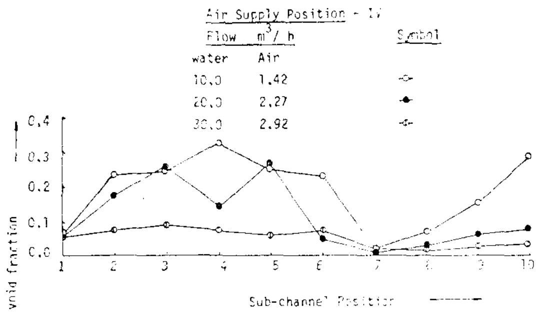

Fig. 7. Measured void fraction as a function of sub-channel Position in 61-rod bundle with helical spacer

void fraction decreases and mean void-fraction also decreases (Fig. 6-9)

3) For particular flow-rates condition, when air supply positions are changed, the pattern of the air-distribution, evaluated at each changed air supply position, shows different tendency. It is further noted that the deistribution patterns for the air-supply positions II and III (through two side inlets), appear to be of opposite tendeny; while those for I and IV (through water inlet and centre of test-section inlet) are of almost similar tendency. (Fig. 6-9).

8. Conclusion

The above interesting findings may be expl-

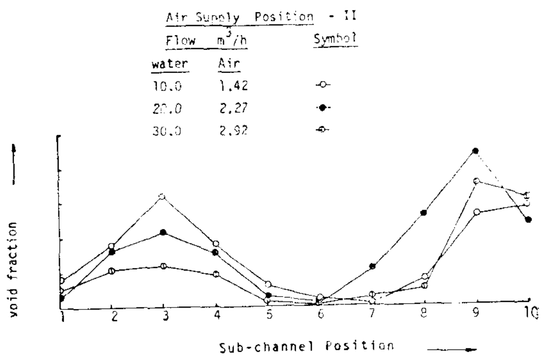

Fig. 8. Measured void fraction as a function of sub-channel Position in 61-rod bundle with helical spacer

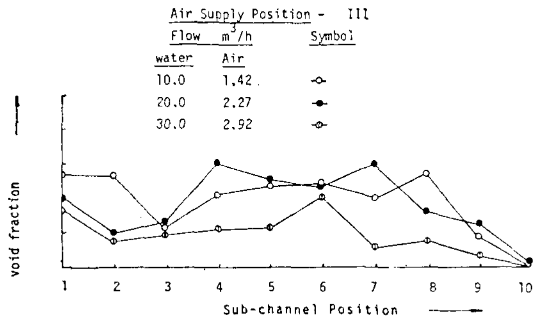

Fig. 9. Measured void fractions as a function o sub-channel Position in 61-rod bundle wit helical spacer

ained that:

a) Measured average air-distribution at test-section shows similar increase in value with the increased void-fraction introduced at inlet. This result, therefore, varifies that the simple theoretical model for void fraction calulation and the experimental solution method used are appropriate in thise xperimental air-distribution study.

b) Increase in void fraction variation across the bundle outlet and increase in mean-void fraction with respect to increase of air flow rate alone are due to increase of inlet void fraction. In this case, the average void fraction at inlet was increased, for example, from~2% to~7%.

c) Decrease in void fraction variation and decrease in mean-void fraction in case of increase of both air and water flow rates are due to decrease of inlet void fraction introduction. In this case, the average void fraction at inlet was decreased from~13% to ~9%.

d) Measured air-distribution tends to be more uniform when water flow is comparatively more increased. Hence it seems that for the same void fraction the air-distribution at outle tends to assume uniform pattern at higher coolant flow. This situation may be considered as an important advantageous factor for safety reasons.

e) Different air-distribution patterns obtained through changing the air-inlet positions have recognized the fact that the effect of air introduction geometry and position should be taken inot account in the design of reactor coolant channel inlet also.

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