International Agreement Report

Assessment of CCFL Model of RELAP5/MOD3 Against Simple Vertical Tubes and Rod Bundle Tests

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Assessment of CCFL Model of RELAP5/MOD3
Against Simple Vertical Tubes and Rod Bundle Tests

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Abstract

The CCFL model used in RELAP5/MOD3 version 5m5 has been assessed against simple vertical tubes and rod bundle tests performed at a facility of Korea Atomic Energy Research Institute.

The effect of changes in tube diameter and nodalization of tube section were investigated. The roles of interfacial drags on the flooding characteristics are discussed. Differences between the calculation and the experiment are also discussed.

A comparison between model assessment results and the test data showed that the calculated value lay well on the experimental flooding curve specified by user, but the pressure jump before onset of flooding was not calculated.

Acknowledgement

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Nomenclatures

ρ_f = Density of Liquid

ρ_g = Density of Gas

μ_f = Dynamic Viscosity of Liquid

μ_g = Dynamic Viscosity of Gas

σ = Surface Tension of Liquid

g = Universal Acceleration Constant

D_H = Equivalent Hydraulic Diameter = $4A/P$

D^* = Nondimensional Diameter = $D_H/[\sigma/\{g(\rho_f - \rho_g)\}]^{1/2}$

K_g^* = Kutateladze Number of Gas Flux = $\rho_g^{0.5} \alpha_g V_g / [g\sigma(\rho_f - \rho_g)]^{0.25}$

K_f^* = Kutateladze Number of Liquid = $\rho_f^{0.5} \alpha_f V_f / [g\sigma(\rho_f - \rho_g)]^{0.25}$

j_g^* = Nondimensional Gas Flux = $\rho_g \alpha_g V_g / [gD_H(\rho_f - \rho_g)]^{0.5}$

j_f^* = Nondimensional Liquid Flux = $\rho_f \alpha_f V_f / [gD_H(\rho_f - \rho_g)]^{0.5}$

P^* = Nondimensional Pressure Gradient = $|dP/dz|/[g(\rho_f - \rho_g)]$

Re_Γ = Film Reynolds Number = $4\Gamma/\mu_f$ where Γ denotes film mass flowrate per unit width

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1. Introduction

RELAP5/MOD2 [1] is an advanced computer code developed at the Idaho National Engineering Laboratory (INEL) for thermal-hydraulic analyses of Pressurized Water Reactor (PWR) system transients. It was produced by improving and extending the modeling base that had been established with the release of RELAP5/MOD1 [2] in December 1980, and was released as a 'frozen' code in April 1985. Numerous assessments have been carried out worldwide under the International Code Assessment and Application Program (ICAP), and a number of deficiencies in the code [3] have been identified. Evaluation of these deficiencies and their regulatory significance was providing the basis for improvements for a new version of RELAP5, namely RELAP5/MOD3. The RELAP5/MOD3 code was frozen at version 5m5 and released in May 1990. The code improvements were made in many areas including a CCFL model [4] and a new interphase drag model [5].

In the present study the CCFL model of RELAP5/MOD3/5m5 is assessed against a simple tube as a sample problem. It is also assessed against the rod bundle tests which were carried out in a test facility at the Korea Atomic Energy Research Institute (KAERI) to check interactions between the CCFL model and interphase drag model under countercurrent condition in rod bundle.

Descriptions of sample problems and test facility are provided in Chapter 2. A description of code and input model is given in Chapter 3. Various assessments against the sample problems and rod bundle tests are provided in Chapter 4. Sensitivity studies including fine nodalization model and RELAP5/MOD2 calculation are discussed in Chapter 5. Run statistics are given in Chapter 6. General conclusions are drawn in Chapter 7.

Appendix A contains the time averaged data for the rod bundle CCFL experiments at KAERI. Appendix B contains the complete set of input lists.

2. Sample Problems and Description of Test Facility

The phenomenon of Counter Current Flow Limitation (CCFL) has been extensively studied experimentally. Considering the geometries and layouts of the nuclear reactor, there could be some different CCFL conditions which need careful examinations to identify the limiting condition. They are at steam generator tubes, at the portion of the hot legs, at annulus of the vessel downcomer, at the upper tie plate of core and the fuel bundle. Most of experimental works have been performed in simple tubes using air/water flow, thus simple tube tests were selected as sample problems. The rod bundle CCFL tests have been completed by Korea Institute of Nuclear Safety (KINS) under contract to Korea Electric Power Co. (KEPCO) at the end of 1989. The tests were also selected as assessment tests to check the CCFL model and interphase drag model under countercurrent flow condition in rod bundles.

2.1 Sample Problems

An extensive experiment was performed by Wallis and Makkenchery [6] with various diameter pipes. In the experiments the liquid was drained into the test tube with various liquid entry design and the air was introduced by a surge tank into the test tube. The experimental results can be correlated by the well known Wallis correlation.

$$j_g^{*1/2} + m j_f^{*1/2} = C \quad (2.1)$$

The experimental constant varied due to the channel inlet shape, length or viscosity effect. For most cases, m has a value between 0.8 to 1.0 and C ranges from 0.7 to 1.0. Simple vertical tubes were chosen as sample problems to assess the RELAP5 model.

The inside diameter of tube is varied from 0.5 cm to 10 cm to check applicability of RELAP5 CCFL model.

2.2 Rod Bundle Tests

The rod bundle CCFL tests have been completed by Korea Institute of Nuclear Safety (KINS) under contract to Korea Electric Power Co. (KEPCO) at the end of 1989. The tests were also selected as assessment tests to check the CCFL model and interphase drag model under countercurrent flow condition in rod bundles.

The test were performed using air and water flow under the atmospheric pressure condition. The test facility consists of test section, water and air supply system, associated sensors and devices to measure flowrates of water and air, differential pressure, water levels, and data recording systems as shown in Fig. 2.1.

The major components of the test section, as shown in Fig.2.2, are (1) a lower plenum, (2) 4x4 cm square channel (145 cm in height) made of transparent lucite to allow visual observations, and (3) an upper plenum. The lower plenum has two inlets, one for water and the other for air. The two inlets are designed in such a way that direct interaction between the incoming air and water and the effects of entrance and entrainment at the inlet can be avoided. The 3x3 stainless steel tube bundle is placed vertically at the center of the lucite square channel. The tube array has the same geometrical dimensions of the typical 17x17 PWR fuel bundle. The outside diameter of each tube and pitch are 0.95 cm and 1.26 cm, respectively.

In order to obtain experimental data on the effects of spacer grids and multi-channel flow interactions on the CCFL, three tube-bundle types were used as shown in Fig.2.2 : The first type

is a 3x3 tube bundle with no spacer grid, the second type is a 3x3 tube bundle with one spacer grid attached at 68.3 cm axially from the top (at "B" in Fig.2.2), and the third type is a 3x3 tube bundle with two spacer grids attached at 17.5 cm and 68.3 cm from the top respectively. For convenience in discussion, these bundles are designated here as type-1 (no spacer-grid), type-2 (one-spacer grid), and type-3 (two spacer grids), respectively.

The grid assembly consists of individual slotted straps interlocked and brazed in an egg-crate arrangement to join the straps permanently. The test section was equipped with two pressure taps. An air-water separator for measuring the entrainment rate and two water level gauges for measuring the film downflow and entrainment rates were also provided.

The water is first introduced into the inlet located at the bottom of the lower plenum, then it rises up to the top of the tube bundle flowing inside of each tube. The water flowing out of the nine tubes at the top (point "A" in Fig.2.2) is then directed, via a nozzle, to flow in reverse direction downward by gravity over the outer surface of the 9-tubes forming a continuous annular water film. The nozzle is placed 30 cm above the top inlet (point "B" in Fig.2.2) of the test channel to form a fully developed flow. The more detailed description for the test facility is given in Reference [7] and [8].

The flooding data were obtained by varying the air flow rate while the water flow rate was fixed. Major quantities measured for each test were (1) liquid penetration rate, (2) liquid carry-over rate, (3) air inlet flow rate, and (4) test channel pressure drop. Actually, to obtain a single CCFL data point with a given test bundle, from 9 to 19 runs were made increasing the air velocity in step until the downward water film flow rate becomes zero (i.e., the zero penetration rate of water) while maintaining a constant water input rate. Although most of data have oscillatory behavior, the time averaged value during 100 seconds

are given in Appendix A. The measurement uncertainties consists of the error of pressure sensor, A/D (Analog to Digital) conversion error, and calibration error. The calculated error of channel pressure drop is about 5 mm H₂O. The estimated error for air flow measurement is about 650 cc/sec and for water flow it is about 1.7 % of liquid injection flow.

Fig. 2.1 Schematic Diagram of Air-Water Counter-current Flooding Test Loop with 3x3 Tube Bundle

Fig. 2.2 Three Type of 3x3 Tube Bundle Test Section

3. Code and Input Model Description

The assessment calculation for sample problems and rod bundle CCFL experiment was done using RELAP5/MOD3/5m5, code received at the beginning of May 1990. The descriptive document available for this code at the time of preparing this report are scheduled to be released later. However document of a CCFL model and a new interphase drag model tested in this assessment are available in reference [4] and [5].

3.1 Code Model Description

A general CCFL model, which was proposed by Bankoff [9], was implemented in the 5m5 version of RELAP5/MOD3 that allows the user to select the Wallis form, the Kutateladze form, or a form in between Wallis and Kutateladze forms. The general form using dimensionless flux is given by :

$$H_g^{1/2} + m H_f^{1/2} = C \quad (3.1)$$

$$H_g = \alpha_g V_g [\rho_g / g w (\rho_f - \rho_g)]^{1/2}$$

$$H_f = \alpha_f V_f [\rho_f / g w (\rho_f - \rho_g)]^{1/2}$$

where

$$w = D_j^{1-\beta} \rho$$

$$I = [\sigma / g (\rho_f - \rho_g)]^{1/2}$$

In the above equation, β can be a number from 0 to 1. For $\beta=0$, the Wallis form of CCFL equation is obtained, and for $\beta=1$, the Kutateladze form of CCFL equation is obtained. The user should make a decision for the input values of m, C , and β using the appropriate experimental results.

With regard to the solution method, if the CCFL model is

requested by the user, the coding checks if counter current flow exists and if the liquid downflow exceeds the limit imposed by eq.(2.2). If this is true, the sum momentum equation and flooding equation (2.2) are applied as the phasic momentum equations. Thus the difference equation, which contains the interfacial friction, is replaced with flooding limit equation (2.2).

Although the RELAP5/MOD3 has a user controlled junction flooding model for flooding at a singularity in the channel geometry, the counter current flow is much related to interfacial drag model. As a part of UK's contribution to the code improvement, the interfacial friction model suggested by CEGB [5] was implemented in a released version of RELAP5/MOD3. The new interfacial friction model was developed for the vertical bubbly and slug flow regimes, and a CCFL correlation appropriate for a straight uniform flow channel was also adopted for the calculation of drift flux used for interfacial friction models.

3.2 The Calculation Input Model

3.2.1 The Sample Problems

The sample problems used in the present calculation is closely related to the test facilities used in many previous experiment for a vertical single tube. The specific nodalization is given by Fig.3.1.

Most experiments were performed using air and water. The water was drained into the test section from the top plenum, forming downward film flow. Air was introduced by a surge tank, flowing up into the test tube. The liquid inlet was modeled as a time dependent junction to specify the constant liquid injection. The air inlet junction from a surge tank was modeled as single junction with a smooth option to avoid the inlet contraction

effect of phasic momentum equation. However, Most experimental data show that the flooding occurs at the air inlet junction due to its geometric singularity, and thus the CCFL option was used at the air inlet junction (JUN-4000000). The air inlet flow was modeled as a time dependent junction. For most experiments the experimental data have oscillatory behavior during the flooding process, and thus the flooding data are presented as the time averaged value during a test period for a given air and liquid injection flow. A steady state calculation for a given air and liquid injection flow will be very time consuming work because there are many different flooding points. Therefore as test sample problems, the liquid flow was fixed and the air flow was increased slowly until the flooding is completed. After some trial and error calculations, we find a 200 second duration is enough to neglect the transient effect of increasing air flow.

For sample problems, the code input of the flooding curve was specified as follows ; the simple Wallis form.

$$j_g^{*1/2} + j_f^{*1/2} = 1 \quad (3.2)$$

In view of the geometries and layout of nuclear reactor, the specific flooding location for a single tube may be steam generator U-tubes. A typical inside diameter of the PWR tubes is about 1.7 cm. Thus a flooding test in 2 cm diameter tubes was selected as a base test case, and calculations for 5 different tube diameters (0.5 cm, 1 cm, 3 cm, 5 cm, and 10 cm) have been performed as sensitivity studies. The results were discussed in Section 5.1.

The test section pipe was modeled as 6 uniform volumes and liquid drain tank was modeled as a relatively large single volume.

In order to compare calculated values with flooding curves specified by user, the liquid velocity and air velocity at the specific junction were converted to nondimensional gas flux using

junction void fraction and velocity as "control variables" as shown below ;

$$\begin{aligned} j_g^* &= \rho_g^{1/2} \alpha_g V_g / [gD(\rho_f - \rho_g)]^{1/2} \cong 0.0112 D^{-1/2} \alpha_{gj} V_{gj} \\ j_f^* &= \rho_f^{1/2} \alpha_f V_f / [gD(\rho_f - \rho_g)]^{1/2} \cong 0.3195 D^{-1/2} \alpha_{fj} V_{fj} \end{aligned} \quad (3.3)$$

The physical properties of each phase were calculated at the experimental condition : 1 atm and 280 K.

3.2.2 Rod Bundle Tests

The specific nodalization and modeling were much similar to the sample problems as shown in Fig. 3.2. But the rod bundle form of the new interfacial friction model was activated by specifying the third flag (b) of an extended volume control flag, bfe, to be unity in the pipe volume of test section. The model geometry and elevation were related to the test facilities described in section 2.3. In the rod bundle CCFL experiment, three test bundles were used, and it was found experimentally that the flooding location is "air inlet" for type-1 test, "spacer grid" for type-2 test, and "first spacer grid" for type-3 test. Therefore three different locations for CCFL junction were examined as shown in Fig. 3.2, 3.3, and 3.4 corresponding to each type of test section.

For moderate high liquid flux, the experimental flooding curves of Kutateladze form are as follows;

$$\begin{aligned} K_g^{*1/2} + K_f^{*1/2} &= D^{*1/4} (= 1.44) && \text{for type-1} \\ K_g^{*1/2} + K_f^{*1/2} &= 1.38 && \text{for type-2} \\ K_g^{*1/2} + K_f^{*1/2} &= 1.23 && \text{for type-3} \end{aligned} \quad (3.4)$$

Therefore the code input value for flooding curve was specified

as above equations (Eq.3.4) for each type of tests.

In order to compare the calculated values with flooding curves specified by user, the liquid velocity and air velocity at the specific junction were converted to nondimensional gas flux using junction void fraction and velocity as "control variables" as shown below;

$$\begin{aligned} K_g^* &= \rho_g^{1/2} \alpha_g V_g / [g\sigma(\rho_f - \rho_g)]^{1/4} \cong 0.214 \alpha_{gj} V_{gj} \\ K_f^* &= \rho_f^{1/2} \alpha_f V_f / [g\sigma(\rho_f - \rho_g)]^{1/4} \cong 6.1 \alpha_{fj} V_{fj} \end{aligned} \quad (3.5)$$

Fig. 3.1 RELAP5 Nodalization for Air/Water Test Problem

Fig. 3.2 RELAP5 Nodalization for Type-1 Test Bundle

Fig. 3.3 RELAP5 Nodalization for Type-2 Test Bundle

Fig. 3.4 RELAP5 Nodalization for Type-3 Test Bundle

4. The Base Case Calculation

4.1 Simple Vertical Tubes

As discussed in section 3.2.1, the air/water countercurrent flow in a tube of 2 cm inside diameter was simulated with RELAP5/MOD3/5m5. Two calculations were performed with and without a CCFL junction option. Two results were compared in terms of air inlet flow and liquid downward flow at a CCFL junction, flooding curve, total mass flux, gas void fraction, flow regime, interfacial friction, and pressure drop in the test section. The time step size was fixed as 0.01 second during the whole transient. If the time step size became larger than 0.01 seconds, it was experienced that the calculation was unstable or failed in some cases.

Fig. 4.1 shows the gas flowrate at junction 4000000 with no CCFL option. The negative value means the upward direction as shown in Fig. 3.1. The gas flow was increased slowly during 200 seconds until the flooding was completed. During the first 10 seconds, the steady state calculation was performed to get the fully developed free falling annular film flow at zero air inlet flow. Although the air inlet flow through junction 6000000 was set to increase monotonously, the air flow into the test section through junction 4000000 had a little fluctuation at the start of restriction of liquid down flow (~ 120 sec.) and at the end of the flooding (~ 170 sec.). Fig 4.2 shows the restriction of the downward liquid flow. This restriction comes from the increase of the interfacial drag as air flow increases. As shown in Fig.4.3, the junction flow regime is annular-mist(regime 6) over the whole flooding range and becomes dispersed flow regime (regime 7) as the gas void fraction becomes nearly to unity (> 0.9999). The gas void fraction is shown in Fig.4.4. As shown in Fig.4.4 the liquid film thickness increase with increasing air flow, and then

decrease after the flooding occurs. The liquid sweep from the bottom to top section was calculated. The trends of the interfacial friction, shown in Fig. 4.5, has the same trends of liquid void fraction, because the interfacial friction factor, which is described by a Bharathan correlation [10], increases with increasing film thickness. The channel pressure drop trend is similar to that of liquid void fraction, as shown in Fig. 4.6. The new interfacial friction which is based on drift flux, V_{gj} , may not be applied because the mass flux is lower than $50 \text{ kg/m}^2\text{sec}$ over most of the flooding range as shown in Fig. 4.7. If we draw a flooding curve using the upward gas flux and the downward liquid flux values calculated during the test transient, it is possible to compare the calculation with the experimental results obtained in single tube tests. Most experimental results can be correlated by the well known Wallis correlation as discussed in section 2.2. The experimental constant in Eq.(2.1) varied due to the channel inlet shape, length or viscosity effect. For most cases, the slope (m) has a value between 0.8 to 1.0 and the constant (C) ranges from 0.7 to 1.0. However the slope of calculated flooding curve (m) is about 0.5, although the CCFL point (C) is about 1.0, as shown in Fig.4.8. Thus the flooding occurs at much higher air velocity ($j_g^* = 0.7$) than the most experimental data. It may be due to lack of CCFL model applicability at the geometric singularity in test section.

Therefore the CCFL option was applied at the junction 4000000 (air inlet). A simple Wallis form (Eq.3.2) was selected as a input value for the flooding curve.

The inlet air flow and downward liquid flow are fluctuated continuously after the flooding was reached (~ 70 seconds) as shown in Fig.4.9 and 4.10. The flow regime in the test section changes between annular-mist (regime 6) and slug (regime 5) during the flooding process, and becomes the dispersed flow regime (regime 7) as the gas void fraction becomes near unity ($>$

0.9999). The gas void fraction in the test channel is shown in Fig.4.12. The bottom junction restricts the downward flow after 70 seconds by the CCFL curve provided by user, and thus the liquid fraction in upper junctions increases to nearly 0.2. The increased liquid fraction results the change of flow regime; slug regime from annular mist flow. The interfacial friction, as shown in Fig. 4.13, increases sharply in slug flow regime. Thus the liquid carry-over occurs through the whole test channel. It reduces the liquid void fraction again, and the above cycling process is continued until the flooding is completed. The channel pressure drop, shown in Fig. 4.14, increases sharply after the onset of flooding (70 sec.) and decreases slowly during the flooding process. These oscillatory behavior and pressure trends are much similar to the observed phenomena in most CCFL experiments. The total inlet mass flux also oscillates during the flooding. Although the air inlet flow and the downward liquid flow oscillate, their oscillations lie near the CCFL curve specified by user to satisfy the difference momentum equation of RELAP5, as shown in Fig. 4.16.

4.2 Rod Bundle Tests

As described in section 3.2.2, the calculations for each test type were performed and compared with the experimental data. The input data for calculations were prepared based on the specific experimental condition. The liquid injection flow rate was fixed to 2600 cc/min. The corresponding mass flux is about $35 \text{ kg/m}^2\text{sec}$ in the case of no air flow. The gas flow was increased slowly enough to neglect the transient effect of increasing the air flow.

4.2.1 Type-1 Test Bundle

For test type-1, two calculations were performed with or without CCFL option. Two calculation results were compared with experimental data obtained from the test facility described in section 2.2.

The air inlet flow was increased during 200 seconds until the flooding is completed, as shown in Fig. 4.17. The downward liquid film flow was restricted at 110 seconds by the increased interphase drag force (Fig. 4.18). A little fluctuation occurs at the early stage of the flooding. The calculated flooding curve using the above air flow and liquid flow at junction 4000000 was presented in Fig. 4.19 as a Kutateladze form. The calculated flooding occurs at much higher air velocity than the experimental data (more than 20 %). The complete flooding occurs at $K_g^* = 3.6$, although it was not presented in figure. The channel pressure drop was presented in Fig. 4.20, with respect to the nondimensional air velocity (K_g^*) in order to compare the experimental data. As shown in the figure, the pressure continuously increases with increasing air flow, while the experimental data shows the sudden jump after the onset of flooding. The flow regime changes from annular mist flow (mode 6) to slug flow (mode 5) as shown in Fig. 4.21. The gas void fraction decreases with increasing air flow rate and maintained nearly constant during the flooding process (Fig. 4.22). The interfacial friction factor increases somewhat slowly, not dramatically (Fig. 4.23). However the interphase drag force was sufficient to carry over the water flow due to the high air velocity. All discrepancies may be resulted from the lack of applicability of CCFL model at the geometric singularity in test section.

In the experiment of type-1 test, the flooding occurs at the air inlet junction. Therefore the experimental flooding curve ,Eq. (3.4), was specified as code input value at the air inlet junction. The calculated air inlet flow and the downward liquid

flow at junction 4000000 are shown in Fig. 4.24 and 4.25. These calculated values were used to generate the flooding curve, i.e. the Fig. 4.26. The calculated flooding values lie well on the specified CCFL curve which was obtained from the experimental data. The pressure drop in the test channel is shown in Fig. 4.27. The experimental data of the liquid injection 2600 cc/min are also presented in the figure. In the experiment, it was shown that the static pressure drop in the channel is nearly proportional to the liquid void fraction. The pressure drop increased suddenly before the onset of flooding and oscillated continuously. After the liquid carry over, the pressure decreased again with decreasing liquid fraction. There are two discrepancies between calculation results and experimental results. First, a sudden jump occurred at a higher gas velocity compared with experiment. In the experiment, the liquid downward flow was restricted by the singularity at the air inlet with $K_g^* = 0.9$, and the liquid fraction increased. Although the liquid flow oscillated due to flow restriction, the total time averaged liquid flow remained constant. Sometimes it was called "the onset of liquid mixing". It resulted a sudden increase of pressure drop before onset of flooding. In the simulation a sudden pressure drop occurred after "the onset of flooding" ($K_g^* = 1.1$), because the liquid holdup in the channel is possible after "the onset of flooding". Second, the peak pressure drop was lower than the experimental results and increased with the air flow. It may be resulted from the interphase drag for rod bundle. The transition to slug flow (mode 5) from annular mist flow (mode 6) occurred after the onset of flooding, as shown in Fig. 4.28, and thus a sharp increase of interfacial friction coefficient was also calculated (Fig. 4.29). The liquid film thickness increased with increasing air flow and jumped suddenly at the point of flooding due to restriction of the downward liquid flow at the air inlet junction (Fig. 4.30). Although the liquid fraction decreased

slowly during the flooding process, the calculated pressure drop increased due to increase of interphase drag force with increase of air flow as shown in Fig. 4.27.

4.2.2. Type-2 and Type-3 Test Bundle

In the experiment for the other type of test bundle, the main characteristics of flooding phenomena are almost identical to the characteristics of type-1 test bundle. However the flooding locations due to the singularity of geometry were quite different. Thus a different location of CCFL junction was examined as presented by the nodalizations shown in Fig. 3.3 and 3.4, following the experimental observation. The flooding curve was specified according to the equation (3.4) which was determined by the experiments. The calculated flooding curve at the location of the spacer grid (junction 3-030000) was compared for type-2 test bundle in Fig. 4.31. The calculated values lie well on the curve specified by user and the channel pressure drop during flooding process agrees well with the experimental data, as shown in Fig. 4.32. But a sudden jump of pressure occurs just after the onset of flooding due to the same reason described in the previous section.

The calculated flooding curve at the location of the first spacer grid (junction 3-010000) was compared with experimental data for type-3 test bundle also. The calculation results lie well on the curve specified by user, but the results of CCFL at a higher air velocity than the complete flooding point are somewhat curious (Fig. 4.33). It may be resulted from a wrong implementation or coding error of flooding model in 5m5 version of RELAP5/MOD3 code. Thus no further discussions for the curious results are given here. The pressure drop agreed well with experimental data, except for the point of sudden jump, as shown in Fig. 4.34. The curious pressure increase after the complete

flooding was considered to be a result of coding error of 5m5 version also.

Fig. 4.1 Air Inlet Flowrate at the Junction 4000000

Fig. 4.2 Downward Liquid Flowrate at Junction 4000000

Fig. 4.3 Flow Regime Change at the Test Section Junction
(1 - jun.3010000 : 2 - jun.3020000 : 3 - jun.3030000)
4 - jun.3040000 : 5 - jun.3050000 : 6 - jun.4000000)

Fig. 4.4 Gas Void Fraction at the Test Section Junction
(1 - jun.3010000 : 2 - jun.3020000 : 3 - jun.3030000)
4 - jun.3040000 : 5 - jun.3050000 : 6 - jun.4000000)

Fig. 4.5 Interfacial Drag Coefficient at the Test Section Junction
(1 - jun.3010000 : 2 - jun.3020000 : 3 - jun.3030000
4 - jun.3040000 : 5 - jun.3050000 : 6 - jun.4000000)

Fig. 4.6 Pressure Drop in the Test Section

Fig. 4.7 Mass Flux through the Junction 4000000

Fig. 4.8 Calculated Flooding Data at the Junction 4000000

Fig. 4.9 Air Inlet Flowrate at the Junction 4000000

Fig. 4.10 Downward Liquid Flowrate at Junction 4000000

Fig. 4.11 Flow Regime Change at the Test Section Junction
(1 - jun.3010000 : 2 - jun.3020000 : 3 - jun.3030000
4 - jun.3040000 : 5 - jun.3050000 : 6 - jun.4000000)

Fig. 4.12 Gas Void Fraction at the Test Section Junction
(1 - jun.3010000 : 2 - jun.3020000 : 3 - jun.3030000
4 - jun.3040000 : 5 - jun.3050000 : 6 - jun.4000000)

Fig. 4.13 Interfacial Drag Coefficient at the Test Section Junction
(1 - jun.3010000 : 2 - jun.3020000 : 3 - jun.3030000
4 - jun.3040000 : 5 - jun.3050000 : 6 - jun.4000000)

Fig. 4.14 Pressure Drop in the Test Section

Fig. 4.15 Mass Flux through the Junction 4000000

Fig. 4.16 Calculated Flooding Data at the Junction 4000000

Fig. 4.17 Air Inlet Flowrate at the Junction 4000000

Fig. 4.18 Downward Liquid Flowrate at Junction 4000000

Fig. 4.19 Calculated Flooding Data at the Junction 4000000
($\square$ - Experiment ; + - Calculation)

Fig. 4.20 Pressure Drop in the Test Section
($\square$ - Experiment ; + - Calculation)

Fig. 4.21 Flow Regime Change at the Test Section Junction
 (1 - jun.3010000 : 2 - jun.3020000 : 3 - jun.3030000
 4 - jun.3040000 : 5 - jun.3050000 : 6 - jun.4000000)

Fig. 4.22 Gas Void Fraction at the Test Section Junction
 (1 - jun.3010000 : 2 - jun.3020000 : 3 - jun.3030000
 4 - jun.3040000 : 5 - jun.3050000 : 6 - jun.4000000)

Fig. 4.23 Interfacial Drag Coefficient at the Test Section Junction
 (1 - jun.3010000 : 2 - jun.3020000 : 3 - jun.3030000
 4 - jun.3040000 : 5 - jun.3050000 : 6 - jun.4000000)

Fig. 4.24 Air Inlet Flowrate at the Junction 4000000

Fig. 4.25 Downward Liquid Flowrate at Junction 4000000

Fig. 4.26 Calculated Flooding Data at the Junction 4000000
($\square$ - Experiment ; + - Calculation)

Fig. 4.27 Pressure Drop in the Test Section
($\square$ - Experiment ; + - Calculation)

Fig. 4.28 Flow Regime Change at the Test Section Junction
(1 - jun.3010000 : 2 - jun.3020000 : 3 - jun.3030000
4 - jun.3040000 : 5 - jun.3050000 : 6 - jun.4000000)

Fig. 4.29 Interfacial Drag Coefficient at the Test Section Junction
(1 - jun.3010000 : 2 - jun.3020000 : 3 - jun.3030000
4 - jun.3040000 : 5 - jun.3050000 : 6 - jun.4000000)

Fig. 4.30 Gas Void Fraction at the Test Section Junction
(1 - jun.3010000 : 2 - jun.3020000 : 3 - jun.3030000
4 - jun.3040000 : 5 - jun.3050000 : 6 - jun.4000000)

Fig. 4.31 Calculated Flooding Data at the Junction 3030000
($\square$ - Experiment ; + - Calculation)

Fig. 4.32 Pressure Drop in the Test Section
($\square$ - Experiment ; + - Calculation)

Fig. 4.33 Calculated Flooding Data at the Junction 3010000
($\square$ - Experiment ; + - Calculation)

Fig. 4.34 Pressure Drop in the Test Section
($\square$ - Experiment ; + - Calculation)

5. Sensitivity Results and Discussion

5.1 Tube Diameter

The base calculations for the sample problem of a simple vertical tube the inside diameter of which is 2 cm has been performed. Although the inside diameter was selected for the reason of the similarity of the steam generator U-tubes, there are many other possibilities for the flooding in the tubes which have a different size of the diameter. The different hydraulic diameter causes the different interfacial drag and may result in different flooding characteristics. The calculations have been performed for a wide range of diameter size. A pair of calculations were done for each case of a tube diameter, with and without a CCFL junction option. The test cases and specified CCFL curves are summarized in Table 5.1

Table 5.1 Test cases for the simple vertical tubes.

Case	Tube Diameter	CCFL curves specified at junction 4000000 by user's input
1	0.5 cm	$j_g^{*1/2} + j_f^{*1/2} = 1.0$
2	1.0 cm	$j_g^{*1/2} + j_f^{*1/2} = 1.0$
3	2.0 cm	$j_g^{*1/2} + j_f^{*1/2} = 1.0$ (Base Case)
4	3.0 cm	$j_g^{*1/2} + j_f^{*1/2} = 1.0$
5	5.0 cm	$j_g^{*1/2} + j_f^{*1/2} = 1.0$
6	10.0 cm	$K_g^{*1/2} + K_f^{*1/2} = 3.2^{1/2}$ (Large Tube)

For the 0.5cm tube diameter (case 1), the flooding occurs much earlier than the flooding curve specified by user. Therefore there are no differences between the results obtained with a CCFL

option and those obtained without a CCFL option, as shown in Fig. 5.1, 5.2, 5.3 and 5.4. The calculated pressure drop increased monotonously with increasing air velocity, while most experiments showed a sudden jump of pressure drop. The dispersed values were due to oscillation before the reaching of the steady state for the free falling film flow.

For the 1 cm tube diameter (case 2), the flooding curve and the pressure drop in the test channel calculated without a CCFL option are presented in Fig. 5.5 and 5.6. With a specified CCFL option chosen for test junction, the downward liquid flow was restricted by the CCFL curve or the interfacial drag force in case the interfacial drag force resulted in a lower liquid down flow. In this case the flooding data would lie not on the CCFL curve but on the restriction line determined by interfacial drag, in the regions between $j_f^{*1/2} = 0.05$ and $j_f^{*1/2} = 0.2$. The calculated flooding curve and pressure drop are presented in Fig. 5.7 and 5.8. The pressure drop increase suddenly just after the flooding condition is reached due to the increase of liquid void fraction resulted from the restriction of downward liquid flow.

For the 2 cm tube diameter (case 3), the results were fully discussed as a base case in the previous section.

For the 3 cm tube diameter (case 4), a flooding occurred at a much higher gas velocity when a CCFL junction option was not chosen and the pressure drop increased monotonously with increasing air velocity, as shown in Fig. 5.9 and 5.10. With a CCFL junction option, the flooding data lay well on the CCFL curve specified by user, and a sudden jump of pressure drop was predicted as shown in Fig. 5.11 and 5.12. The Fig. 5.12 shows a continuous oscillation of pressure drop during the flooding process. The above trend of pressure drop is a phenomenon which was observed in most experiments.

For the 5 cm tube diameter (case 5), the calculated flooding and pressure characteristics without a CCFL junction option have

almost similar trends of the case 4, except for the high oscillation due to flow instability (Fig.5.13, Fig. 5.14). This flow instability might be resulted from the reduced interfacial drag force and wall friction with increasing hydraulic diameter. When a CCFL option was applied at the junction, the flooding data lay on the specified flooding curve. However the high oscillations were calculated in the region between $j_f^{*1/2} = 0.1$ and $j_f^{*1/2} = 0.3$. The liquid flow oscillated from the countercurrent flow to cocurrent flow, while it was restricted by the CCFL curve, as shown in Fig. 5.15. The calculated pressure drop also oscillated continuously during the flooding process (Fig. 5.16). Since the oscillatory behavior are found in most experiments, the CCFL curve to be specified for the calculation was determined by the time averaging of the oscillatory values. Thus the calculated values oscillation should fall on the specified CCFL curve. The oscillations were resulted from the fact that the 5m5 code select the lower value of the two flows determined by a normal junction equation and the other by a CCFL junction equation.

For the 10 cm tube diameter (case 6) , the Wallis type of flooding curve is not valid any more due to the characteristics of a large diameter. Thus all calculated flooding data were presented by the form of Kutateladze form in Fig. 5.17 for the comparison of the experimental results. The calculation results show that high oscillations occurred and a complete flooding occurred at the $K_g^* = 4.8$ whereas the experimental results show that a complete flooding occurred at $K_g^* = 3.2$. The pressure drop, shown in Fig. 5.18, oscillated highly also. When the CCFL option was specified at the junction, the calculated flooding data lay well on the specified CCFL curve, although the downward flow oscillated between countercurrent flow and cocurrent flow as shown in Fig.5.19 and 20. The curious results were produced above the complete flooding, $K_g^* = 3.2$. This might have been caused by a coding error or incorrect implementation of a CCFL model in

version 5m5. Therefore no further discussions are provided for the curious calculated results.

In summary of sensitivity studies using various tube diameters, the high interfacial drags of the code for the small diameter tubes can restrict the countercurrent flow before the CCFL condition is actually reached. As the tube diameter increases, the calculated downward liquid flow becomes unstable because the calculated flow regime oscillated between the annular mist flow and slug flow. The flooding occurs at a much higher air velocity than predicted by the experiments, and thus the application of the CCFL option at the specific junction is needed.

5.2 Nodalization

The flooding characteristics may be affected by the nodalization. The major concern for a nodalization effect was in the test section area in which the actual countercurrent flow existed. The figures of the fine nodalization are presented in Fig. 5.21 and 5.22. The results are shown in Fig. 5.23 to Fig. 33. The major calculated values of fine nodalization are not quite different from the results of the coarse nodalization as shown in the section 4, and thus it is concluded that flooding characteristics are not sensitive to the number of nodalization.

Fig. 5.1 Calculated Flooding Data without CCFL option ($D = 0.5$ cm)

Fig. 5.2 Pressure Drop in the Test Section ($D = 0.5$ cm)

Fig. 5.3 Calculated Flooding Data with CCFL option ($D = 0.5$ cm)

Fig. 5.4 Pressure Drop in the Test Section ($D = 0.5$ cm)

Fig. 5.5 Calculated Flooding Data without CCFL option ($D = 1.0$ cm)

Fig. 5.6 Pressure Drop in the Test Section ($D = 1.0$ cm)

Fig. 5.7 Calculated Flooding Data with CCFL option ($D = 1.0$ cm)

Fig. 5.8 Pressure Drop in the Test Section ($D = 1.0$ cm)

Fig. 5.9 Calculated Flooding Data without CCFL option ($D = 3.0$ cm)

Fig. 5.10 Pressure Drop in the Test Section ($D = 3.0$ cm)

Fig. 5.11 Calculated Flooding Data with CCFL option ($D = 3.0$ cm)

Fig. 5.12 Pressure Drop in the Test Section ($D = 3.0$ cm)

Fig. 5.13 Calculated Flooding Data without CCFL option ($D = 5.0$ cm)

Fig. 5.14 Pressure Drop in the Test Section ($D = 5.0$ cm)

Fig. 5.15 Calculated Flooding Data with CCFL option ($D = 5.0$ cm)

Fig. 5.16 Pressure Drop in the Test Section ($D = 5.0$ cm)

Fig. 5.17 Calculated Flooding Data without CCFL option ($D = 10$. cm)

Fig. 5.18 Pressure Drop in the Test Section ($D = 10$. cm)

Fig. 5.19 Calculated Flooding Data with CCFL option ($D = 10$. cm)

Fig. 5.20 Pressure Drop in the Test Section ($D = 10$. cm)

Fig. 5.21 RELAP5 Fine Nodalization for Air/Water Test Problem

Fig. 5.22 RELAP5 Fine Nodalization for Type-1 Test Bundle

Fig. 5.23 Calculated Flooding Data with Fine Nodalization

Fig. 5.24 Pressure Drop with Fine Nodalization

Fig. 5.25 Flow Regime Change at the Test Section Junction
(1 - jun.3010000 : 2 - jun.3020000 : 3 - jun.3030000
4 - jun.3040000 : 5 - jun.3050000 : 6 - jun.4000000)

Fig. 5.26 Interfacial Drag Coefficient at the Test Section Junction
(1 - jun.3010000 : 2 - jun.3020000 : 3 - jun.3030000
4 - jun.3040000 : 5 - jun.3050000 : 6 - jun.4000000)

Fig. 5.27 Gas Void Fraction at the Test Section Junction
(1 - jun.3010000 : 2 - jun.3020000 : 3 - jun.3030000
4 - jun.3040000 : 5 - jun.3050000 : 6 - jun.4000000)

Fig. 5.28 Mass Flux through the Junction 4000000

Fig. 5.29 Calculated Flooding Data with Fine Nodalization

Fig. 5.30 Pressure Drop with Fine Nodalization

Fig. 5.31 Flow Regime Change at the Test Section Junction
 (1 - jun.3010000 : 2 - jun.3020000 : 3 - jun.3030000
 4 - jun.3040000 : 5 - jun.3050000 : 6 - jun.4000000)

Fig. 5.32 Interfacial Drag Coefficient at the Test Section Junction
 (1 - jun.3010000 : 2 - jun.3020000 : 3 - jun.3030000
 4 - jun.3040000 : 5 - jun.3050000 : 6 - jun.4000000)

Fig. 5.33 Gas Void Fraction at the Test Section Junction
 (1 - jun.3010000 : 2 - jun.3020000 : 3 - jun.3030000
 4 - jun.3040000 : 5 - jun.3050000 : 6 - jun.4000000)

6. Run Statistics

The simulation for the CCFL model assessment is not a transient case basically, thus it is meaningless to compare the simulation time. However the range of air flow used to test the CCFL model was obtained by increasing air flow during a given period. Therefore the run time required by the simulation will be helpful for the other assessment or determination of the transient period.

The computer used for the simulation is a CRAY-2S which has 4 central process units, and the operating system is UNICOS. The time step size was fixed as 0.01 second to avoid the numerical instability of the liquid film flow, discussed in the section 4.1. The whole transient time was also fixed as 200 seconds. The computation efficiency is summarized in Table 6.1. A plot of CPU time was not needed because it increases linearly with the transient time.

Table 6.1 CPU time required in the simulation

Case	Transient Real Time (sec)	Computing Time (CPU)	Number of Total Volume (C)	Number of Time Step (DT)	Total Grind Time (CPU/C/DT)
1	200.0	151.52	11	20,000	6.89×10^{-4}
2	200.0	152.34	11	20,000	6.92×10^{-4}
3	200.0	156.41	11	20,000	7.11×10^{-4}
4	200.0	159.83	11	20,000	7.27×10^{-4}
5	200.0	263.14	17	20,000	7.74×10^{-4}

- * case 1 : coarse noding without CCFL option in simple tube
- * case 2 : coarse noding with CCFL option in simple tube
- * case 3 : coarse noding without CCFL option in rod bundle
- * case 4 : coarse noding with CCFL option in rod bundle
- * case 5 : fine noding with CCFL option in simple tube

7. Conclusion

Assessment calculations for sample problems in a simple tube and a rod bundle were carried out using RELAP5/MOD3/5m5 code. For the purpose of comparison, a pair of calculations were performed with and without CCFL option. Sensitivity studies with respect to the diameter of tube was also performed. In the small diameter case, the flooding was calculated to occur before the CCFL occurred in the experiment, due to the increased interfacial drag force. In the large diameter case, the flooding occurs at a higher gas velocity than the experimental results, when the CCFL model option was not selected. With applying the CCFL option to the specific junction, the calculated values lay well on the curve specified by user, and the pressure oscillations and jump after onset of flooding agreed with most experimental observations. Curious calculation results obtained by specifying the Kutateladze CCFL curve for the large diameter tube may be resulted from a coding error of 5m5 version.

Other assessment calculations were carried out for a rod bundle test, which was performed by KINS(Korea Institute of Nuclear Safety). Calculated results were compared with experimental data for each type of test section ; type-1 which has no spacer grid, type-2 which has one spacer grid, and type-3 which has two spacer grids. A flooding curve which was determined by experiments was applied to the specific junction. Calculated values lay well on the curve specified by user, and the pressure drop increased suddenly just after onset of flooding due to restriction of downward liquid flow at the specific junction. However, the pressure jump before onset of flooding was not calculated because RELAP5 did not have models of "liquid mixing" which was observed in the experiment at the transition area before "onset of flooding".

The fine nodalization for the test section did not affect the

whole flooding phenomena, and it was concluded that the interfacial drag model and CCFL curve given by user mainly characterized the flooding process.

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APPENDIX A. EXPERIMENTAL DATA FOR ROD BUNDLE CCFL TEST

Appendix A. Experimental Data for Rod Bundle CCFL Test

Numerical data for experiments of the three type of test section are tabulated as following. In the following tables the oscillation data are presented as averaged value ± 1 standard deviation. The nondimensional conversions are performed by using the physical and geometrical conditions of the present experiment. The conditions used for nondimensional conversions are listed as following.

$$T_l = \text{Temperature of Liquid} = 282 \text{ }^\circ\text{K}$$

$$T_g = \text{Temperature of Gas} = 280 \text{ }^\circ\text{K}$$

$$\rho_f = \text{Density of Liquid} = 1000 \text{ Kg/m}^3$$

$$\rho_g = \text{Density of Gas} = 1.2713 \text{ Kg/m}^3$$

$$\mu_f = \text{Dynamic Viscosity of Liquid} = 1303 \times 10^{-6} \text{ Kg/m.sec}$$

$$\mu_g = \text{Dynamic Viscosity of Gas} = 173.9 \times 10^{-6} \text{ Kg/m.sec}$$

$$\sigma = \text{Surface Tension of Liquid} = 73.656 \times 10^{-3} \text{ N/m}$$

$$g = \text{Universal acceleration Constant} = 9.81 \text{ m/sec}^2$$

$$D_H = \text{Equivalent Hydraulic Diameter} = 4A/P = 1.03 \times 10^{-2} \text{ m}$$

The following lists of the nomenclatures are used in tables.

$$Q_l = \text{Water Injection Rate}$$

$$K_g^* = \text{Kutateladze Number of Gas Flux} = \rho_g^{0.5} \alpha_g V_g / [g\sigma(\rho_f - \rho_g)]^{0.25}$$

$$K_f^* = \text{Kutateladze Number of Liquid} = \rho_f^{0.5} \alpha_f V_f / [g\sigma(\rho_f - \rho_g)]^{0.25}$$

$$K_l^* = \text{Kutateladze Number of Water Injection}$$

$$j_g^* = \text{Nondimensional Gas Flux} = \rho_g \alpha_g V_g / [gD_H(\rho_f - \rho_g)]^{0.5}$$

$$j_f^* = \text{Nondimensional Liquid Flux} = \rho_f \alpha_f V_f / [gD_H(\rho_f - \rho_g)]^{0.5}$$

$$j_l^* = \text{Nondimensional Liquid Injection}$$

$$P^* = \text{Nondimensional Pressure Gradient} = |dP/dz| / [g(\rho_f - \rho_g)]$$

Re_T = Film Reynolds Number = $4\Gamma/\mu_f$ where Γ denotes film mass flowrate per unit width

V_C^* = Critical Nondimensional Gas Velocity

$$= \frac{\mu_f V_{g,c}}{\sigma} (\rho_g/\rho_f)^{0.5} (1/N_\mu)^{0.8},$$

where N_μ = Viscosity Number = $\mu_f/[\rho_f \sqrt{\sigma/g(\rho_f - \rho_g)}]^{1/2}$

$V_{g,c}$ = Gas Velocity which results flooding

Test Data for Single Phase Air Flow in Bare Rod Bundle
 $Q_l = 0$ cc/min $T_l = 282$ °K $T_g = 280$ °K

	Air Flowrate (1000 cc/sec)		Channel Velocity (m/sec)	Pressure Drop (mm-H ₂ O)		Liquid Flowrate Downward Upward (cc/min) (cc/min)	
1	0.252±	0.257	0.224	1.3 ±	3.7	0.0	0.0
2	5.150±	0.061	4.573	16.4 ±	0.0	0.0	0.0
3	5.799±	0.053	5.149	20.8 ±	2.8	0.0	0.0
4	6.825±	0.023	6.061	25.2 ±	1.2	0.0	0.0
5	8.207±	0.066	7.288	34.0 ±	0.3	0.0	0.0
6	9.134±	0.053	8.111	38.4 ±	0.0	0.0	0.0
7	9.718±	0.046	8.629	43.8 ±	0.5	0.0	0.0
8	11.240±	0.053	9.981	77.7 ±	0.5	0.0	0.0
9	11.732±	0.063	10.418	79.2 ±	1.3	0.0	0.0

Nondimensional Form of Test Data

$$K_l^* = 0.0 \quad j_l^* = 0.0 \quad Re_T = 0.0 \quad V_c^* = 0.0$$

	K_g^*		P^*		K_f^*		K_c^*		j_g^*		j_f^*		j_c^*	
1	0.049±	0.050	0.001±	0.004	0.000	0.000	0.000	0.000	0.025±	0.026	0.000	0.000	0.000	0.000
2	0.995±	0.012	0.016±	0.000	0.000	0.000	0.000	0.000	0.513±	0.006	0.000	0.000	0.000	0.000
3	1.120±	0.010	0.021±	0.003	0.000	0.000	0.000	0.000	0.578±	0.005	0.000	0.000	0.000	0.000
4	1.318±	0.005	0.025±	0.001	0.000	0.000	0.000	0.000	0.680±	0.002	0.000	0.000	0.000	0.000
5	1.586±	0.013	0.034±	0.000	0.000	0.000	0.000	0.000	0.818±	0.007	0.000	0.000	0.000	0.000
6	1.765±	0.010	0.038±	0.000	0.000	0.000	0.000	0.000	0.911±	0.005	0.000	0.000	0.000	0.000
7	1.877±	0.009	0.044±	0.000	0.000	0.000	0.000	0.000	0.969±	0.005	0.000	0.000	0.000	0.000
8	2.171±	0.010	0.078±	0.001	0.000	0.000	0.000	0.000	1.120±	0.005	0.000	0.000	0.000	0.000
9	2.266±	0.012	0.079±	0.001	0.000	0.000	0.000	0.000	1.169±	0.006	0.000	0.000	0.000	0.000

Test Data for Two Phase Air Flow in Bare Rod Bundle
 $Q_l = 230 \text{ cc/min}$ $T_l = 282^\circ \text{K}$ $T_g = 280^\circ \text{K}$

	Air Flowrate (1000 cc/sec)	Channel Velocity (m/sec)	Pressure Drop (mm-H ₂ O)	Liquid Flowrate Downward Upward (cc/min) (cc/min)
1	0.000± 0.000	0.000	26.7 ± 2.3	227.5 0.0
2	6.764± 0.035	6.007	28.4 ± 6.0	227.5 0.0
3	7.853± 0.016	6.974	33.9 ± 2.7	227.5 0.0
4	9.355± 0.069	8.041	82.7 ± 4.1	85.8 141.6
5	9.456± 0.044	8.397	94.7 ± 6.8	62.2 165.3
6	9.844± 0.054	8.741	110.3 ± 6.9	38.6 188.9
7	10.736± 0.026	9.533	80.5 ± 3.5	23.6 203.9
8	11.248± 0.073	9.988	82.3 ± 1.9	0.0 227.5
9	8.823± 0.012	7.834	91.9 ± 7.7	79.4 148.1
10	8.448± 0.066	7.502	99.1 ± 7.3	126.6 100.9
11	8.083± 0.039	7.178	111.9 ± 9.2	156.7 70.8

Nondimensional Form of Test Data

$$K_l^* = 0.021 \quad j_l^* = 0.011 \quad Re_T = 43.7 \quad V_c^* = 1.323$$

	K_g^*	P^*	K_f^*	K_c^*	j_g^*	j_f^*	j_c^*
1	0.000± 0.000	0.027± 0.002	0.021	0.000	0.000± 0.000	0.011	0.000
2	1.307± 0.007	0.028± 0.006	0.021	0.000	0.674± 0.004	0.011	0.000
3	1.517± 0.003	0.034± 0.003	0.021	0.000	0.783± 0.002	0.011	0.000
4	1.749± 0.013	0.083± 0.004	0.008	0.013	0.903± 0.007	0.004	0.007
5	1.827± 0.009	0.095± 0.007	0.006	0.015	0.943± 0.004	0.003	0.008
6	1.902± 0.010	0.110± 0.007	0.003	0.017	0.981± 0.005	0.002	0.009
7	2.074± 0.005	0.081± 0.004	0.002	0.018	1.070± 0.003	0.001	0.009
8	2.173± 0.014	0.082± 0.002	0.000	0.021	1.121± 0.007	0.000	0.011
9	1.704± 0.002	0.092± 0.008	0.007	0.013	0.879± 0.001	0.004	0.007
10	1.632± 0.013	0.099± 0.007	0.011	0.009	0.842± 0.007	0.006	0.005
11	1.562± 0.008	0.112± 0.009	0.014	0.006	0.806± 0.004	0.007	0.003

Test Data for Two Phase Air Flow in Bare Rod Bundle
 $Q_l = 530 \text{ cc/min}$ $T_l = 282^\circ \text{K}$ $T_g = 280^\circ \text{K}$

	Air Flowrate (1000 cc/sec)	Channel Velocity (m/sec)	Pressure Drop (mm-H ₂ O)	Liquid Flowrate Downward Upward (cc/min) (cc/min)
1	0.000± 0.000	0.000	25.6 ± 2.2	530.1 0.0
2	6.195± 0.023	5.501	55.5 ± 0.0	530.1 0.0
3	7.220± 0.072	6.411	123.3 ± 12.2	530.1 0.0
4	7.453± 0.045	6.618	130.0 ± 11.7	354.1 149.3
5	7.818± 0.045	6.942	127.7 ± 10.7	255.4 247.7
6	8.058± 0.051	7.155	122.7 ± 7.9	176.0 327.5
7	8.332± 0.020	7.399	119.2 ± 7.4	137.4 365.5
8	10.041± 0.034	8.916	87.3 ± 3.8	57.9 450.7
9	11.710± 0.072	10.399	85.9 ± 4.9	0.0 530.5

Nondimensional Form of Test Data

$$K_l^* = 0.048 \quad j_l^* = 0.025 \quad Re_T = 100.7 \quad V_c^* = 1.235$$

	K_g^*	P^*	K_f^*	K_c^*	j_g^*	j_f^*	j_c^*
1	0.000± 0.000	0.026± 0.002	0.048	0.027	0.000± 0.000	0.025	0.000
2	1.197± 0.004	0.056± 0.000	0.048	0.027	0.618± 0.002	0.025	0.000
3	1.395± 0.014	0.123± 0.012	0.048	0.027	0.720± 0.007	0.025	0.000
4	1.440± 0.009	0.130± 0.012	0.032	0.040	0.743± 0.005	0.016	0.007
5	1.510± 0.009	0.128± 0.011	0.023	0.042	0.779± 0.004	0.012	0.012
6	1.557± 0.010	0.123± 0.008	0.016	0.044	0.803± 0.005	0.008	0.015
7	1.610± 0.004	0.119± 0.007	0.012	0.046	0.831± 0.002	0.006	0.017
8	1.940± 0.007	0.087± 0.004	0.005	0.041	1.001± 0.003	0.003	0.021
9	2.262± 0.014	0.086± 0.005	0.000	0.036	1.167± 0.007	0.000	0.025

Test Data for Two Phase Air Flow in Bare Rod Bundle
 $Q_l = 730 \text{ cc/min}$ $T_l = 282^\circ \text{K}$ $T_g = 280^\circ \text{K}$

	Air Flowrate (1000 cc/sec)	Channel Velocity (m/sec)	Pressure Drop (mm-H ₂ O)	Liquid Flowrate Downward Upward (cc/min) (cc/min)
1	0.535± 0.134	0.475	38.4 ± 0.6	727.6 -0.0
2	6.228± 0.024	5.530	57.3 ± 1.6	727.6 -0.0
3	6.829± 0.023	6.065	139.3 ± 11.5	706.1 21.5
4	7.287± 0.060	6.471	135.5 ± 12.6	530.1 197.5
5	7.677± 0.064	6.817	134.7 ± 11.6	321.9 405.6
6	8.045± 0.047	7.144	130.7 ± 11.2	216.8 510.8
7	8.299± 0.027	7.370	127.5 ± 8.3	176.0 551.6
8	8.472± 0.068	7.523	124.7 ± 6.8	133.1 594.5
9	8.946± 0.046	7.944	116.4 ± 4.0	118.0 609.5
10	9.683± 0.038	8.599	101.3 ± 2.4	57.9 669.6
11	10.375± 0.030	9.213	85.4 ± 4.0	0.0 727.6
12	10.807± 0.042	9.597	80.5 ± 2.2	0.0 727.6
13	11.421± 0.043	10.142	84.7 ± 2.7	0.0 727.6
14	8.396± 0.047	7.456	123.2 ± 6.3	137.4 590.2
15	7.859± 0.020	6.979	133.5 ± 10.2	236.1 491.5
16	7.176± 0.080	6.372	139.0 ± 11.4	510.8 216.8
17	7.336± 0.020	6.515	136.4 ± 11.4	491.5 236.1
18	7.466± 0.048	6.630	134.1 ± 11.4	431.4 296.2
19	7.704± 0.074	6.841	133.7 ± 10.5	313.3 414.2

Nondimensional Form of Test Data

$$K_l^* = 0.066 \quad j_l^* = 0.034 \quad Re_T = 138.7 \quad V_c^* = 1.147$$

	K_g^*	P^*	K_f^*	K_c^*	j_g^*	j_f^*	j_c^*
1	0.103± 0.026	0.038± 0.001	0.066 -0.000	0.053± 0.013	0.034 -0.000		
2	1.203± 0.005	0.057± 0.002	0.066 -0.000	0.621± 0.002	0.034 -0.000		
3	1.319± 0.005	0.139± 0.012	0.064 0.002	0.681± 0.002	0.033 0.001		
4	1.408± 0.012	0.136± 0.013	0.048 0.018	0.726± 0.006	0.025 0.009		
5	1.483± 0.012	0.135± 0.012	0.029 0.037	0.765± 0.006	0.015 0.019		
6	1.554± 0.009	0.131± 0.011	0.020 0.046	0.802± 0.005	0.010 0.024		
7	1.603± 0.005	0.128± 0.008	0.016 0.050	0.827± 0.003	0.008 0.026		
8	1.637± 0.013	0.125± 0.007	0.012 0.054	0.844± 0.007	0.006 0.028		
9	1.728± 0.009	0.117± 0.004	0.011 0.055	0.892± 0.005	0.005 0.028		
10	1.871± 0.007	0.101± 0.002	0.005 0.060	0.965± 0.004	0.003 0.031		
11	2.004± 0.006	0.086± 0.004	0.000 0.066	1.034± 0.003	0.000 0.034		
12	2.088± 0.008	0.081± 0.002	0.000 0.066	1.077± 0.004	0.000 0.034		
13	2.206± 0.008	0.085± 0.003	0.000 0.066	1.138± 0.004	0.000 0.034		
14	1.622± 0.009	0.123± 0.006	0.012 0.053	0.837± 0.005	0.006 0.027		
15	1.518± 0.004	0.134± 0.010	0.021 0.044	0.783± 0.002	0.011 0.023		
16	1.386± 0.016	0.139± 0.011	0.046 0.020	0.715± 0.008	0.024 0.010		
17	1.417± 0.004	0.137± 0.011	0.044 0.021	0.731± 0.002	0.023 0.011		
18	1.442± 0.009	0.134± 0.011	0.039 0.027	0.744± 0.005	0.020 0.014		
19	1.488± 0.014	0.134± 0.011	0.028 0.037	0.768± 0.007	0.015 0.019		

Test Data for Two Phase Air Flow in Bare Rod Bundle
 $Q_l = 1570$ cc/min $T_l = 282$ °K $T_g = 280$ °K

	Air Flowrate (1000 cc/sec)		Channel Velocity (m/sec)	Pressure Drop (mm-H ₂ O)		Liquid Flowrate Downward Upward (cc/min) (cc/min)	
1	0.052±	0.150	0.046	13.3 ±	0.7	1571.0	-0.0
2	4.711±	0.055	4.183	45.6 ±	7.5	1571.0	-0.0
3	5.715±	0.058	5.075	135.7 ±	15.7	1571.0	0.0
4	6.214±	0.027	5.518	161.1 ±	17.6	1296.3	274.7
5	6.454±	0.063	5.631	161.6 ±	18.4	1098.9	472.2
6	6.563±	0.043	5.827	158.3 ±	14.6	1021.6	549.4
7	6.808±	0.023	6.046	158.3 ±	13.5	903.5	667.5
8	6.892±	0.045	6.120	154.9 ±	14.8	824.1	746.9
9	7.206±	0.076	6.399	153.8 ±	14.1	652.4	918.6
10	7.613±	0.029	6.760	148.9 ±	12.0	354.1	1216.9
11	8.066±	0.045	7.163	140.3 ±	11.8	156.7	1414.3
12	8.290±	0.032	7.361	137.6 ±	11.2	118.0	1453.0
13	8.535±	0.042	7.579	132.8 ±	9.5	79.4	1491.6
14	9.014±	0.049	8.005	123.1 ±	4.6	62.2	1508.8
15	10.065±	0.044	8.937	99.5 ±	5.0	38.6	1532.4
16	10.657±	0.058	9.463	85.1 ±	3.1	0.0	1571.0

Nondimensional Form of Test Data

$$K_l^* = 0.142 \quad j_l^* = 0.073 \quad Re_T = 298.3 \quad V_c^* = 1.015$$

	K_g^*		P^*		K_f^*		K_c^*		j_g^*		j_f^*	j_c^*
1	0.010±	0.029	0.013±	0.001	0.142	-0.000	0.005±	0.015	0.073	-0.000		
2	0.910±	0.011	0.046±	0.007	0.142	-0.000	0.470±	0.005	0.073	-0.000		
3	1.104±	0.011	0.136±	0.016	0.142	-0.000	0.570±	0.006	0.073	-0.000		
4	1.200±	0.005	0.161±	0.018	0.117	0.025	0.619±	0.003	0.060	0.013		
5	1.247±	0.012	0.162±	0.018	0.099	0.043	0.643±	0.006	0.051	0.022		
6	1.268±	0.008	0.158±	0.015	0.092	0.050	0.654±	0.004	0.048	0.026		
7	1.315±	0.004	0.158±	0.014	0.082	0.060	0.679±	0.002	0.042	0.031		
8	1.331±	0.009	0.155±	0.015	0.074	0.067	0.687±	0.004	0.038	0.035		
9	1.392±	0.015	0.154±	0.014	0.059	0.083	0.718±	0.008	0.030	0.043		
10	1.471±	0.006	0.149±	0.012	0.032	0.110	0.759±	0.003	0.016	0.057		
11	1.558±	0.009	0.140±	0.012	0.014	0.128	0.804±	0.005	0.007	0.066		
12	1.601±	0.006	0.138±	0.011	0.011	0.131	0.826±	0.003	0.005	0.068		
13	1.649±	0.008	0.133±	0.010	0.007	0.135	0.851±	0.004	0.004	0.069		
14	1.741±	0.009	0.123±	0.005	0.006	0.136	0.899±	0.005	0.003	0.070		
15	1.944±	0.009	0.100±	0.005	0.003	0.138	1.003±	0.004	0.002	0.071		
16	2.059±	0.011	0.085±	0.003	0.000	0.142	1.062±	0.006	0.000	0.073		

Test Data for Two Phase Air Flow in Bare Rod Bundle
 $Q_l = 2600$ cc/min $T_l = 282$ °K $T_g = 280$ °K

	Air Flowrate (1000 cc/sec)	Channel Velocity (m/sec)	Pressure Drop (mm-H ₂ O)	Liquid Flowrate Downward Upward (cc/min) (cc/min)	
1	4.509± 0.120	4.004	55.8 ± 1.5	2590.5	-0.0
2	4.898± 0.065	4.349	187.7 ± 30.1	2590.5	-0.0
3	5.194± 0.059	4.612	210.4 ± 34.6	2120.4	470.0
4	5.517± 0.063	4.900	205.5 ± 31.9	1807.1	783.4
5	5.790± 0.081	5.142	200.4 ± 32.1	1571.0	1019.4
6	5.995± 0.103	5.324	197.9 ± 29.9	1491.6	1098.9
7	6.377± 0.080	5.663	189.8 ± 25.5	1216.9	1373.6
8	6.832± 0.027	6.066	172.9 ± 18.0	942.2	1648.3
9	7.441± 0.045	6.608	159.3 ± 14.3	588.1	2002.4
10	8.136± 0.061	7.225	146.2 ± 12.5	156.7	2433.8
11	8.387± 0.042	7.448	140.5 ± 12.1	79.4	2511.1
12	9.114± 0.061	8.093	125.5 ± 7.5	62.2	2528.2
13	10.056± 0.040	8.929	108.8 ± 7.1	0.0	2590.5

Nondimensional Form of Test Data

$$K_l^* = 0.234 \quad j_l^* = 0.121 \quad Re_T = 494.0 \quad V_c^* = 0.794$$

	K_g^*	P^*		K_f^*	K_c^*	j_g^*		j_f^*	j_c^*
1	0.871± 0.023	0.056±	0.001	0.234	-0.000	0.449±	0.012	0.121	-0.000
2	0.946± 0.013	0.188±	0.030	0.234	-0.000	0.488±	0.006	0.121	-0.000
3	1.003± 0.011	0.211±	0.035	0.191	0.042	0.518±	0.006	0.099	0.022
4	1.066± 0.012	0.206±	0.034	0.163	0.071	0.550±	0.006	0.084	0.036
5	1.119± 0.016	0.201±	0.032	0.142	0.092	0.577±	0.008	0.073	0.047
6	1.158± 0.020	0.198±	0.030	0.135	0.099	0.598±	0.010	0.069	0.051
7	1.232± 0.015	0.190±	0.026	0.110	0.124	0.636±	0.008	0.057	0.064
8	1.320± 0.005	0.173±	0.018	0.085	0.149	0.681±	0.003	0.044	0.077
9	1.438± 0.009	0.159±	0.014	0.053	0.181	0.742±	0.005	0.027	0.093
10	1.572± 0.012	0.146±	0.012	0.014	0.220	0.811±	0.006	0.007	0.113
11	1.620± 0.008	0.141±	0.012	0.007	0.227	0.836±	0.004	0.004	0.117
12	1.761± 0.012	0.126±	0.008	0.006	0.228	0.908±	0.006	0.003	0.118
13	1.943± 0.008	0.109±	0.007	0.000	0.234	1.002±	0.004	0.000	0.121

Test Data for Two Phase Air Flow in Bare Rod Bundle
 $Q_l = 3600 \text{ cc/min}$ $T_l = 282^\circ \text{K}$ $T_g = 280^\circ \text{K}$

	Air Flowrate (1000 cc/sec)	Channel Velocity (m/sec)	Pressure Drop (mm-H ₂ O)	Liquid Flowrate Downward Upward (cc/min) (cc/min)
1	4.137± 0.118	3.673	39.6 ± 8.1	3612.1 -0.0
2	4.580± 0.155	4.067	194.3 ± 37.2	3219.3 392.8
3	5.110± 0.092	4.538	213.5 ± 32.7	2199.9 1412.2
4	5.355± 0.124	4.756	218.1 ± 29.2	1901.5 1710.5
5	5.900± 0.076	5.239	208.1 ± 25.1	1455.1 2156.9
6	6.184± 0.036	5.491	201.2 ± 24.2	1373.6 2238.5
7	6.510± 0.054	5.781	188.9 ± 21.5	1139.6 2472.4
8	6.972± 0.062	6.191	176.2 ± 15.3	942.2 2669.9
9	7.722± 0.083	6.857	156.5 ± 9.8	510.8 3101.3
10	8.172± 0.072	7.257	151.4 ± 10.3	236.1 3376.0
11	8.584± 0.040	7.623	143.5 ± 10.5	79.4 3532.6
12	9.521± 0.072	8.455	118.6 ± 6.7	0.0 3612.1

Nondimensional Form of Test Data

$$K_l^* = 0.326 \quad j_l^* = 0.128 \quad Re_T = 684.0 \quad V_c^* = 0.706$$

	K_g^*	P^*	K_f^*	K_c^*	j_g^*	j_f^*	j_c^*
1	0.799± 0.023	0.040± 0.008	0.326	-0.000	0.412± 0.012	0.168	-0.000
2	0.885± 0.030	0.195± 0.037	0.291	0.035	0.457± 0.015	0.150	0.018
3	0.987± 0.018	0.214± 0.033	0.199	0.128	0.509± 0.009	0.102	0.066
4	1.035± 0.024	0.218± 0.029	0.172	0.154	0.534± 0.012	0.089	0.080
5	1.140± 0.015	0.208± 0.025	0.131	0.195	0.588± 0.008	0.068	0.100
6	1.195± 0.007	0.201± 0.024	0.124	0.202	0.616± 0.004	0.064	0.104
7	1.258± 0.011	0.189± 0.022	0.103	0.223	0.649± 0.005	0.053	0.115
8	1.347± 0.012	0.176± 0.015	0.085	0.241	0.695± 0.006	0.044	0.124
9	1.492± 0.016	0.157± 0.010	0.046	0.280	0.770± 0.008	0.024	0.144
10	1.579± 0.014	0.152± 0.010	0.021	0.305	0.815± 0.007	0.011	0.157
11	1.658± 0.008	0.144± 0.010	0.007	0.319	0.856± 0.004	0.004	0.165
12	1.839± 0.014	0.119± 0.007	0.000	0.326	0.949± 0.007	0.000	0.168

Test Data for Single Phase Air Flow in Single Grid Rod Bundle
 $Q_l = 0$ cc/min $T_l = 282$ °K $T_g = 280$ °K

	Air Flowrate (1000 cc/sec)	Channel Velocity (m/sec)	Pressure Drop (mm-H ₂ O)	Liquid Flowrate Downward Upward (cc/min) (cc/min)	
1	3.243± 0.102	2.880	15.4 ± 1.3	0.0	0.0
2	4.597± 0.109	4.082	20.8 ± 3.2	0.0	0.0
3	5.524± 0.024	4.905	24.7 ± 2.7	0.0	0.0
4	6.316± 0.058	5.608	29.2 ± 3.2	0.0	0.0
5	7.295± 0.034	6.478	34.2 ± 1.2	0.0	0.0
6	7.842± 0.020	6.963	37.2 ± 1.9	0.0	0.0
7	8.569± 0.023	7.609	42.3 ± 3.3	0.0	0.0
8	8.841± 0.028	7.851	52.6 ± 5.3	0.0	0.0
9	10.134± 0.055	8.999	74.5 ± 3.9	0.0	0.0
10	10.757± 0.035	9.552	88.8 ± 5.4	0.0	0.0

Nondimensional Form of Test Data

$$K_l^* = 0.0 \quad j_l^* = 0.0 \quad Re_T = 0.0 \quad V_c^* = 0.0$$

	K_g^*	P^*	K_f^*	K_c^*	j_g^*	j_f^*	j_c^*
1	0.626± 0.020	0.015± 0.001	0.000	0.000	0.323± 0.010	0.000	0.000
2	0.888± 0.021	0.021± 0.003	0.000	0.000	0.458± 0.011	0.000	0.000
3	1.067± 0.005	0.025± 0.003	0.000	0.000	0.551± 0.002	0.000	0.000
4	1.220± 0.011	0.029± 0.003	0.000	0.000	0.630± 0.006	0.000	0.000
5	1.409± 0.007	0.034± 0.001	0.000	0.000	0.727± 0.003	0.000	0.000
6	1.515± 0.004	0.037± 0.002	0.000	0.000	0.782± 0.002	0.000	0.000
7	1.655± 0.004	0.042± 0.003	0.000	0.000	0.854± 0.002	0.000	0.000
8	1.708± 0.005	0.053± 0.005	0.000	0.000	0.881± 0.003	0.000	0.000
9	1.958± 0.011	0.075± 0.004	0.000	0.000	1.010± 0.005	0.000	0.000
10	2.078± 0.007	0.089± 0.005	0.000	0.000	1.072± 0.003	0.000	0.000

Test Data for Two Phase Air Flow in Single Grid Rod Bundle
 $Q_l = 180 \text{ cc/min}$ $T_l = 282^\circ \text{K}$ $T_g = 280^\circ \text{K}$

	Air Flowrate (1000 cc/sec)	Channel Velocity (m/sec)	Pressure Drop (mm-H ₂ O)	Liquid Flowrate Downward Upward (cc/min) (cc/min)
1	3.434± 0.033	3.050	42.7 ± 3.0	180.6 0.0
2	5.655± 0.045	5.022	56.8 ± 0.8	180.6 0.0
3	7.843± 0.020	6.965	124.4 ± 3.6	157.1 23.6
4	7.980± 0.051	7.086	128.5 ± 5.4	117.8 62.8
5	7.978± 0.059	7.084	130.2 ± 6.6	94.2 86.4
6	8.027± 0.050	7.128	127.9 ± 4.9	110.0 70.7
7	8.277± 0.036	7.350	129.4 ± 6.6	62.8 117.8
8	8.819± 0.015	7.831	120.9 ± 5.1	15.7 164.9
9	8.977± 0.041	7.972	107.2 ± 5.6	4.7 175.9
10	9.374± 0.042	8.325	76.1 ± 3.0	0.0 180.6
11	10.064± 0.042	8.937	54.7 ± 3.0	0.0 180.6

Nondimensional Form of Test Data

$$K_l^* = 0.016 \quad j_l^* = 0.008 \quad Re_T = 34.2 \quad V_c^* = 1.323$$

	K_g^*	P^*	K_f^*	K_c^*	j_g^*	j_f^*	j_c^*
1	0.663± 0.006	0.043± 0.003	0.016	0.000	0.342± 0.003	0.008	0.000
2	1.092± 0.009	0.057± 0.001	0.016	0.000	0.564± 0.005	0.008	0.000
3	1.515± 0.004	0.125± 0.004	0.014	0.002	0.782± 0.002	0.007	0.001
4	1.542± 0.010	0.129± 0.005	0.011	0.006	0.795± 0.005	0.005	0.003
5	1.541± 0.011	0.130± 0.007	0.009	0.008	0.795± 0.006	0.004	0.004
6	1.551± 0.010	0.128± 0.005	0.010	0.006	0.800± 0.005	0.005	0.003
7	1.599± 0.007	0.130± 0.007	0.006	0.011	0.825± 0.004	0.003	0.005
8	1.704± 0.003	0.121± 0.005	0.001	0.015	0.879± 0.001	0.001	0.008
9	1.734± 0.008	0.107± 0.006	0.000	0.016	0.895± 0.004	0.000	0.008
10	1.811± 0.008	0.076± 0.003	0.000	0.016	0.934± 0.004	0.000	0.008
11	1.944± 0.008	0.055± 0.003	0.000	0.016	1.003± 0.004	0.000	0.008

Test Data for Two Phase Air Flow in Single Grid Rod Bundle
 $Q_l = 530 \text{ cc/min}$ $T_l = 282^\circ \text{K}$ $T_g = 280^\circ \text{K}$

	Air Flowrate (1000 cc/sec)	Channel Velocity (m/sec)	Pressure Drop (mm-H ₂ O)	Liquid Flowrate Downward Upward (cc/min) (cc/min)
1	2.554± 0.078	2.268	53.3 ± 4.6	530.1 0.0
2	5.132± 0.067	4.557	71.4 ± 4.4	530.1 0.0
3	6.977± 0.051	6.195	109.7 ± 8.2	432.0 98.2
4	7.318± 0.027	6.498	104.0± 11.1	353.4 149.2
5	7.445± 0.047	6.611	104.8 ± 8.2	255.2 255.2
6	7.865± 0.022	6.984	104.6 ± 8.0	98.2 412.3
7	7.954± 0.047	7.063	88.5 ± 7.4	58.9 471.2
8	8.282± 0.030	7.354	83.0 ± 6.3	39.3 490.9
9	8.361± 0.016	7.424	90.1± 12.8	19.6 510.5
10	8.819± 0.007	7.831	88.1 ± 8.6	3.9 530.0
11	9.228± 0.023	8.195	76.1 ± 3.4	0.0 530.1

Nondimensional Form of Test Data

$$K_l^* = 0.048 \quad j_l^* = 0.025 \quad Re_T = 100.7 \quad V_c^* = 1.191$$

	K_g^*	P^*	K_f^*	K_c^*	j_g^*	j_f^*	j_c^*
1	0.493± 0.015	0.053± 0.005	0.048	0.000	0.255± 0.008	0.025	0.000
2	0.991± 0.013	0.072± 0.004	0.048	0.000	0.512± 0.007	0.025	0.000
3	1.348± 0.010	0.110± 0.008	0.039	0.009	0.695± 0.005	0.020	0.005
4	1.414± 0.005	0.104± 0.011	0.032	0.013	0.729± 0.003	0.016	0.007
5	1.438± 0.009	0.105± 0.008	0.023	0.023	0.742± 0.005	0.012	0.012
6	1.519± 0.004	0.105± 0.008	0.009	0.037	0.784± 0.002	0.005	0.019
7	1.537± 0.009	0.089± 0.007	0.005	0.043	0.793± 0.005	0.003	0.022
8	1.600± 0.006	0.083± 0.006	0.004	0.044	0.826± 0.003	0.002	0.023
9	1.615± 0.003	0.090± 0.013	0.002	0.046	0.833± 0.002	0.001	0.024
10	1.704± 0.001	0.088± 0.009	0.000	0.048	0.879± 0.001	0.000	0.025
11	1.783± 0.005	0.076± 0.003	0.000	0.048	0.920± 0.002	0.000	0.025

Test Data for Two Phase Air Flow in Single Grid Rod Bundle
 $Q_l = 750 \text{ cc/min}$ $T_l = 282^\circ \text{K}$ $T_g = 280^\circ \text{K}$

	Air Flowrate (1000 cc/sec)	Channel Velocity (m/sec)	Pressure Drop (mm-H ₂ O)	Liquid Flowrate Downward Upward (cc/min) (cc/min)	
1	2.849± 0.008	2.530	46.1 ± 7.6	746.1	0.0
2	5.495± 0.058	4.879	53.7± 14.8	746.1	0.0
3	6.249± 0.011	5.549	74.1 ± 5.1	742.2	3.9
4	6.895± 0.045	6.122	107.0 ± 9.8	490.9	255.2
5	7.052± 0.047	6.262	108.3 ± 8.4	451.6	294.5
6	7.404± 0.036	6.574	107.1 ± 9.0	294.5	451.6
7	7.792± 0.066	6.919	107.6 ± 7.2	106.0	628.3
8	8.013± 0.052	7.116	105.2 ± 6.7	58.9	687.2
9	8.312± 0.022	7.381	97.1 ± 8.2	19.6	726.5
10	8.630± 0.069	7.664	80.8 ± 2.2	3.9	742.2
11	9.154± 0.048	8.129	71.8 ± 5.9	0.0	746.1

Nondimensional Form of Test Data

$$K_l^* = 0.067 \quad j_l^* = 0.035 \quad Re_T = 142.5 \quad V_c^* = 1.059$$

	K_g^*	P^*	K_f^*	K_c^*	j_g^*	j_f^*	j_c^*
1	0.550± 0.002	0.046± 0.008	0.067	0.000	0.284± 0.001	0.035	0.000
2	1.061± 0.011	0.054± 0.015	0.067	0.000	0.548± 0.006	0.035	0.000
3	1.207± 0.002	0.074± 0.005	0.067	0.000	0.623± 0.001	0.035	0.000
4	1.332± 0.009	0.107± 0.010	0.044	0.023	0.687± 0.005	0.023	0.012
5	1.362± 0.009	0.108± 0.008	0.041	0.027	0.703± 0.005	0.021	0.014
6	1.430± 0.007	0.107± 0.009	0.027	0.041	0.738± 0.004	0.014	0.021
7	1.505± 0.013	0.108± 0.007	0.010	0.057	0.777± 0.007	0.005	0.029
8	1.548± 0.010	0.105± 0.007	0.005	0.062	0.799± 0.005	0.003	0.032
9	1.606± 0.004	0.097± 0.008	0.002	0.066	0.829± 0.002	0.001	0.034
10	1.667± 0.013	0.081± 0.002	0.000	0.067	0.860± 0.007	0.000	0.035
11	1.768± 0.009	0.072± 0.006	0.000	0.067	0.913± 0.005	0.000	0.035

Test Data for Two Phase Air Flow in Single Grid Rod Bundle

$$Q_l = 1650 \text{ cc/min} \quad T_l = 282 \text{ }^\circ\text{K} \quad T_g = 280 \text{ }^\circ\text{K}$$

	Air Flowrate (1000 cc/sec)	Channel Velocity (m/sec)	Pressure Drop (mm-H ₂ O)	Liquid Flowrate Downward Upward (cc/min) (cc/min)
1	4.365± 0.054	3.876	72.5 ± 6.3	1649.3 0.0
2	4.714± 0.050	4.186	79.8 ± 6.1	1649.3 7.9
3	5.412± 0.114	4.806	92.0± 11.8	1335.2 314.2
4	5.599± 0.023	4.972	94.0± 11.6	1217.4 432.0
5	6.167± 0.036	5.476	91.7± 10.3	981.7 667.6
6	6.371± 0.078	5.658	105.2± 10.9	824.7 824.7
7	6.666± 0.095	5.920	110.9 ± 9.8	628.3 1021.0
8	7.070± 0.043	6.278	112.0 ± 8.4	353.4 1295.9
9	7.424± 0.048	6.592	108.7 ± 7.7	235.6 1413.7
10	7.922± 0.044	7.035	104.9 ± 7.4	117.8 1531.5
11	8.293± 0.029	7.364	105.4 ± 7.5	39.3 1610.1
12	8.587± 0.025	7.625	79.1 ± 2.5	0.0 1649.3

Nondimensional Form of Test Data

$$K_l^* = 0.149 \quad j_l^* = 0.077 \quad Re_T = 313.5 \quad V_c^* = 0.750$$

	K_g^*	P^*	K_f^*	K_c^*	j_g^*	j_f^*	j_c^*
1	0.843± 0.010	0.073± 0.006	0.149	0.000	0.435± 0.005	0.077	0.000
2	0.911± 0.010	0.080± 0.006	0.149	0.001	0.470± 0.005	0.077	0.000
3	1.046± 0.022	0.092± 0.012	0.121	0.028	0.539± 0.011	0.062	0.015
4	1.082± 0.004	0.094± 0.012	0.110	0.039	0.558± 0.002	0.057	0.020
5	1.191± 0.007	0.092± 0.010	0.089	0.060	0.615± 0.004	0.046	0.031
6	1.231± 0.015	0.105± 0.011	0.074	0.074	0.635± 0.008	0.038	0.038
7	1.288± 0.018	0.111± 0.010	0.057	0.092	0.665± 0.010	0.029	0.048
8	1.366± 0.008	0.112± 0.008	0.032	0.117	0.705± 0.004	0.016	0.060
9	1.434± 0.009	0.109± 0.008	0.021	0.128	0.740± 0.005	0.011	0.066
10	1.530± 0.009	0.105± 0.007	0.011	0.138	0.790± 0.004	0.005	0.071
11	1.602± 0.006	0.105± 0.008	0.004	0.145	0.827± 0.003	0.002	0.075
12	1.659± 0.005	0.079± 0.003	0.000	0.149	0.856± 0.002	0.000	0.077

Test Data for Two Phase Air Flow in Single Grid Rod Bundle
 $Q_l = 2800 \text{ cc/min}$ $T_l = 282^\circ \text{K}$ $T_g = 280^\circ \text{K}$

	Air Flowrate (1000 cc/sec)	Channel Velocity (m/sec)	Pressure Drop (mm-H ₂ O)	Liquid Flowrate Downward Upward (cc/min) (cc/min)
1	2.545± 0.135	2.260	54.2 ± 6.3	2827.4 0.0
2	3.614± 0.173	3.209	84.7± 11.5	2811.7 15.7
3	3.826± 0.113	3.397	88.7± 11.8	2772.5 55.0
4	4.340± 0.070	3.854	101.2± 13.3	2200.0 628.3
5	4.640± 0.087	4.120	101.8± 12.4	2042.0 785.4
6	5.086± 0.077	4.516	97.2± 11.3	1492.3 1335.2
7	5.574± 0.028	4.950	95.3± 10.8	1256.6 1570.8
8	6.230± 0.023	5.532	106.8± 11.1	942.5 1885.0
9	6.604± 0.077	5.865	113.9 ± 8.6	628.3 2199.1
10	6.892± 0.045	6.120	115.4 ± 7.6	455.5 2371.9
11	7.335± 0.022	6.514	108.7 ± 8.1	274.9 2552.5
12	7.846± 0.045	6.967	92.6 ± 9.2	117.8 2709.6
13	8.316± 0.025	7.385	94.6 ± 9.7	39.3 2788.1
14	8.725± 0.085	7.748	91.9 ± 6.7	0.0 2827.4
15	9.311± 0.048	8.268	77.6 ± 2.8	0.0 2827.4

Nondimensional Form of Test Data

$$K_l^* = 0.255 \quad j_l^* = 0.132 \quad Re_T = 532.0 \quad V_c^* = 0.662$$

	K_g^*	P^*	K_f^*	K_c^*	j_g^*	j_f^*	j_c^*
1	0.492± 0.026	0.054± 0.006	0.255	0.000	0.254± 0.013	0.132	0.000
2	0.698± 0.033	0.085± 0.012	0.254	0.001	0.360± 0.017	0.131	0.001
3	0.739± 0.022	0.089± 0.012	0.250	0.005	0.381± 0.011	0.129	0.003
4	0.838± 0.014	0.101± 0.013	0.199	0.057	0.433± 0.007	0.103	0.029
5	0.896± 0.017	0.102± 0.012	0.184	0.071	0.463± 0.009	0.095	0.037
6	0.982± 0.015	0.097± 0.011	0.135	0.121	0.507± 0.008	0.070	0.062
7	1.077± 0.005	0.095± 0.011	0.113	0.142	0.556± 0.003	0.059	0.073
8	1.204± 0.004	0.107± 0.011	0.085	0.170	0.621± 0.002	0.044	0.088
9	1.276± 0.015	0.114± 0.009	0.057	0.199	0.658± 0.008	0.029	0.102
10	1.331± 0.009	0.116± 0.008	0.041	0.214	0.687± 0.004	0.021	0.111
11	1.417± 0.004	0.109± 0.008	0.025	0.230	0.731± 0.002	0.013	0.119
12	1.516± 0.009	0.093± 0.009	0.011	0.245	0.782± 0.004	0.005	0.126
13	1.607± 0.005	0.095± 0.010	0.004	0.252	0.829± 0.002	0.002	0.130
14	1.686± 0.016	0.092± 0.007	0.000	0.255	0.870± 0.008	0.000	0.132
15	1.799± 0.009	0.078± 0.003	0.000	0.255	0.928± 0.005	0.000	0.132

Test Data for Two Phase Air Flow in Single Grid Rod Bundle
 $Q_l = 3900 \text{ cc/min}$ $T_l = 282^\circ \text{K}$ $T_g = 280^\circ \text{K}$

	Air Flowrate (1000 cc/sec)		Channel Velocity (m/sec)	Pressure Drop (mm-H ₂ O)		Liquid Flowrate Downward Upward (cc/min) (cc/min)	
1	3.326±	0.137	2.953	97.0±	15.6	3887.7	39.3
2	3.778±	0.153	3.355	109.3±	14.2	3479.3	447.7
3	4.199±	0.078	3.729	106.8±	13.0	3102.3	1138.8
4	4.836±	0.032	4.295	103.9±	11.7	1885.0	2042.0
5	5.490±	0.067	4.875	101.0±	10.8	1335.2	2591.8
6	6.013±	0.093	5.339	102.6±	12.4	1021.0	2906.0
7	6.403±	0.073	5.686	117.0 ±	9.6	667.6	3259.4
8	6.758±	0.063	6.001	115.4 ±	9.2	526.2	3400.8
9	7.177±	0.079	6.373	112.6 ±	8.1	353.4	3573.6
10	7.542±	0.050	6.697	106.5 ±	8.3	223.8	3703.2
11	7.913±	0.035	7.027	92.9 ±	8.1	110.0	3817.0
12	8.497±	0.061	7.545	77.5 ±	3.5	7.9	3919.1
13	9.105±	0.059	8.086	85.6 ±	5.4	0.0	3927.0

Nondimensional Form of Test Data

$$K_l^* = 0.351 \quad j_l^* = 0.181 \quad \text{Re}_T = 741.0 \quad V_c^* = 0.556$$

	K_g^*		P^*		K_f^*		K_c^*		j_g^*		j_f^*		j_c^*	
1	0.642±	0.027	0.097±	0.016	0.351	0.004	0.332±	0.014	0.181	0.002				
2	0.730±	0.030	0.109±	0.014	0.314	0.040	0.377±	0.015	0.162	0.021				
3	0.811±	0.015	0.107±	0.013	0.280	0.103	0.419±	0.008	0.145	0.053				
4	0.934±	0.006	0.104±	0.012	0.170	0.184	0.482±	0.003	0.088	0.095				
5	1.061±	0.013	0.101±	0.011	0.121	0.234	0.547±	0.007	0.062	0.121				
6	1.162±	0.018	0.103±	0.012	0.092	0.262	0.599±	0.009	0.048	0.135				
7	1.237±	0.014	0.117±	0.010	0.060	0.294	0.638±	0.007	0.031	0.152				
8	1.305±	0.012	0.116±	0.009	0.048	0.307	0.674±	0.006	0.025	0.158				
9	1.387±	0.015	0.113±	0.008	0.032	0.323	0.715±	0.008	0.016	0.167				
10	1.457±	0.010	0.107±	0.008	0.020	0.334	0.752±	0.005	0.010	0.173				
11	1.529±	0.007	0.093±	0.008	0.010	0.345	0.789±	0.003	0.005	0.178				
12	1.641±	0.012	0.078±	0.003	0.001	0.354	0.847±	0.006	0.000	0.183				
13	1.759±	0.011	0.086±	0.005	0.000	0.355	0.908±	0.006	0.000	0.183				

Test Data for Single Phase Air Flow in Double Grid Rod Bundle
 $Q_l = 0$ cc/min $T_l = 282$ °K $T_g = 280$ °K

	Air Flowrate (1000 cc/sec)	Channel Velocity (m/sec)	Pressure Drop (mm-H ₂ O)	Liquid Flowrate Downward Upward (cc/min) (cc/min)
1	2.706± 0.024	2.403	13.8 ± 0.4	0.0 0.0
2	3.993± 0.027	3.546	22.5 ± 1.7	0.0 0.0
3	5.119± 0.065	4.546	29.7 ± 1.7	0.0 0.0
4	6.248± 0.014	5.548	35.8 ± 2.2	0.0 0.0
5	7.205± 0.078	6.398	46.1 ± 5.5	0.0 0.0
6	7.645± 0.044	6.788	55.7 ± 2.7	0.0 0.0
7	8.323± 0.017	7.391	61.7 ± 5.4	0.0 0.0
8	8.579± 0.023	7.619	72.4 ± 4.6	0.0 0.0
9	9.093± 0.063	8.075	78.0 ± 1.4	0.0 0.0
10	9.496± 0.068	8.433	87.3 ± 2.5	0.0 0.0
11	9.722± 0.052	8.633	90.2 ± 4.9	0.0 0.0
12	10.125± 0.066	8.991	104.9 ± 4.6	0.0 0.0

Nondimensional Form of Test Data

$$K_l^* = 0.0 \quad j_l^* = 0.0 \quad Re_T = 0.0 \quad V_c^* = 0.0$$

	K_g^*	P^*	K_f^*	K_c^*	j_g^*	j_f^*	j_c^*
1	0.523± 0.005	0.014± 0.000	0.000	0.000	0.270± 0.002	0.000	0.000
2	0.771± 0.005	0.023± 0.002	0.000	0.000	0.398± 0.003	0.000	0.000
3	0.989± 0.012	0.030± 0.002	0.000	0.000	0.510± 0.006	0.000	0.000
4	1.207± 0.003	0.036± 0.002	0.000	0.000	0.623± 0.001	0.000	0.000
5	1.392± 0.015	0.046± 0.005	0.000	0.000	0.718± 0.008	0.000	0.000
6	1.477± 0.008	0.056± 0.003	0.000	0.000	0.762± 0.004	0.000	0.000
7	1.608± 0.003	0.062± 0.005	0.000	0.000	0.830± 0.002	0.000	0.000
8	1.657± 0.005	0.072± 0.005	0.000	0.000	0.855± 0.002	0.000	0.000
9	1.757± 0.012	0.078± 0.001	0.000	0.000	0.906± 0.006	0.000	0.000
10	1.834± 0.013	0.087± 0.002	0.000	0.000	0.947± 0.007	0.000	0.000
11	1.878± 0.010	0.090± 0.005	0.000	0.000	0.969± 0.005	0.000	0.000
12	1.956± 0.013	0.105± 0.005	0.000	0.000	1.009± 0.007	0.000	0.000

Test Data for Two Phase Air Flow in Double Grid Rod Bundle
 $Q_l = 170 \text{ cc/min}$ $T_l = 282^\circ\text{K}$ $T_g = 280^\circ\text{K}$

	Air Flowrate (1000 cc/sec)	Channel Velocity (m/sec)	Pressure Drop (mm-H ₂ O)	Liquid Flowrate Downward Upward (cc/min) (cc/min)
1	2.847± 0.011	2.529	0.2 ± 2.1	172.8 0.0
2	4.666± 0.052	4.144	20.2 ± 3.0	172.8 0.0
3	5.574± 0.028	4.949	32.3 ± 0.7	172.8 0.0
4	6.421± 0.070	5.702	40.0 ± 3.2	128.8 44.0
5	6.756± 0.053	6.000	55.5 ± 1.0	94.2 78.6
6	7.074± 0.037	6.282	58.7 ± 2.1	62.8 110.0
7	7.366± 0.023	6.541	81.5 ± 6.6	23.6 149.2
8	7.624± 0.020	6.771	87.4 ± 1.1	3.1 169.7
9	8.110± 0.043	7.202	87.1 ± 1.6	0.0 172.8
10	8.491± 0.064	7.540	66.2 ± 3.2	0.0 172.8

Nondimensional Form of Test Data

$$K_l^* = 0.016 \quad j_l^* = 0.008 \quad Re_T = 32.3 \quad V_c^* = 1.059$$

	K_g^*	P^*	K_f^*	K_c^*	j_g^*	j_f^*	j_c^*
1	0.550± 0.002	0.000± 0.002	0.016	0.000	0.284± 0.001	0.008	0.000
2	0.901± 0.010	0.020± 0.003	0.016	0.000	0.465± 0.005	0.008	0.000
3	1.077± 0.005	0.032± 0.001	0.016	0.000	0.556± 0.003	0.008	0.000
4	1.240± 0.014	0.040± 0.003	0.012	0.004	0.640± 0.007	0.006	0.002
5	1.305± 0.010	0.056± 0.001	0.009	0.007	0.673± 0.005	0.004	0.004
6	1.367± 0.007	0.059± 0.002	0.006	0.010	0.705± 0.004	0.003	0.005
7	1.423± 0.005	0.082± 0.007	0.002	0.013	0.734± 0.002	0.001	0.007
8	1.473± 0.004	0.088± 0.001	0.000	0.015	0.760± 0.002	0.000	0.008
9	1.567± 0.008	0.087± 0.002	0.000	0.016	0.808± 0.004	0.000	0.008
10	1.640± 0.012	0.066± 0.003	0.000	0.016	0.846± 0.006	0.000	0.008

Test Data for Two Phase Air Flow in Double Grid Rod Bundle
 $Q_l = 510 \text{ cc/min}$ $T_l = 282 \text{ }^\circ\text{K}$ $T_g = 280 \text{ }^\circ\text{K}$

	Air Flowrate (1000 cc/sec)		Channel Velocity (m/sec)	Pressure Drop (mm-H ₂ O)		Liquid Flowrate Downward Upward (cc/min) (cc/min)	
1	1.922±	0.065	1.707	34.2 ±	0.8	510.5	0.0
2	3.906±	0.030	3.468	38.6 ±	1.3	510.5	0.0
3	5.134±	0.063	4.559	55.8 ±	0.6	502.7	7.9
4	5.848±	0.056	5.193	36.8 ±	1.4	361.3	149.2
5	6.191±	0.018	5.498	43.6 ±	6.0	255.3	255.3
6	6.515±	0.032	5.786	47.7 ±	7.0	176.7	333.8
7	6.792±	0.018	6.031	53.9 ±	4.7	137.4	373.1
8	7.102±	0.044	6.307	87.0 ±	1.8	58.9	451.6
9	7.314±	0.029	6.495	82.5 ±	1.3	39.3	471.2
10	7.594±	0.039	6.744	89.8 ±	5.3	0.0	510.5
11	8.042±	0.048	7.141	87.6 ±	0.8	0.0	510.5
12	8.554±	0.035	7.596	63.3 ±	3.7	0.0	510.5

Nondimensional Form of Test Data

$$K_l^* = 0.046 \quad j_l^* = 0.024 \quad Re_T = 96.9 \quad V_c^* = 0.882$$

	K_g^*		P^*		K_f^*	K_c^*	j_g^*		j_f^*	j_c^*
1	0.371±	0.013	0.034±	0.001	0.046	0.000	0.192±	0.006	0.024	0.000
2	0.754±	0.006	0.039±	0.001	0.046	0.000	0.389±	0.003	0.024	0.000
3	0.992±	0.012	0.056±	0.001	0.045	0.001	0.512±	0.006	0.023	0.000
4	1.130±	0.011	0.037±	0.001	0.033	0.013	0.583±	0.006	0.017	0.007
5	1.196±	0.003	0.044±	0.006	0.023	0.023	0.617±	0.002	0.012	0.012
6	1.259±	0.006	0.048±	0.007	0.016	0.030	0.649±	0.003	0.008	0.016
7	1.312±	0.004	0.054±	0.005	0.012	0.034	0.677±	0.002	0.006	0.017
8	1.372±	0.009	0.087±	0.002	0.005	0.041	0.708±	0.004	0.003	0.021
9	1.413±	0.006	0.083±	0.001	0.004	0.043	0.729±	0.003	0.002	0.022
10	1.467±	0.007	0.090±	0.005	0.000	0.046	0.757±	0.004	0.000	0.024
11	1.554±	0.009	0.088±	0.001	0.000	0.046	0.802±	0.005	0.000	0.024
12	1.653±	0.007	0.063±	0.004	0.000	0.046	0.853±	0.003	0.000	0.024

Test Data for Two Phase Air Flow in Double Grid Rod Bundle

$$Q_l = 750 \text{ cc/min} \quad T_l = 282 \text{ }^\circ\text{K} \quad T_g = 280 \text{ }^\circ\text{K}$$

	Air Flowrate (1000 cc/sec)		Channel Velocity (m/sec)	Pressure Drop (mm-H ₂ O)		Liquid Flowrate Downward Upward (cc/min) (cc/min)	
1	2.329±	0.232	2.068	36.5 ±	1.4	746.1	0.0
2	4.261±	0.074	3.784	22.9 ±	1.5	746.1	0.0
3	4.956±	0.062	4.401	33.2 ±	0.7	687.2	58.9
4	5.614±	0.027	4.985	38.9 ±	2.2	451.6	294.5
5	6.116±	0.044	5.431	44.7 ±	7.3	314.2	432.0
6	6.312±	0.063	5.605	53.8 ±	5.1	216.0	530.1
7	6.633±	0.086	5.890	57.8 ±	3.1	157.1	589.0
8	7.071±	0.038	6.279	65.9 ±	5.3	58.9	687.2
9	7.407±	0.030	6.578	58.6 ±	1.7	19.6	726.5
10	7.862±	0.020	6.981	57.8 ±	1.3	0.0	746.1
11	8.386±	0.042	7.447	68.0±	10.4	0.0	746.1
12	5.228±	0.019	4.643	59.0 ±	2.6	628.3	117.8
13	5.589±	0.022	4.963	58.8 ±	3.1	510.5	235.6

Nondimensional Form of Test Data

$$K_l^* = 0.067 \quad j_l^* = 0.035 \quad Re_T = 142.5 \quad V_c^* = 0.838$$

	K_g^*		P^*		K_f^*		K_c^*		j_g^*		j_f^*	j_c^*
1	0.450±	0.045	0.037±	0.001	0.067	0.000	0.232±	0.023	0.035	0.000		
2	0.823±	0.014	0.023±	0.001	0.067	0.000	0.425±	0.007	0.035	0.000		
3	0.957±	0.012	0.033±	0.001	0.062	0.005	0.494±	0.006	0.032	0.003		
4	1.084±	0.005	0.039±	0.002	0.041	0.027	0.560±	0.003	0.021	0.014		
5	1.181±	0.009	0.045±	0.007	0.028	0.039	0.610±	0.004	0.015	0.020		
6	1.219±	0.012	0.054±	0.005	0.020	0.048	0.629±	0.006	0.010	0.025		
7	1.281±	0.017	0.058±	0.003	0.014	0.053	0.661±	0.009	0.007	0.027		
8	1.366±	0.007	0.066±	0.005	0.005	0.062	0.705±	0.004	0.003	0.032		
9	1.431±	0.006	0.059±	0.002	0.002	0.066	0.738±	0.003	0.001	0.034		
10	1.519±	0.004	0.058±	0.001	0.000	0.067	0.784±	0.002	0.000	0.035		
11	1.620±	0.008	0.068±	0.010	0.000	0.067	0.836±	0.004	0.000	0.035		
12	1.010±	0.004	0.059±	0.003	0.057	0.011	0.521±	0.002	0.029	0.005		
13	1.080±	0.004	0.059±	0.003	0.046	0.021	0.557±	0.002	0.024	0.011		

Test Data for Two Phase Air Flow in Double Grid Rod Bundle
 $Q_l = 1500 \text{ cc/min}$ $T_l = 282^\circ \text{K}$ $T_g = 280^\circ \text{K}$

	Air Flowrate (1000 cc/sec)		Channel Velocity (m/sec)	Pressure Drop (mm-H ₂ O)		Liquid Flowrate Downward Upward (cc/min) (cc/min)	
1	3.246±	0.100	2.882	45.6 ±	6.7	1492.3	0.0
2	3.989±	0.023	3.542	55.8 ±	1.0	1413.7	78.5
3	4.391±	0.031	3.899	57.1 ±	1.3	1295.9	196.3
4	4.916±	0.045	4.365	64.7 ±	4.4	942.5	549.8
5	5.198±	0.032	4.616	66.5 ±	4.0	863.9	628.3
6	5.573±	0.027	4.949	71.1 ±	5.2	628.3	863.9
7	6.201±	0.020	5.506	84.5 ±	5.3	353.4	1138.8
8	6.583±	0.061	5.846	96.1 ±	7.1	219.9	1272.3
9	7.010±	0.053	6.225	79.9 ±	1.7	78.5	1413.7
10	7.313±	0.030	6.494	64.5 ±	3.3	47.1	1445.1
11	7.723±	0.081	6.858	63.0 ±	8.8	0.0	1492.3
12	8.319±	0.028	7.387	80.7 ±	3.9	0.0	1492.3

Nondimensional Form of Test Data

$$K_l^* = 0.135 \quad j_l^* = 0.070 \quad Re_T = 285.0 \quad V_c^* = 0.662$$

	K_g^*		P^*		K_f^*	K_c^*	j_g^*		j_f^*	j_c^*
1	0.627±	0.019	0.046±	0.007	0.135	0.000	0.324±	0.010	0.070	0.000
2	0.771±	0.004	0.056±	0.001	0.128	0.007	0.398±	0.002	0.066	0.004
3	0.848±	0.006	0.057±	0.001	0.117	0.018	0.438±	0.003	0.060	0.009
4	0.950±	0.009	0.065±	0.004	0.085	0.050	0.490±	0.004	0.044	0.026
5	1.004±	0.006	0.067±	0.004	0.078	0.057	0.518±	0.003	0.040	0.029
6	1.077±	0.005	0.071±	0.005	0.057	0.078	0.555±	0.003	0.029	0.040
7	1.198±	0.004	0.085±	0.005	0.032	0.103	0.618±	0.002	0.016	0.053
8	1.272±	0.012	0.096±	0.007	0.020	0.115	0.656±	0.006	0.010	0.059
9	1.354±	0.010	0.080±	0.002	0.007	0.128	0.699±	0.005	0.004	0.066
10	1.413±	0.006	0.065±	0.003	0.004	0.130	0.729±	0.003	0.002	0.067
11	1.492±	0.016	0.063±	0.009	0.000	0.135	0.770±	0.008	0.000	0.070
12	1.607±	0.005	0.081±	0.004	0.000	0.135	0.829±	0.003	0.000	0.070

Test Data for Two Phase Air Flow in Double Grid Rod Bundle
 $Q_l = 2500$ cc/min $T_l = 282$ °K $T_g = 280$ °K

	Air Flowrate (1000 cc/sec)		Channel Velocity (m/sec)	Pressure Drop (mm-H ₂ O)		Liquid Flowrate Downward Upward (cc/min) (cc/min)	
1	0.723±	0.152	0.642	33.2 ±	0.6	2513.3	0.0
2	1.722±	0.188	1.530	51.4 ±	6.1	2513.3	0.0
3	2.763±	0.049	2.454	44.2 ±	6.4	2497.6	15.7
4	3.919±	0.033	3.480	56.4 ±	1.4	2081.3	432.0
5	4.330±	0.070	3.845	58.0 ±	2.3	1649.3	863.9
6	4.731±	0.051	4.201	60.6 ±	3.6	1453.0	1060.3
7	5.258±	0.050	4.669	73.4 ±	5.1	1060.3	1453.0
8	5.546±	0.022	4.925	77.2 ±	3.6	903.2	1610.1
9	5.689±	0.053	5.052	78.7 ±	3.6	785.4	1727.9
10	6.170±	0.034	5.479	90.6 ±	8.7	573.3	1939.9
11	6.283±	0.051	5.580	103.8 ±	7.9	392.7	2120.6
12	6.646±	0.092	5.901	103.6 ±	7.6	235.6	2277.7
13	6.855±	0.023	6.087	96.3 ±	8.0	196.3	2316.9
14	7.386±	0.020	6.558	87.1 ±	4.3	62.8	2450.4
15	8.133±	0.056	7.222	67.1 ±	3.0	0.0	2513.3

Nondimensional Form of Test Data

$$K_l^* = 0.227 \quad j_l^* = 0.117 \quad Re_T = 475.0 \quad V_c^* = 0.574$$

	K_g^*		P^*		K_f^*	K_c^*	j_g^*		j_f^*	j_c^*
1	0.140±	0.029	0.033±	0.001	0.227	0.000	0.072±	0.015	0.117	0.000
2	0.333±	0.036	0.051±	0.006	0.227	0.000	0.172±	0.019	0.117	0.000
3	0.534±	0.009	0.044±	0.006	0.226	0.001	0.275±	0.005	0.116	0.001
4	0.757±	0.006	0.057±	0.001	0.188	0.039	0.391±	0.003	0.097	0.020
5	0.836±	0.013	0.058±	0.002	0.149	0.078	0.432±	0.007	0.077	0.040
6	0.914±	0.010	0.061±	0.004	0.131	0.096	0.472±	0.005	0.068	0.049
7	1.016±	0.010	0.073±	0.005	0.096	0.131	0.524±	0.005	0.049	0.068
8	1.071±	0.004	0.077±	0.004	0.082	0.145	0.553±	0.002	0.042	0.075
9	1.099±	0.010	0.079±	0.004	0.071	0.156	0.567±	0.005	0.037	0.081
10	1.192±	0.007	0.091±	0.009	0.052	0.175	0.615±	0.003	0.027	0.090
11	1.214±	0.010	0.104±	0.008	0.035	0.191	0.626±	0.005	0.018	0.099
12	1.284±	0.018	0.104±	0.008	0.021	0.206	0.662±	0.009	0.011	0.106
13	1.324±	0.004	0.096±	0.008	0.018	0.209	0.683±	0.002	0.009	0.108
14	1.427±	0.004	0.087±	0.004	0.006	0.221	0.736±	0.002	0.003	0.114
15	1.571±	0.011	0.067±	0.003	0.000	0.227	0.811±	0.006	0.000	0.117

Test Data for Two Phase Air Flow in Double Grid Rod Bundle
 $Q_l = 3700 \text{ cc/min}$ $T_l = 282^\circ \text{K}$ $T_g = 280^\circ \text{K}$

	Air Flowrate (1000 cc/sec)	Channel Velocity (m/sec)	Pressure Drop (mm-H ₂ O)	Liquid Flowrate Downward Upward (cc/min) (cc/min)
1	1.079± 0.317	0.959	59.4 ± 4.5	3691.4 0.0
2	1.661± 0.311	1.475	68.8± 10.7	3675.7 15.7
3	2.708± 0.039	2.405	55.5 ± 2.9	3495.0 196.3
4	3.199± 0.108	2.841	56.4 ± 2.1	2748.9 942.5
5	3.405± 0.038	3.023	56.6 ± 2.5	2434.7 1256.6
6	3.888± 0.021	3.452	58.7 ± 3.4	1885.0 1806.4
7	4.299± 0.076	3.818	60.5 ± 4.0	1570.8 2120.6
8	4.837± 0.028	4.295	68.7 ± 5.4	1335.2 2356.2
9	5.493± 0.074	4.878	76.7 ± 5.5	863.9 2827.4
10	5.809± 0.057	5.158	84.5 ± 4.3	706.9 2984.5
11	6.264± 0.030	5.563	108.6 ± 8.6	432.0 3259.4
12	6.798± 0.020	6.037	101.6± 10.1	235.6 3455.8
13	7.072± 0.037	6.280	98.1 ± 8.4	133.5 3557.9
14	7.438± 0.043	6.605	82.2 ± 4.8	55.0 3636.4
15	8.266± 0.045	7.340	98.8 ± 4.8	0.0 3691.4

Nondimensional Form of Test Data

$$K_l^* = 0.333 \quad j_l^* = 0.172 \quad Re_T = 703.0 \quad V_c^* = 0.424$$

	K_g^*	P^*	K_f^*	K_c^*	j_g^*	j_f^*	j_c^*
1	0.209± 0.061	0.059± 0.004	0.333	0.000	0.108± 0.032	0.172	0.000
2	0.321± 0.060	0.069± 0.011	0.332	0.001	0.166± 0.031	0.171	0.001
3	0.523± 0.008	0.056± 0.003	0.316	0.018	0.270± 0.004	0.163	0.009
4	0.618± 0.021	0.056± 0.002	0.248	0.085	0.319± 0.011	0.128	0.044
5	0.658± 0.007	0.057± 0.003	0.220	0.113	0.339± 0.004	0.113	0.059
6	0.751± 0.004	0.059± 0.003	0.170	0.163	0.388± 0.002	0.088	0.084
7	0.831± 0.015	0.061± 0.004	0.142	0.191	0.429± 0.008	0.073	0.099
8	0.934± 0.005	0.069± 0.005	0.121	0.213	0.482± 0.003	0.062	0.110
9	1.061± 0.014	0.077± 0.005	0.078	0.255	0.548± 0.007	0.040	0.132
10	1.122± 0.011	0.085± 0.004	0.064	0.270	0.579± 0.006	0.033	0.139
11	1.210± 0.006	0.109± 0.009	0.039	0.294	0.624± 0.003	0.020	0.152
12	1.313± 0.004	0.102± 0.010	0.021	0.312	0.678± 0.002	0.011	0.161
13	1.366± 0.007	0.098± 0.008	0.012	0.321	0.705± 0.004	0.006	0.166
14	1.437± 0.008	0.082± 0.005	0.005	0.328	0.741± 0.004	0.003	0.169
15	1.597± 0.009	0.099± 0.005	0.000	0.333	0.824± 0.005	0.000	0.172

APPENDIX B. INPUT DECKS FOR CALCULATIONS

1
2
3

Appendix B. Input Decks for Calculations

=====									
=	ccfl	model test dia=0.5 cm, jg=0 - 1.0							
*	ccfl	junction = 4000000							
*	ccfl	option = wallis type (m=1.0 c=1.0)							
=====									
000100	new	transnt							
0000102	sl	si							
0000110	air								
0000115	1.0								

0000201	10.00	1.0-7	0.01	3	100	1000	10000		
0000202	200.0	1.0-7	0.01	3	100	1000	10000		

0010000	waterin	tmdpvcl							
0010101	1.0	0.1	0.	0.	0.	0.	0.	0.	00
0010200	3								
0010201	0.	1.0+5	282.0						

0020000	waterin	tmdpjun							
0020101	001000000	003000000	5.0-6						
0020200	1								
0020201	0.	6.954-4	0.	0.	* jf = 0.16				

0030000	section	pipe							
0030001	6								
0030101	1.9635--5	6							
0030301	0.30	6							
0030601	-90.0	6							
0030801	0.0	0.005	6						
0031001	00000	6							
0031101	00000	5							
0031201	4	1.+5	282.0	1.000	0.0	0.0	0.0	5	
0031301	0.0	0.0	0.0	0.0	5				

0040000	downflow	sngljun							
0040101	003010000	005000000	1.9635-5	0.0	0.0	100000			
0040110	0.0095	0.0	1.0	1.0	*** wallis flooding				
0040201	1	0.0	0.0	0.0					

0050000	lower!	snglvcl							
0050101	0.0346	0.13	0.0	0.0	-90.0	-0.13	0.0	0.0	00
0050200	4	1.0+5	282.0	1.0					

0060000	airin	tmdpjun							
0050101	007000000	005010003	1.9635-5						
0060200	0								
0060201	0.0	0.0	0.0	0.0	0.0	0.0			
0060202	10.0	0.0	0.0	0.0	0.0	0.0			
0060203	200.0	0.00	7.000	0.0					

0070000	airin	tmdpvcl							
0070101	1.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	00
0070200	4								
0070201	0.0	1.+5	282.0	1.0					

0080000	tankflow	sngljun							
0080101	005010000	009000000	0.0346	0.0	0.0	00000			
0080201	1	0.0	0.0	0.0					
=====									

0090000	tank1	snglvol
0090101	0.0346	0.5 0.0 0.0 -90.0 -0.5 0.0 0.0 0.0 0.0
0090200	4	1.0+5 282.0 1.0

0100000	upflow	sngljun
0100101	003000000	011000000 0.0 0.1 0.1 0000
0100201	1	0.0 0.0 0.0

0110000	upplenum	tmdpvcl
0110101	0.125	0.44 0. 0. 0. 0. 0. 0. 0. 00
0110200	4	
0110201	0.0	1.0+5 282.0 1.0

20500100	i-in	mult 5.0-6 0.0 0
20500101	voldfj,	002000000 velfj,002000000

20500200	i-down1	mult 1.9635-5 0.0 0
20500201	voldfj,	004000000 velfj,004000000

20500300	i-up	mult 1.9635-5 0.0 0
20500301	voldfj,	010000000 velfj,010000000

20500400	j-f	mult 4.5180 0.0 0
20500401	voldfj,	004000000 velfj,004000000

20500500	j-g	mult 0.1584 0.0 0
20500501	voldgj,	004000000 velfgj,004000000

20500600	diff-p	sum 1.0 0.0 0
20500601	0.0	1.0 p,3060000 -1.0 p,3010000

20500700	j-fs	mult 1.0 0.0 0 1 0.0
20500701	cntrivar,	4

20500800	j-gs	mult -1.0 0.0 0 1 0.0
20500801	cntrivar,	5

20500900	j-f-sqrt	stdfnctn 1.0 0.0 0
20500901	sart	cntrivar,7

20501000	j-g-sqrt	stdfnctn 1.0 0.0 0
20501001	sart	cntrivar,8

20501100	curve	sum 1.0 0.0 0
20501101	0.0	1.0 cntrivar,9 1.0 cntrivar,10

00000301	cntrivar,	1
00000302	cntrivar,	2
00000303	cntrivar,	3
00000304	cntrivar,	4
00000305	cntrivar,	5
00000306	cntrivar,	6
00000307	cntrivar,	9
00000308	cntrivar,	10
00000309	cntrivar,	11

* end of input data		

B.2

#####

= ccfl model test dia= 2 cm , ig=0 - 1.0

* ccfl junction = 4000000

* ccfl option = wallis type (m=1.0 c=1.0)

000100 new transnt

0000102 sl si

0000110 air

0000115 1.0

0000201 10.00 1.0-7 0.01 3 100 1000 10000

0000202 200.0 1.0-7 0.01 3 100 1000 10000

0010000 waterin tmdpvol

0010101 1.0 0.1 0. 0. 0. 0. 0. 0. 0. 00

0010200 3

0010201 0. 1.0+5 282.0

0020000 waterin tmdpjun

0020101 001000000 003000000 0.00008

0020200 1

0020201 0. 0.0223 0. 0. * jf = 0.16

0030000 section pipe

0030001 6

0030101 3.1416-4 6

0030301 0.30 6

0030601 -90.0 6

0030801 0.0 0.03 6

0031001 00000 6

0031101 00000 5

0031201 4 1.+5 282.0 1.000 0.0 0.0 6

0031301 0.0 0.0 0.0 5

0040000 downflow sngljun

0040101 003010000 005000000 3.1416-4 0.0 0.0 100000

0040110 0.02 0.0 1.0 1.0 *** wallis flooding

0040201 1 0.0 0.0 0.0

0050000 lowerpi snglvol

0050101 0.0346 0.13 0.0 0.0 -90.0 -0.13 0.0 0.0 00

0050200 4 1.0+5 282.0 1.0

0060000 airin tmdpjun

0060101 007000000 005010003 3.1416-4

0060200 0

0060201 0.0 0.0 0.0 0.0

0060202 10.0 0.0 0.0 0.0

0060203 200.0 0.00 15.00 0.0

0070000 airin tmdpvol

0070101 1.0 0.1 0.0 0.0 0.0 0.0 0.0 0.0 00

0070200 4

0070201 0.0 1.+5 282.0 1.0

0080000 tankflow sngljun

0080101 005010000 009000000 0.0346 0.0 0.0 00000

0080201 1 0.0 0.0 0.0

0090000 tank1 snglvol

0090101 0.0346 0.5 0.0 0.0 -90.0 -0.5 0.0 0.0 00

0090200 4 1.0+5 282.0 1.0

0100000 upflow sngljun

0100101 003000000 011000000 0.0 0.1 0.1 0000

0100201 1 0.0 0.0 0.0

0110000 upplenum tmdpvol

0110101 0.125 0.44 0. 0. 0. 0. 0. 0. 00

0110200 4

0110201 0.0 1.0+5 282.0 1.0

02000100 l-in mult 0.00008 0.0 0

02000101 voldfj,002000000 velfj,002000000

02000200 l-down1 mult 3.1416-4 0.0 0

02000201 voldfj,004000000 velfj,004000000

02000300 l-up mult 3.1416-4 0.0 0

02000301 voldfj,010000000 velfj,010000000

02000400 j-f mult 2.2590 0.0 0

02000401 voldfj,004000000 velfj,004000000

02000500 j-g mult 0.07920 0.0 0

02000501 voldg,004000000 velfj,004000000

02000600 diff-p sum 1.0 0.0 0

02000601 0.0 1.0 p,306+000 -1.0 p,3010000

02000700 j-fs mult 1.0 0.0 0 i 0.0

02000701 cntrivar,4

02000800 j-gs mult -1.0 0.0 0 1 0.0

02000801 cntrivar,5

02000900 j-f-sqrt stdfnctn 1.0 0.0 0

02000901 sqrt cntrivar,7

02001000 j-g-sqrt stdfnctn 1.0 0.0 0

02001001 sqrt cntrivar,8

02001100 curve sum 1.0 0.0 0

02001101 0.0 1.0 cntrivar,9 1.0 cntrivar,10

02001200 massf mult 3183.00 0.0 0

02001201 mflow,004000000

0000301 cntrivar,1

0000302 cntrivar,2

0000303 cntrivar,3

0000304 cntrivar,4

0000305 cntrivar,5

0000306 cntrivar,6

0000307 cntrivar,9

0000308 cntrivar,10

0000309 cntrivar,11

0000310 cntrivar,12

20800001 voidj,3010000

20800002 voidj,3020000

20800003 voidj,3030000

20800004 voidj,3040000

20800005 voidj,3050000

20800006 voidj,4000000

20800007 fjj,3010000

20800008 fjj,3020000

20800009 fjj,3030000

20800010 fjj,3040000

20800011 fjj,3050000

20800012 fjj,4000000

20800013 iregj,3010000

20800014 iregj,3020000

20800015 iregj,3030000

20800016 iregj,3040000

20800017 iregj,3050000

20800018 iregj,4000000

20800019 florgj,3010000

20800020 florgj,3020000

20800021 florgj,3030000

20800022 florgj,3040000

20800023 florgj,3050000

20800024 florgj,4000000

20800025 vgjj,3010000

20800026 vgjj,3020000

20800027 vgjj,3030000

20800028 vgjj,3040000

20800029 vgjj,3050000

20800030 vgjj,4000000

B.4

#####

= ccfl model test tube diameter = 10 cm
* ccfl junction = 4000000
* ccfl option = kutateladze type (m=1.0 c= sort{3.2})

000100 new transnt
0000102 si
0000110 air
0000115 1.0

0000201 10.00 1.0-7 0.01 3 100 1000 10000
0000202 300.0 1.0-7 0.01 3 100 1000 10000

0010000 waterin tmdpvol
0010101 1.0 0.1 0. 0. 0. 0. 0. 0. 0. 00
0010200 3
0010201 0. 1.0+5 282.0

0020000 waterin tmdplun
0020101 001000000 003000000 0.002
0020200 1
0020201 0. 1.244100 0. 0. * 2800 cc/min

0030000 section pipe
0030001 6
0030101 7.8540-3 6
0030301 0.25 6
0030601 -90.0 6
0030801 0.0 0.1000 6
0031001 00000 6
0031101 00000 5
0031201 4 1.+5 282.0 1.000 0.0 0.0 6
0031301 0.0 0.0 0.0 5

0

0040000 downflow sngljun
0040101 003010000 005000000 7.8540-3 0.0 0.0 1000000
0040110 0.1000 1.0 1.79 1.0 *** kutateladze form
0040201 1 0.0 0.0 0.0

0050000 lowerpl snglvol
0050101 0.0346 0.13 0.0 0.0 -90.0 -0.13 0.0 0.0 00
0050200 4 1.0+5 282.0 1.0

0060000 airin tmdplun
0060101 007000000 005010003 7.8540-3
0060200 0
0060201 0.0 0.0 0.0 0.0
0060202 10.0 0.0 0.0 0.0
0060203 200.0 0.00 20.0 0.0
0060204 300.0 0.00 30.0 0.0

0070000 airin tmdpvol
0070101 1.0 0.1 0.0 0.0 0.0 0.0 0.0 0.0 00
0070200 4
0070201 0.0 1.+5 282.0 1.0

0080000 tankflow sngljun
0080101 005010000 009000000 0.0346 0.0 0.0 00000
0080201 1 0.0 0.0 0.0

0090000 tank1 snglvol
0090101 0.0346 0.5 0.0 0.0 -90.0 -0.5 0.0 0.0 00
0090200 4 1.0+5 282.0 1.0

0100000 upflow sngljun
0100101 003000000 011000000 0.0 0.1 0.1 0000
0100201 1 0.0 0.0 0.0

0110000 upplenum tmdpvol
0110101 0.125 0.44 0. 0. 0. 0. 0. 0. 00
0110200 4
0110201 0.0 1.0+5 282.0 1.0

02000100 l-in mult 0.0020 0.0 0
02000101 voldfj,002000000 voldfj,002000000

02000200 l-down1 mult 7.8540-3 0.0 0
02000201 voldfj,004000000 voldfj,004000000

02000300 l-up mult 7.8540-3 0.0 0
02000301 voldfj,010000000 voldfj,010000000

02000400 k-f mult 6.1000 0.0 0
02000401 voldfj,004000000 voldfj,004000000

02000500 k-g mult 0.214 0.0 0
02000501 voldg,004000000 voldg,004000000

02000600 diff-p sum 1.0 0.0 0
02000601 0.0 1.0 p,3050000 -1.0 p,3010000

02000700 k-fs mult 1.0 0.0 0 1 0.0
02000701 cntrivar,4

02000800 k-gs mult -1.0 0.0 0 1 0.0
02000801 cntrivar,5

02000900 k-f-sqrt stdfnctn 1.0 0.0 0
02000901 sqrt cntrivar,7

02001000 k-g-sqrt stdfnctn 1.0 0.0 0
02001001 sqrt cntrivar,8

02001100 curve sum 1.0 0.0 0
02001101 0.0 1.0 cntrivar,9 1.0 cntrivar,10

* end of input data

0000301 cntrivar,1
0000302 cntrivar,2
0000303 cntrivar,3
0000304 cntrivar,4
0000305 cntrivar,5
0000306 cntrivar,6
0000307 cntrivar,9
0000308 cntrivar,10
0000309 cntrivar,11

20800011	fj,j,3050000
20800012	fj,j,4000000
20800013	fj,rg,j,3010000
20800014	fj,rg,j,3020000
20800015	fj,rg,j,3030000
20800016	fj,rg,j,3040000
20800017	fj,rg,j,3050000
20800018	fj,rg,j,4000000
* end of Input data	

20800011	upflow sngljun
20800012	01000000 01000000 0.0 0.1 0.1 0000
20800013	01000101 0.0 0.0 0.0
20800014	0100201 1 0.0 0.0 0.0

20800011	upplenum tmdpvol
20800012	0.125 0.44 0. 0. 0. 0. 0. 0. 00
20800013	01010101 4
20800014	010110200 1.0
20800015	0.0 1.0+5 282.0 1.0

208000100	l-in mult 3.80-4 0.0 0
208000101	voidfj,002000000 voidfj,002000000
208000102	voidfj,004000000 voidfj,004000000
208000103	voidfj,006000000 voidfj,006000000
208000104	voidfj,008000000 voidfj,008000000
208000105	voidfj,010000000 voidfj,010000000
208000106	voidfj,012000000 voidfj,012000000
208000107	voidfj,014000000 voidfj,014000000
208000108	voidfj,016000000 voidfj,016000000
208000109	voidfj,018000000 voidfj,018000000
208000110	voidfj,020000000 voidfj,020000000
208000111	voidfj,022000000 voidfj,022000000
208000112	voidfj,024000000 voidfj,024000000
208000113	voidfj,026000000 voidfj,026000000
208000114	voidfj,028000000 voidfj,028000000
208000115	voidfj,030000000 voidfj,030000000
208000116	voidfj,032000000 voidfj,032000000
208000117	voidfj,034000000 voidfj,034000000
208000118	voidfj,036000000 voidfj,036000000
208000119	voidfj,038000000 voidfj,038000000
208000120	voidfj,040000000 voidfj,040000000
208000121	voidfj,042000000 voidfj,042000000
208000122	voidfj,044000000 voidfj,044000000
208000123	voidfj,046000000 voidfj,046000000
208000124	voidfj,048000000 voidfj,048000000
208000125	voidfj,050000000 voidfj,050000000
208000126	voidfj,052000000 voidfj,052000000
208000127	voidfj,054000000 voidfj,054000000
208000128	voidfj,056000000 voidfj,056000000
208000129	voidfj,058000000 voidfj,058000000
208000130	voidfj,060000000 voidfj,060000000
208000131	voidfj,062000000 voidfj,062000000
208000132	voidfj,064000000 voidfj,064000000
208000133	voidfj,066000000 voidfj,066000000
208000134	voidfj,068000000 voidfj,068000000
208000135	voidfj,070000000 voidfj,070000000
208000136	voidfj,072000000 voidfj,072000000
208000137	voidfj,074000000 voidfj,074000000
208000138	voidfj,076000000 voidfj,076000000
208000139	voidfj,078000000 voidfj,078000000
208000140	voidfj,080000000 voidfj,080000000
208000141	voidfj,082000000 voidfj,082000000
208000142	voidfj,084000000 voidfj,084000000
208000143	voidfj,086000000 voidfj,086000000
208000144	voidfj,088000000 voidfj,088000000
208000145	voidfj,090000000 voidfj,090000000
208000146	voidfj,092000000 voidfj,092000000
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208000148	voidfj,096000000 voidfj,096000000
208000149	voidfj,098000000 voidfj,098000000
208000150	voidfj,100000000 voidfj,100000000
208000151	voidfj,102000000 voidfj,102000000
208000152	voidfj,104000000 voidfj,104000000
208000153	voidfj,106000000 voidfj,106000000
208000154	voidfj,108000000 voidfj,108000000
208000155	voidfj,110000000 voidfj,110000000
208000156	voidfj,112000000 voidfj,112000000
208000157	voidfj,114000000 voidfj,114000000
208000158	voidfj,116000000 voidfj,116000000
208000159	voidfj,118000000 voidfj,118000000
208000160	voidfj,120000000 voidfj,120000000
208000161	voidfj,122000000 voidfj,122000000
208000162	voidfj,124000000 voidfj,124000000
208000163	voidfj,126000000 voidfj,126000000
208000164	voidfj,128000000 voidfj,128000000
208000165	voidfj,130000000 voidfj,130000000
208000166	voidfj,132000000 voidfj,132000000
208000167	voidfj,134000000 voidfj,134000000
208000168	voidfj,136000000 voidfj,136000000
208000169	voidfj,138000000 voidfj,13800

B.10

B.10

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11. ABSTRACT (200 words or less)

The CCFL model used in RELAP5/MOD3 version 5m5 has been assessed against simple vertical tubes and rod bundle tests performed at a facility of Korea Atomic Energy Research Institute.

The effect of changes in tube diameter and nodalization of tube section were investigated. The roles of interfacial drags on the flooding characteristics are discussed. Differences between the calculation and the experiment are also discussed.

A comparison between model assessment results and the test data showed that the calculated value lay well on the experimental flooding curve specified by user, but the pressure jump before onset of flooding was not calculated.

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