THE UNIVERSITY OF MANITOBA

HYDRODYNAMICS AND HEAT TRANSFER IN TWO-PHASE TWO-COMPONENT FLOW IN A VERTICAL TUBE

by

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ABSTRACT

An experimental investigation was made to determine the effect of reducing the surface tension on flow pattern, frictional pressure drop and local and mean heat-transfer coefficients in two-phase two-component (gas-liquid) upward flow in a 0.46 inch (1.168 cm) I.D. vertical tube. The liquids used were water and a water-surfactant solution while the gas used was air. A surfactant reduces the surface tension of water while other properties remain essentially unaltered.

The surface tension produced essentially no effect on the slug-churn, churn-annular, annular-mist and bubble-froth transitions for all liquid and air flow rates while significant effects were observed for the bubble-slug boundary; the region previously occupied by slug flow for water was mainly occupied by bubble flow for the surfactant solution. Surface tension was found to have little effect on the frictional pressure drop; the tendency was for the frictional pressure drop to be slightly lower for the surfactant solution than for water where differences existed.

There appeared to be no effect of reducing the surface tension on the shape of the local heat-transfer coefficient

profiles; however, the surfactant produced some effects on the mean heat-transfer coefficients. In general where differences were significant, the tendency was for the mean heat-transfer coefficients for the surfactant solution to be lower than for water; also these differences were associated with changes in the flow patterns.

Local heat-transfer coefficients were correlated by a modified form of the single-phase heat-transfer theory of Spalding which with certain justifiable exclusions, gave agreement with an rms deviation of 18%. Mean heat-transfer data were tested against some of the well-known existing correlations and certain recommendations were made.

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NOMENCLATURE

A_c	Cross-sectional area of tube wall	ft^2
A_G	Flow area of the gas phase	ft^2
A_L	Flow area of the liquid phase	ft^2
A_m	Eigenvalues, Eq. (6.3)	
A_T	Flow area of the tube	ft^2
A_1, A_2	Constants in various equations	
B_0, B , B_2, B_3	Constants appearing in Eq. (C.7)	
C	Circumference of the ring, defined in Section C.19, or discharge coefficient for flow through an orifice plate	
C_p	Specific heat	Btu/lbm °F
d	Diameter of orifice throat	ft
D	Inside diameter of the tube	ft
D_o	Outside diameter of the tube	ft
D_p	Diameter of the pipe connected to the orifice plate	ft
D*	Parameter defined in Eq. (6.20)	
e	Local voltage of the heated tube	volts
$\bar{e}$	Mean deviation defined in Eq. (5.1)	
$\overline{e'}$	Root mean square deviation, Eq. (5.2)	

E	Total voltage drop across the heated tube	volts
E_{LG}, E_{UG}	Voltage drop across the lower and upper guard heaters respectively	volts
f	Friction factor	
F	Velocity of approach factor, Eq. (C.48), or correction factor, Eq. (C.55)	
F_a	Thermal expansion factor of the orifice plate, Eq. (C.48)	
g	Acceleration due to gravity	ft/sec^2
g_c	Conversion factor	$lbm\text{-}ft/lb_f\text{-}sec^2$
G	Mass velocity	$lbm/hr\text{-}ft^2$
G_{SG}	Mass velocity of the gas phase as if it were flowing alone in the tube	$lbm/hr\text{-}ft^2$
G_{SL}	Mass velocity of the liquid phase as if it were flowing alone in the tube	$lbm/hr\text{-}ft^2$
h	Enthalpy per unit mass of fluid	Btu/lbm
$h, h(Z)$	Local heat-transfer coefficient	$Btu/hr\text{-}ft^2\text{-}°F$
$\bar{h}$	Length-mean heat-transfer coefficients	$Btu/hr\text{-}ft^2\text{-}°F$
h'	Manometer reading	inch

$\bar{h}_{AG}$	Single-phase gas heat-transfer coefficient based on actual mean velocity and cross-sectional area of the gas-phase	Btu/hr-ft^2-°F
$\bar{h}_{AL}$	Same as $\bar{h}_{AG}$, defined for liquid	Btu/hr-ft^2-°F
h_w	Differential pressure drop across the orifice plate	in. H_2O
i	Axial current density	Amp/ft^2
I	Total current flowing through the tube	Amp
k	Thermal conductivity	Btu/hr-ft^2-°F
k	Ratio of specific heats of air = 1.4	
k'_o, k_t	Thermal conductivity of tube material	Btu/hr-ft^2-°F
ℓ_E	Entrance length, Eq. (5.10)	
L	Length of the heated test section	ft
L'	Calming length	ft
ΔL	Length used to calculate the length mean heat-transfer coefficient	ft
m	Variable defined in Eq. (C.9)	°F/ft^2
$\dot{m}$	Mass flow rate	lbm/hr
n	Blasius exponent or number of variables	

Nu	Local Nusselt number = $\frac{hD}{k}$	
$\bar{Nu}$	Mean Nusselt number	
Nu_{α}	Value of Nusselt number when $Z \rightarrow \alpha$	
$\overset{*}{Nu}_{TP}$	Modified Nusselt number, Eq. (6.19)	
P	Pressure	lbf/in^2
P_a	Partial pressure of dry air	lbf/in^2
P_{FN}	P-function, Eq. (6.8)	
P_g	Saturation pressure of vapour in air	lbf/in^2
P_v	Partial pressure of vapour	lbf/in^2
Pr	Prandtl number	
Pr_T	Turbulent Prandtl number	
ΔP	Pressure drop (total without subscripts)	lbf/in^2
$\Delta P/\Delta L$	Total pressure drop per unit length	lbf/in^2
q	Heat flux	$Btu/hr\text{-}ft^2$
q_v	Heat generated per unit volume of the heated tube	$Btu/hr\text{-}ft^3$
q_w	Heat flux at the wall	$Btu/hr\text{-}ft^2$
Q	Volumetric flow rate	ft^3/hr

r	Radial coordinate measured from the axis of the tube	ft
R	Inside radius of the tube, or	ft
	Gas constant	ft-lbf/lbm°F
R_o	Outer radius of the tube	ft
R_t	Total resistance of test tube	ohm
Re	Reynolds number	
Re_d	Reynolds number based on orifice throat diameter	
Re_{SG}	Superficial gas Reynolds number	
Re_{SL}	Superficial liquid Reynolds number	
Re_{TP}	$= Re_{SL} + Re_{SG}$, Eq. (2.4)	
S	Slip ratio, Eq. (C.38)	
Sq	Spalding function, Eq. (6.7)	
t	Wall thickness of the tube	ft
T	Temperature	°F
T_{AVG}	Mean temperature of tube wall, Eq. (C.11)	°F
T_L	Temperature of the liquid at the inlet to the mixer	°F
T_o	Temperature as measured by the thermocouples on the heated tube	°F
ΔT_w	Temperature drop across the tube wall	°F

V	Velocity	ft/sec
V_{EXP}	Experimental value of a variable	
V_{THL}	Expected or theoretical value of V_{EXP}	
W	Wattmeter reading	watts
x	Flow quality = $\dot{m}_G/(\dot{m}_G + \dot{m}_L)$	
X	A variable in Eq. (5.7)	
y	Coordinate measured from the tube wall	ft
Y	Expansion factor, Eq. (C.49)	
Y	A variable in Eq. (5.6)	
Z	Axial coordinate measured from the commencement of heated section	in.
Z^+	Variable defined in Eq. (6.13)	
$\bar{Z}$	Variable defined in Eq. (6.2)	
Z'	Variable defined in Eq. (6.4)	

Greek Symbols

α	Void fraction	
α'	Temperature coefficient of thermal conductivity of tube material	$(°F)^{-1}$
β	d/D_p, (Appendix C)	
β'	Temperature-coefficient of electrical resistivity of tube material	$(°F)^{-1}$

γ_m^2	Eigenvalues, Eq. (6.3)	
ρ	density	lbm/ft^3
ρ', ρ_o', $\bar{\rho}$, ρ_t'	Resistivity defined in Appendix C	ohm-ft
μ	Dynamic viscosity	lbm/hr-ft
ν	Kinematic viscosity	ft^2/hr
σ	Surface tension	lbf/ft
τ	Shear stress	lbf/ft^2
ϕ	Relative humidity	

Subscripts

a	Dry air
abs	Absolute
app	Apparent
B	Bulk, liquid or mixture
cw	Cooling water (heat exchanger)
EVAP	Evaporation
e	Effective
G	Gas
G1, G2	At the inlet and outlet of orifice plate
GO	
i	Location at which a thermocouple is attached to the wall

IN, OUT	At the inlet and outlet of heated tube
L	Liquid
LP	Lower Phase
UP	Upper Phase
SG	Superficial gas
SL	Superficial liquid
SP	Single-phase (generally, liquid)
SPF	Single-phase frictional
SPG	Single-phase hydraulic
TP	Two-phase
TPG	Two-phase hydraulic
t	Turbulent
V	Vapour
W	At the wall
WG	Gas at the wall
WL	Liquid at the wall (temperature)

CHAPTER 1

INTRODUCTION

1.1 Background

The simultaneous flow of a liquid and a permanent gas (usually referred to as two-phase two-components flow) or a liquid and its own vapours (two-phase single-component flow) with or without heat transfer takes place in a wide range of industrial applications such as in nuclear reactors, oil wells, oil and gas pipelines, rocket motors, evaporators and condensers, boilers, air-conditioning and refrigerating equipment and many forms of chemical process equipment. In these applications, requirements for economic design, optimization of operating conditions and assessment of safety factor provide an incentive for investigating two-phase phenomena in much greater depth.

A considerable amount of work has been done in this field and a large volume of literature exists (44, 50, 24, 11, 20, 8, 17, 3, 25). Due to the increasing importance of two-phase flow and heat transfer in the power and process industry, recently there has been an exponential growth in the literature on this subject (8, 25, 3, 17). A survey of this literature reveals that only a few investigators have dealt with heat transfer in two-phase two-component (gas-

liquid) flow in vertical tubes. A comprehensive literature review on the subject of two-phase two-component heat transfer, recently presented by Vijay (48) and Aggour (1), indicates that the experimental data in this area are scanty, while in recent years, the growth of computer-based design methods had led to the need for more accurate input data covering a wide range of two-phase flow and heat transfer conditions in order to predict the detailed performance of complex plants.

It is well recognized that fluid properties will affect the hydrodynamics and heat transfer in two-phase two-component flows, and some work has been done (15, 32, 28, 27, 7, 22, 45, 46, 48, 1). It seems that liquid viscosity is the only property which has received considerable attention (22, 15, 28, 45, 46, 32, 48). Very limited experimental work has been conducted on the effect of gas-phase density on the hydrodynamic and heat transfer aspects in two-phase two-component upflow (7, 1). Surface tension has received very little attention. Some investigators (45, 55, 32) have dealt with the effect of surface tension on some of the hydrodynamic aspects; these data are very limited. So far as the present author is aware, no one has attempted so far to investigate the effect of surface tension on the heat-transfer coefficients in two-phase two-component upflow in vertical tubes, the present study was carried out as a first step.

The present investigation is a part of a continuing program at the University of Manitoba which seeks to investigate the effect of fluid properties and other geometrical parameters on flow patterns, pressure drop and local and mean heat-transfer coefficients for two-phase, two-component (gas-liquid) flow in a vertical tube. It was desired to change the individual properties systematically. In the earlier work Vijay (48) investigated the effect of liquid-phase Prandtl number through variation of viscosity, Aggour (1) investigated the effect of the ratio of gas-phase density to liquid-phase density by changing the gas-phase. The present work investigated the effect of reducing the surface tension (and hence the Weber number) on flow patterns, pressure drop and local and mean heat-transfer coefficients for two-phase, two-component upward flow in a vertical tube. For this purpose, experiments were performed with two liquid-air systems; the liquid used were distilled water and a surface active agent (surfactant) solution prepared in tap water. The lower surface tension was achieved by using a surface active agent (surfactant) mainly because a surfactant is capable of reducing the surface tension of water to quite low values at relatively low concentrations while other properties remain essentially unaltered.

After a careful study, fluorocarbon surfactant FC-128 (Potassium Fluorinated alkyl carboxylates) produced by 3M Company was selected for the reasons outlined in Chapter 3. Measurements of static (equilibrium) surface tension were made throughout the investigation by using a Fisher (Model 215) du Nouy ring-type tensiometer. In order to achieve equilibrium distribution of surfactant at the surface, the samples of solution were aged in covered plastic Petri dishes for 16-24 hours and the surface tension measured; these values are reported in the thesis. It is recognized that measurements of static surface tension do not necessarily represent the actual surface tension under operating conditions in the apparatus where gas-liquid interfaces are moving. In the case of the dynamic situation, the effective surface concentration of surfactant would be somewhat less than the static surface concentration; therefore, the dynamic surface tension is expected to be higher than the corresponding static value (35). However, measuring the static surface tension is still an obvious first step to take in the investigation of the effect of surface tension. If changes in any of the observed or measured variables (flow pattern, pressure drop and heat-transfer coefficients) occur, then these are most certainly

due to changes in the surface tension.

In the present investigation, the main independent variables were liquid and air flow rates and surface tension (by adding a surfactant to tap water) and the main dependent variables measured were flow patterns, pressure drop and heat-transfer coefficients. The range of variables studied is given in Table 4.2.

1.2 Purpose and Scope

In summary, the objectives of the present investigation are:

(i) To generate experimental data on flow patterns, frictional pressure drop and local and mean heat-transfer coefficients for two-phase, two-component (gas-liquid) upward flow in a vertical tube at different values of surface tension,

(ii) by comparison with the present water-air data, to determine the effect of reducing the surface tension, at least through the medium of surfactant, on the variables mentioned above,

(iii) to compare the present experimental flow pattern data against some of the existing empirical and analytical flow pattern maps for vertical upflow of liquid-gas mixtures,

(iv) to correlate the present local heat transfer data in the manner proposed in Reference (48) and to compare mean heat transfer data against some of the existing correlations.

1.3 Layout of the Thesis

A brief review of well known work in two-phase, two-component (gas-liquid) upflow in vertical tubes is presented in Chapter 2.

The experimental apparatus is described in Chapter 3; the detailed information on equipment is given in Appendix A.

Chapter 4 describes the experimental procedure and conditions; the calculation procedure is given in Appendix C.

The flow pattern and frictional pressure drop data are presented in Chapter 5. The flow pattern maps for the present data are shown in Figs. 5.5 and 5.6 while the effect of surface tension on flow patterns is illustrated in Fig. 5.7.

The frictional pressure drop data are shown in Figs. 5.10 and 5.11 and the effect of surface tension on frictional pressure drop is illustrated in Fig. 5.12.

The raw heat-transfer data are presented in Chapter 6 in Figs. 6.5 to 6.8 and the effect of surface tension on mean heat-transfer coefficient shown in Fig. 6.9 A and B. Figure 6.10 and 6.11 illustrates the results of correlation of the local heat-transfer coefficients. A summary of the present work together with the main conclusion are presented in Chapter 7.

The number of each figure, table and equation in the body of the thesis begins with the number of the Chapter, or the letter of the Appendix in which it appears.

The variables appearing in the body of the thesis are listed in the "Nomenclature" and the units employed are also mentioned in the Nomenclature.

CHAPTER 2

LITERATURE REVIEW

2.1 Introductory Remarks

An excellent comprehensive review of the literature on the subject of forced-convective heat transfer in two-phase, two-component upflow in vertical tubes has been recently presented by Vijay (48) and Aggour (1). These surveys document studies made on this subject up to 1977. Since these authors thoroughly summarize the work available on this subject, only those better known works whose correlation were compared with the present heat transfer results, are presented in this chapter. As to the knowledge of present author, a very limited amount of work has been published on forced convective heat transfer in two-phase two-component upward flow in vertical tubes after Vijay (48) and Aggour (1); that work is also included in this chapter. Therefore the work presented in this chapter combined with the previous reviews (48, 1) could be considered as an up-to-date summary of the work done in two-phase, two-component heat transfer in upward flow in vertical tubes.

As mentioned in the Introduction, the present investigation also includes the hydrodynamic aspects (pressure drop and flow pattern) of two-phase, two-component upflow in a vertical tube. The literature relating to these hydro-

dynamic studies is not reviewed in this chapter; the literature pertaining to the flow pattern and pressure drop relevant to the present work will be discussed at the appropriate places throughout the thesis.

2.2 Groothuis and Hendal (22)

The authors measured heat transfer to water-air and (gas-oil) air mixtures in a vertical tube and obtained empirical correlations. They also performed single-phase experiments using water and gas-oil and correlated their results with the following correlations:

$$\overline{Nu} = C\, Re_{SL}^{0.81}\, Pr_L^{1/3}\, (\mu_L/\mu_w)^{0.14} \qquad (2.1)$$

where

$C = 0.030$ for water ($Re_{SL} > 5{,}000$)

$C = 0.028$ for gas-oil ($Re_{SL} > 4{,}000$)

The experimental results of two-phase heat-transfer coefficients for water-air and (gas-oil)-air mixtures are shown in Fig. 2.1. The authors observed that an initial amount of air caused a rapid increase in the heat-transfer coefficients. Also the influence of air on heat transfer was most pronounced at the lowest Re because air would be more effective in promoting turbulence there. For each

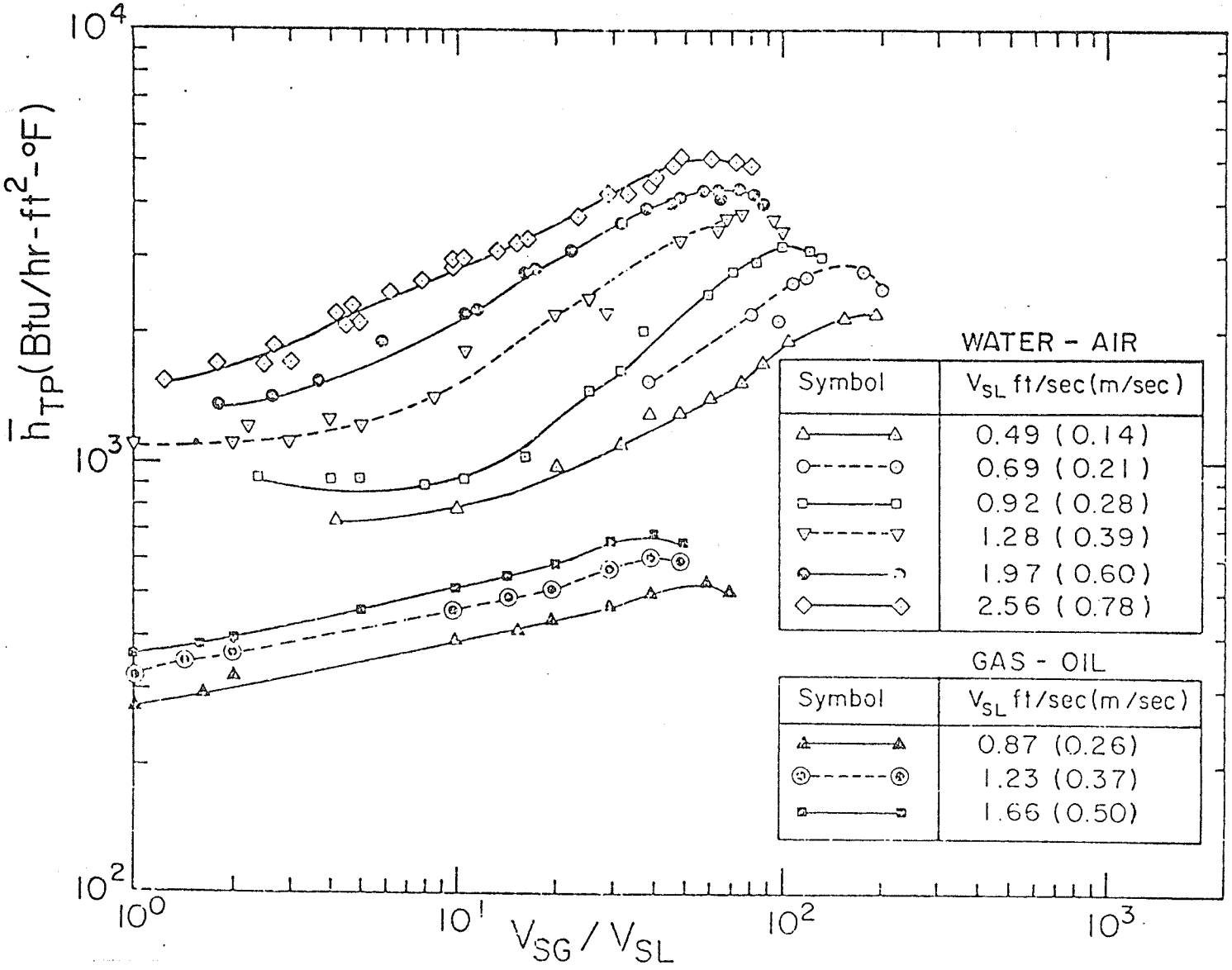


Fig. 2.1 Heat-Transfer Results of Groothuis and Hendal [From Reference (1)]

V_{SL}, the $\bar{h}_{TP}$ passed through a maximum value; the value of V_{SG}/V_{SL} at which this maximum occurred decreased with an increase in liquid mass velocity. The maxima for (gas-oil)-air mixtures occurred at considerably lower values of V_{SG}/V_{SL} than for water-air mixtures. The existence of the maxima was attributed to the transition of slug flow to annular-mist (note that the authors did not observe the flow patterns). The drop in $\bar{h}_{TP}$ beyond the maxima was attributed to the appearance of dry spots on the heated wall due to disintegration of the liquid film on the wall.

The $\bar{h}_{TP}$ data up to the maxima just described were correlated in a modified Sieder-Tate-type equation as given below.

For the water-air system:

$$\overline{Nu}_{TP} = 0.029\ Re_{TP}^{0.87}\ Pr_L^{1/3}\ (\mu_L/\mu_w)^{0.14}$$

$$Re_{SL} > 5{,}000 \text{ and } \frac{V_{SG}}{V_{SL}} \geq 1 \qquad (2.2)$$

For the (gas-oil)-air system:

$$\overline{Nu}_{TP} = 2.6\ Re_{TP}^{0.39}\ Pr_L^{1/3}\ (\mu_L/\mu_w)^{0.14}$$

$$1400 < Re_{SL} < 3500 \text{ and } \frac{V_{SG}}{V_{SL}} \geq 1 \qquad (2.3)$$

where

$$Re_{TP} = Re_{SL} + Re_{SG} \quad . \tag{2.4}$$

2.3 Knott, Anderson, Acrivos and Petersen (27)

The authors performed experiments to study the rate of heat transfer to a viscous oil and nitrogen gas mixture in a vertical tube over a range of $6.7 \leq Re_{SL} \leq 162$ and $126 \leq Re_{SG} \leq 3920$.

The experimental data are shown in Fig. 2.2 where $\frac{\overline{h_{TP}}}{\overline{h_{SP}}}$ is plotted against the volumetric flow ratio $\frac{V_{SG}}{V_{SL}}$; $\overline{h}_{TP}$ is the experimental length-mean two-phase heat-transfer coefficient and $\overline{h}_{SP}$ is the single-phase heat-transfer coefficient calculated from the Sieder-Tate equation.

The authors observed a very small increase in $\overline{h_{TP}}$ up to $\frac{V_{SG}}{V_{SL}}$ of 0.2; however, as the gas flow rate increased, $\frac{\overline{h_{TP}}}{\overline{h_{SP}}}$ increased up to a value of 2 at $\frac{V_{SG}}{V_{SL}} = 10.0$. Assuming that the introduction of the gas-phase (in bubble flow) did not affect the boundary layer region, the increase in $\overline{h}_{TP}$ was attributed to an increase in the mean velocity of the fluid because of the addition of the gas-phase. Based upon this conclusion, they estimated $\overline{h}_{TP}$ by the equation of Sieder-Tate employing Re_{TP} based on the mean velocity ($\overline{V_{TP}}$) of both phases. They proposed the following correlation.

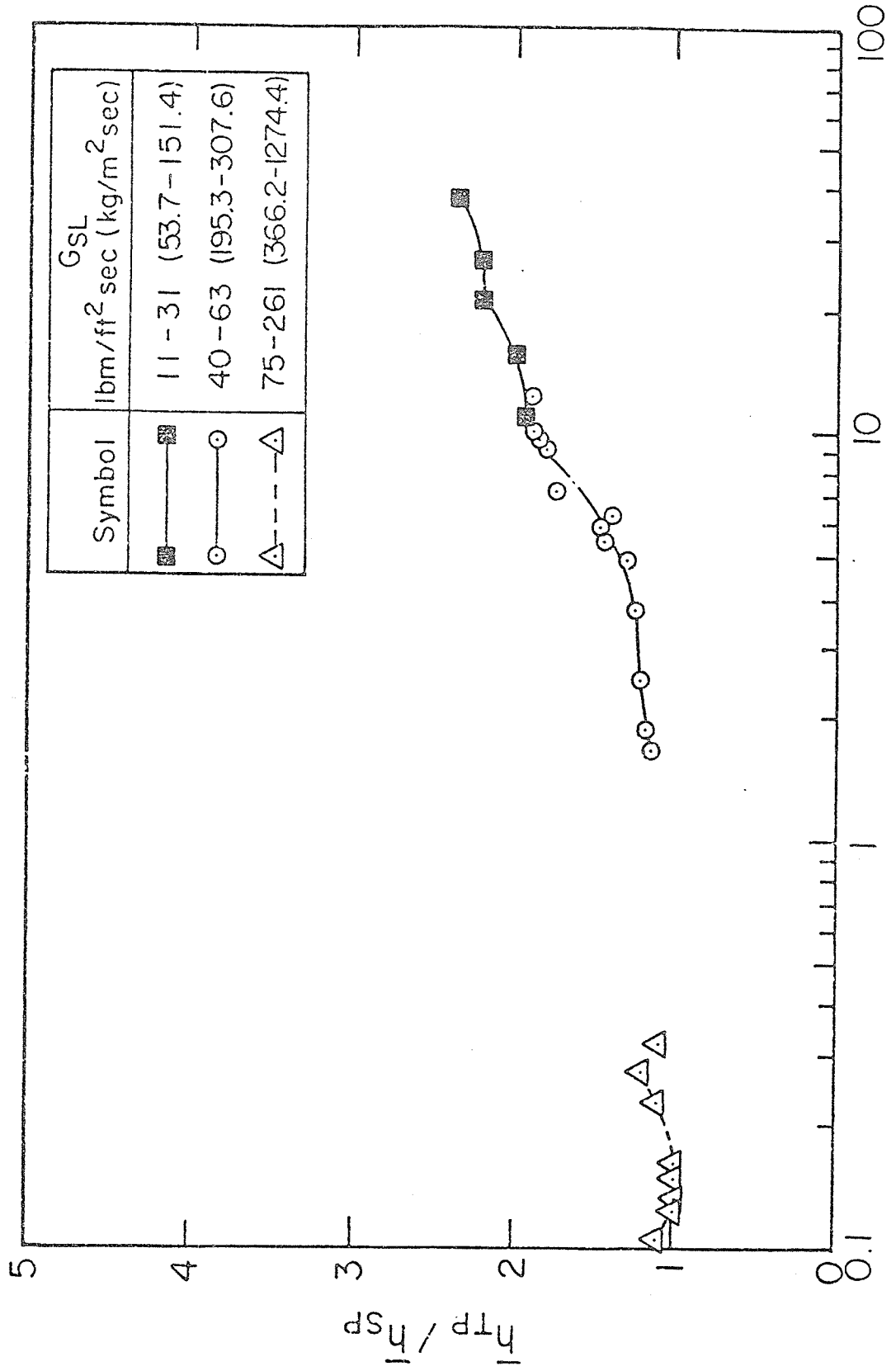


Fig. 2.2 Heat Transfer Results of Knott et al. [From Reference (1)].

$$\frac{\overline{h_{TP}}}{\overline{h_{SP}}} = \left(1 + \frac{V_{SG}}{V_{SL}}\right)^{1/3} \qquad (2.5)$$

$$0.1 < \frac{V_{SG}}{V_{SL}} < 40$$

Generally Eq. (2.5) overpredicted their experimental data; however, it indicated the approximate trends of the results.

2.4 Kudirka (28)

The author investigated the hydrodynamic aspects of two-phase heat transfer in the lower quality range. The boiling process was simulated by bubbling air through the wall of a porous, electrically heated, vertical tube into water and ethylene glycol flowing inside the tube. The conditions of two-phase, two-component heat transfer with an impermeable wall (present case) prevailed by shutting off the air supply through the walls of the porous test section and injecting the air through the section of the tube preceding the heated section. Only these results of no-air injection (zero injection) are considered here.

The values of local heat-transfer coefficients at a location Z = 14.3D from the beginning of the heated section were obtained. The h_{TP} for air-ethylene glycol were found to be much lower than those of air-water as the viscosity of

ehtylene glycol was 17 times higher than that of the water. The reported results are shown in Fig. 2.3 plotted as $\frac{h_{TP}}{h_{SP}}$ against $\frac{V_{SG}}{V_{SL}}$. The local h_{SP} for water were obtained from the Sieder-Tate equation while for ethylene glycol, measured values of h_{SP} were used. The amount of increase in h_{TP} at various V_{SL} was related to the level of turbulence and mixing action already present (in the liquid phase) prior to the addition of gas-phase.

The results were correlated within $\pm$ 20% with the following relationship.

$$Nu_{TP} = \frac{h_{TP}D}{k_L} = 125 \left(\frac{V_{SG}}{V_{SL}}\right)^{0.125} \left(\frac{\mu_G}{\mu_L}\right)^{0.6} Re_{SL}^{0.25} Pr_L^{1/3} \left(\frac{\mu_L}{\mu_w}\right)^{0.14} \qquad (2.6)$$

$$1.0 \leq V_{SL} \leq 9.0 \text{(ft/sec)} \; ; \; 0.1 < \frac{V_{SG}}{V_{SL}} < 80 \quad .$$

Equation (2.6) reflects the small dependence of heat transfer rate on the volumetric flow ratio. This equation also indicates a much lower dependence of h_{TP} on Re_{SL} than for single-phase heat transfer.

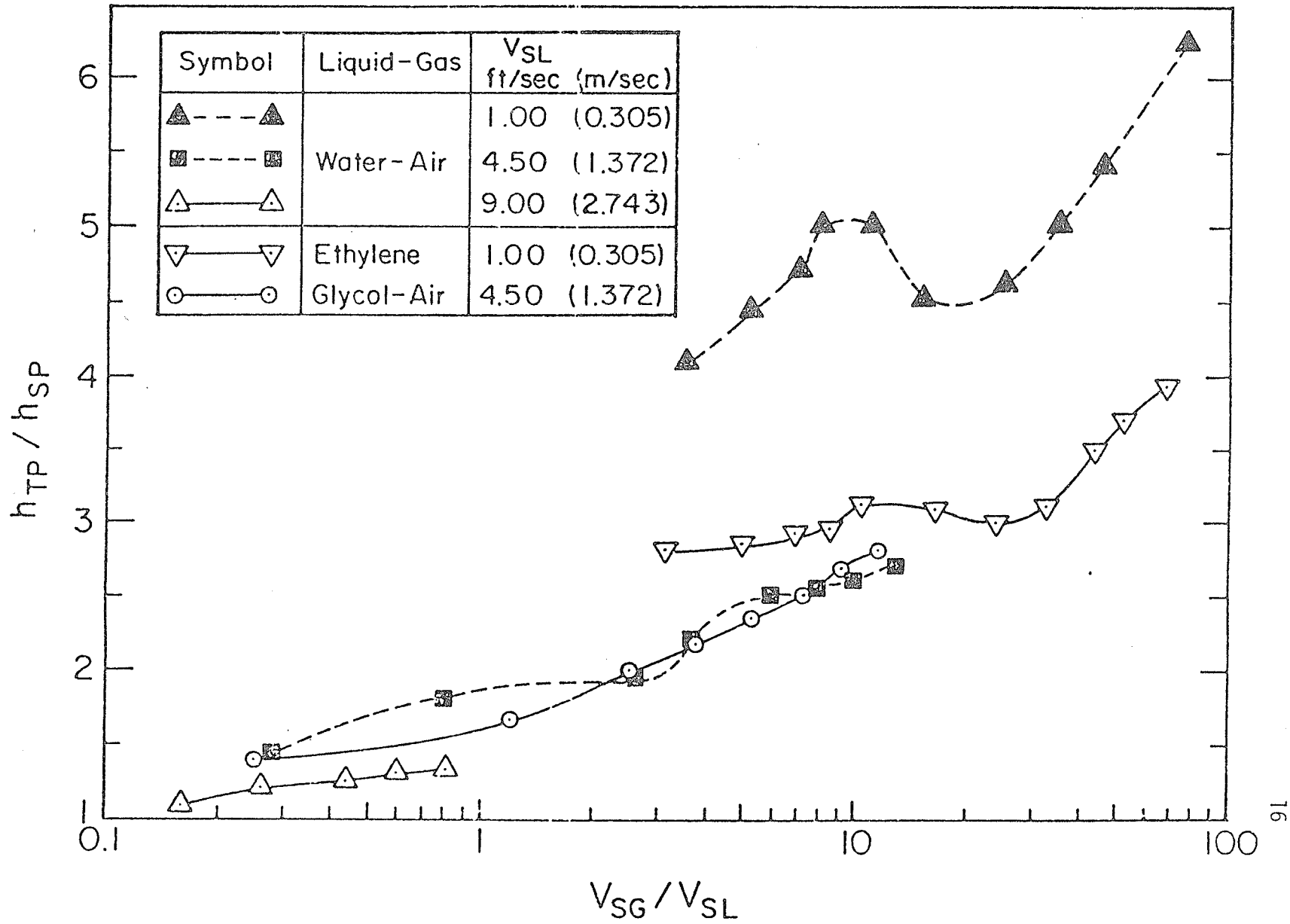


Fig. 2.3 Heat-Transfer Results of Kudirka [From Reference (1)]

2.5 Vijay (48)

The author studied the effect of liquid viscosity and liquid Prandtl number (through viscosity) on the two-phase local and mean heat-transfer coefficients, pressure drops and flow patterns. Experiments were performed in a vertical electrically heated tube using water-air, water glycerine solution-air and glycerine-air mixtures. The author obtained data covering the widest range of variables.

Single-phase heat transfer experiments using the above-mentioned three liquids were carried out and the results were successfully compared with the well-known theories and correlations. The author presented measurements of two-phase local and mean heat-transfer coefficients, frictional pressure drops and flow patterns along with samples of photographs.

In an attempt to compare his local heat transfer data, the author modified Spalding's theory for single-phase heat transfer and correlated 84% of his local h_{TP} data points within $\pm$ 50%. The liquid properties were used for mixture properties to achieve this comparison. The author observed that the shape of the profiles of h_{SP} with distance along the test tube was a function of the initial liquid velocity, flow pattern and the liquid viscosity. In the bubble and slug flow at low liquid flow rates, the h_{SP} was observed

to rise with distance from the commencement of the heated tube. A theory was developed by modifying the classical Graetz problem which qualitatively explained this observed behaviour of $h_{TP} \sim Z$.

The mean heat-transfer coefficients were obtained by integrating the local values along the test tube and are shown in Figs. 2.4, 2.5 and 2.6 for all three liquid-air mixtures. The mean h_{TP} were observed to depend on the intial liquid velocity, flow patterns and the liquid viscosity. The author proposed a simple correlation to predict the $\overline{h_{TP}}$. This was based on a separated flow model and is given below.

$$\overline{h_{TP}} = \overline{h_{AL}} + \overline{h_{AG}} \tag{2.7}$$

where

$\overline{h_{AL}}$ is the single-phase liquid heat-transfer coefficient based on the actual mean velocity and the actual flow cross-sectional area of the liquid,

$\overline{h_{AG}}$ is the single-phase gas heat-transfer coefficient based on the actual mean velocity and the actual flow cross-sectional area of the gas.

The following single-phase heat transfer expressions were used to evaluate $\overline{h_{AL}}$ and $\overline{h_{AG}}$.

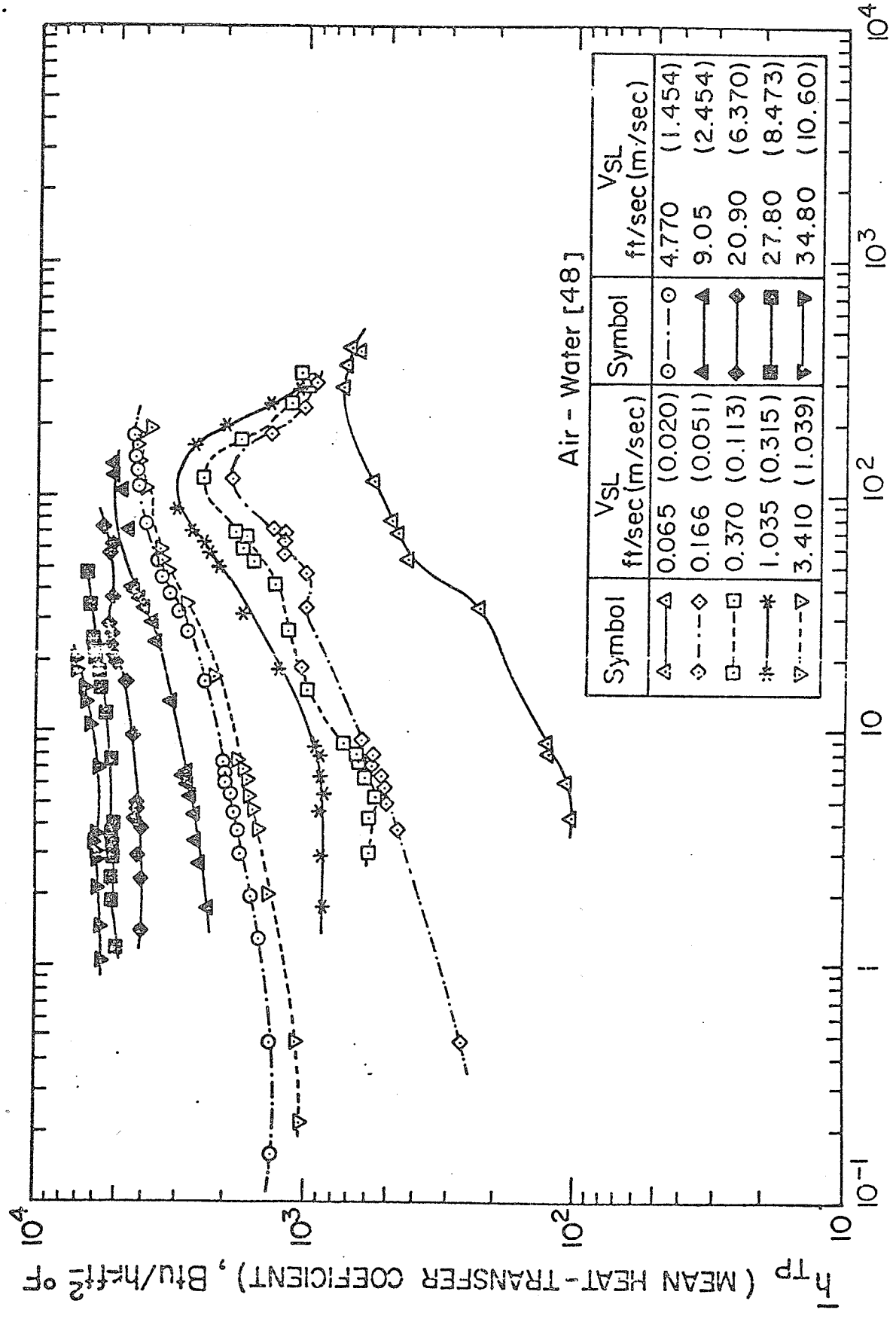


Fig. 2.4 Mean Heat-Transfer Data of Vijay, Water-Air [From Reference (1)]

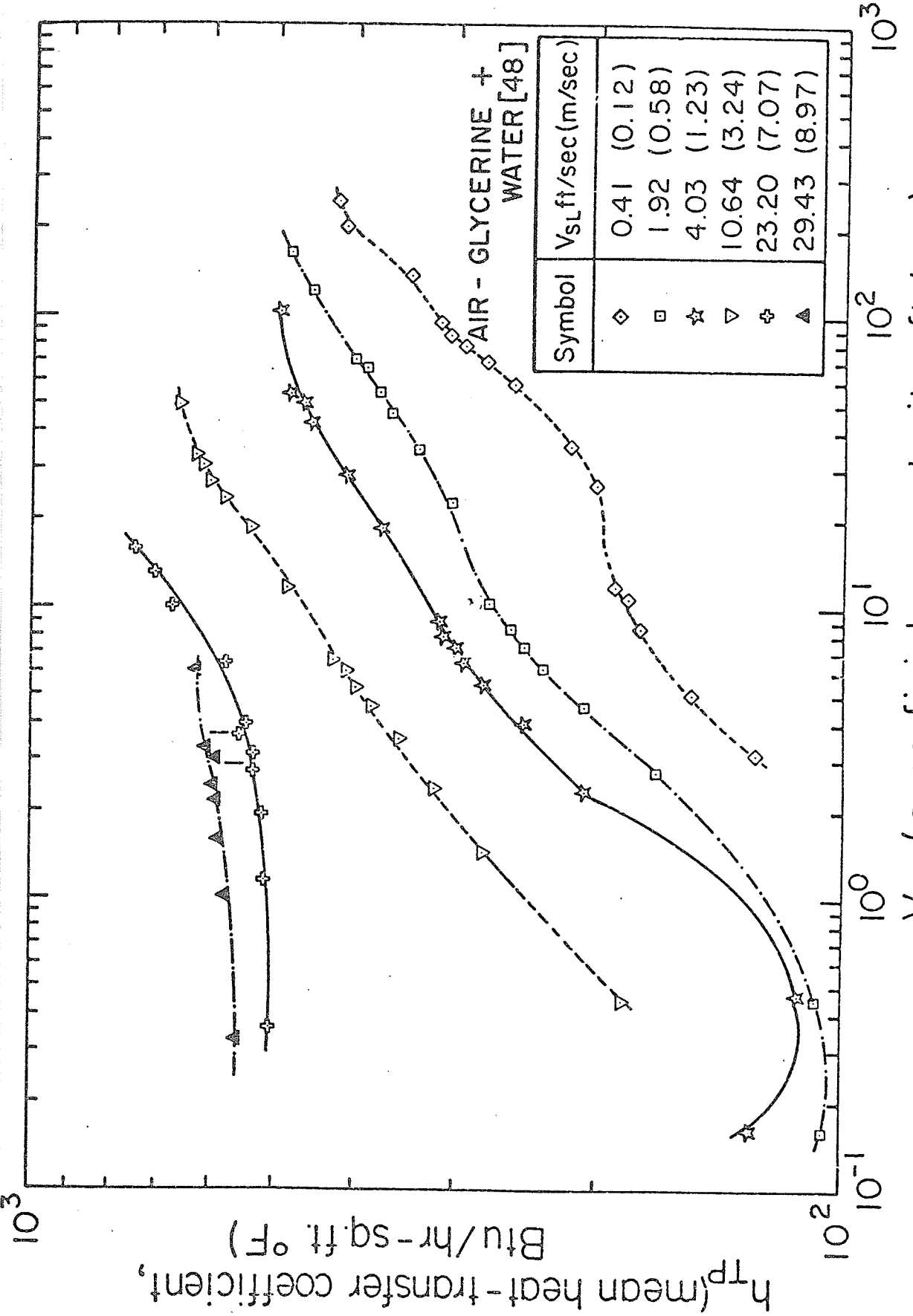


Fig. 2.5 Mean Heat Transfer Data of Vijay, Air-Glycerine + Water [From Reference (1)]

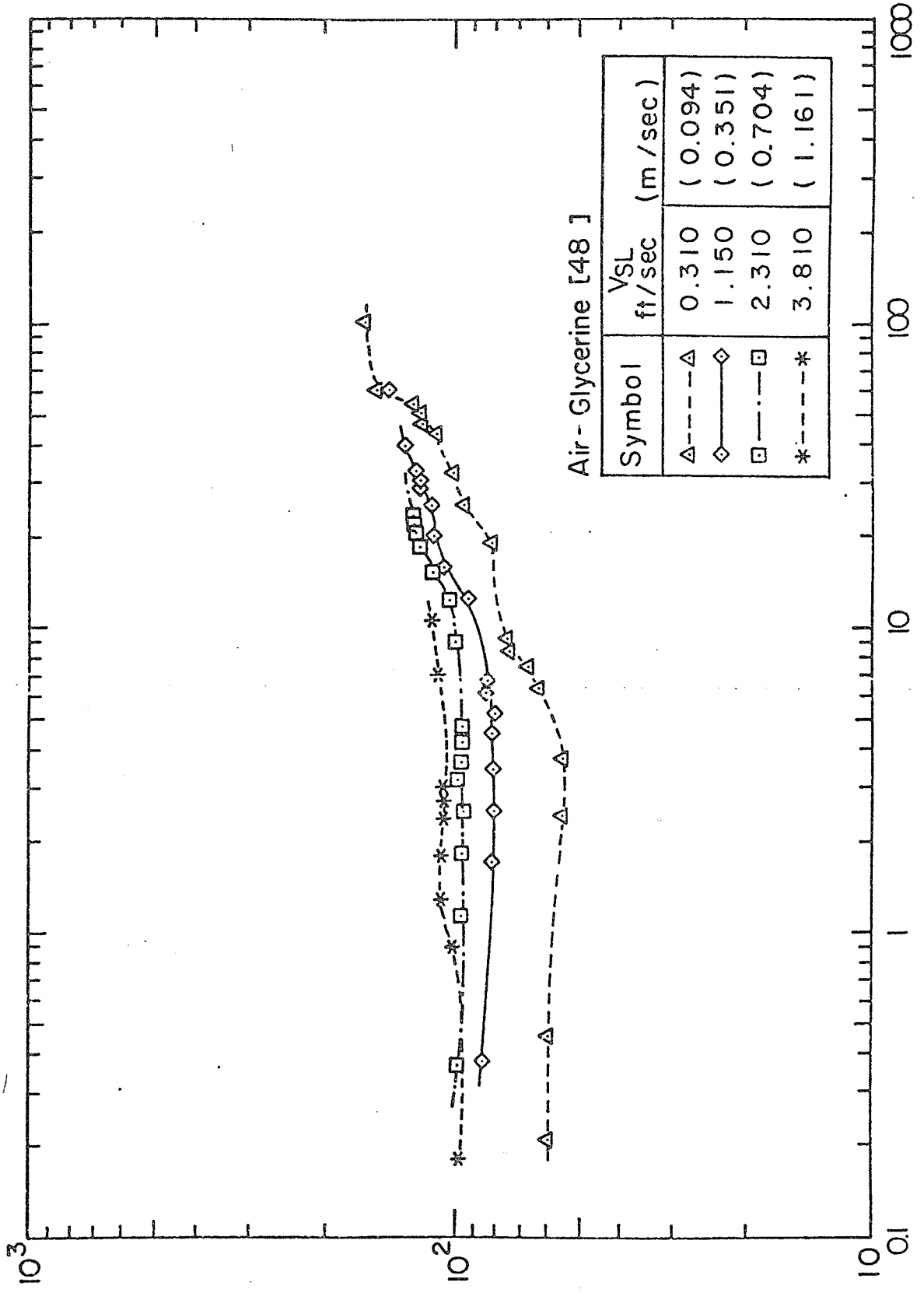


Fig. 2.6 Mean Heat-Transfer Data of Vijay, Air-Glycerine [From Reference (1)]

For laminar flow (both gas and liquid)

$$\overline{Nu}_{SP} = 1.615\ [Re\ Pr\ (D/L)]^{1/3} \qquad (2.8)$$

For turbulent flow of water

$$\overline{Nu}_{SP} = 0.0155\ (Pr_L)^{0.5}\ (Re_L)^{0.83} \qquad (2.9)$$

For turbulent flow of glycerine and its solution

$$\overline{Nu}_{SP} = 0.0118\ (Pr_L)^{0.3}\ (Re_L)^{0.9} \qquad (2.10)$$

For turbulent flow of air

$$\overline{Nu}_{SP} = 0.022\ (Pr_G)^{0.6}\ (Re_G)^{0.8} \quad . \qquad (2.11)$$

It should be noted that in the above-noted equations, Re was calculated on the basis of actual mean V_L and actual flow area of the fluid. The author compared his data with Eq.(2.7) and found that 86% were correlated within $\pm$ 50%.

The liquid viscosity affected the friction-pressure-drop results in such a way that for a given V_{SL}, the higher the viscosity, the higher the pressure drop. Also the effect of liquid viscosity was more pronounced at lower liquid flow rates than higher liquid flow rates.

The physical configuration of the same flow pattern was observed to be influenced by the liquid viscosity.

The author observed an inverse relationship between the heat-transfer coefficient and the liquid-phase viscosity. The main reason for the behavior was the lower Reynold number for higher viscosity.

2.6 Aggour (1)

The author studied the effect of gas-phase density (by changing the gas-phase) on the two-phase local and mean heat-transfer coefficients, pressure drops and flow patterns. For this purpose, he performed experiments in a vertical electrically heated tube by using three different gas-water mixtures; the gases used were air, helium and Freon-12 which allowed gas density changes by a factor of approximately 52.

Results of measurements of the heat-transfer coefficients, frictional pressure drop and flow patterns were presented along with the photographs of flow patterns.

The author correlated his local heat transfer data with the modified theory of Spalding in the manner proposed in Reference (48). In an attempt to generalize the modified theory, the author defined its range of applicability and tested it against a wide range of data (2142 data points); 93% of these points agreed within $\pm$ 50%.

The author also conducted a flow-visualization study in order to confirm the existence of downflow of liquid film at the wall in bubble flow where local heat-transfer coefficients were observed to increase with increasing distance along the test section. High-speed cine movie films of water-air mixtures at low flow rates of both phases were obtained by employing the hydrogen-bubble and dye-injection techniques. The author observed downflow of liquid near the tube wall in bubble and slug flow (this phenomenon was already well known in slug flow), so confirming one of the possible mechanisms proposed to explain the shape of local $h_{TP} \sim Z$ results.

The integrated mean heat-transfer coefficients were obtained from the measured local values of h_{TP} along the test section; these results are shown in Figs. 2.7, 2.8 and 2.9 for all three gas-water mixtures. The author also developed a simple correlation to predict $\overline{h_{TP}}$, which is based on a single-phase liquid flow model having a Re based on the actual mean velocity of the liquid in the two-phase flow. The proposed correlation is as follows:

$$\overline{h_{TP}} = \overline{h_{SP}} \, (1 - \alpha)^n \qquad (2.12)$$

where

$n = -1/3$ for laminar flow

$n = -0.83$ for turbulent flow.

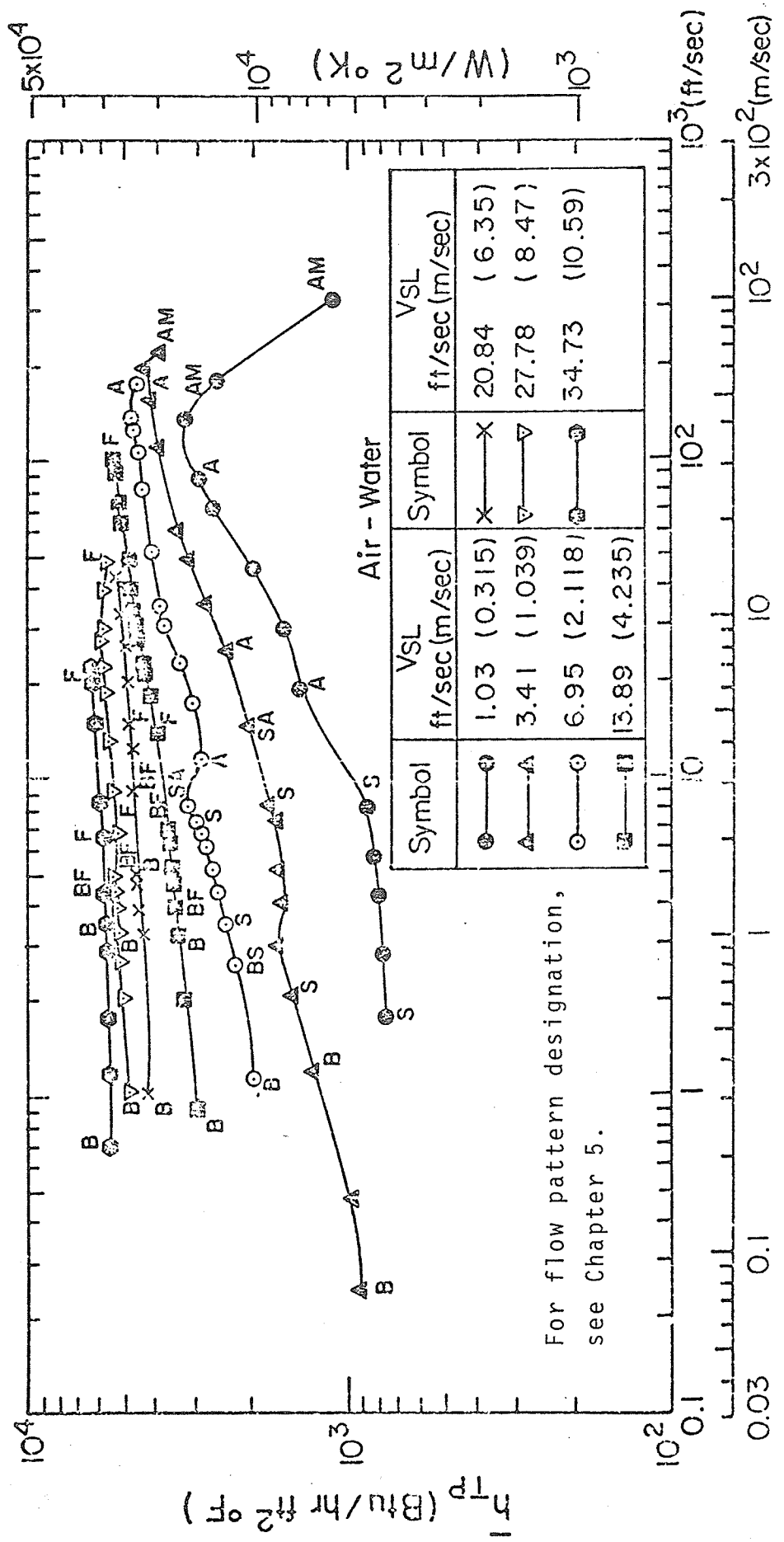


Fig.2.7 Two-Phase Air-Water Mean Heat-Transfer Data of Aggour [From Reference (1)]

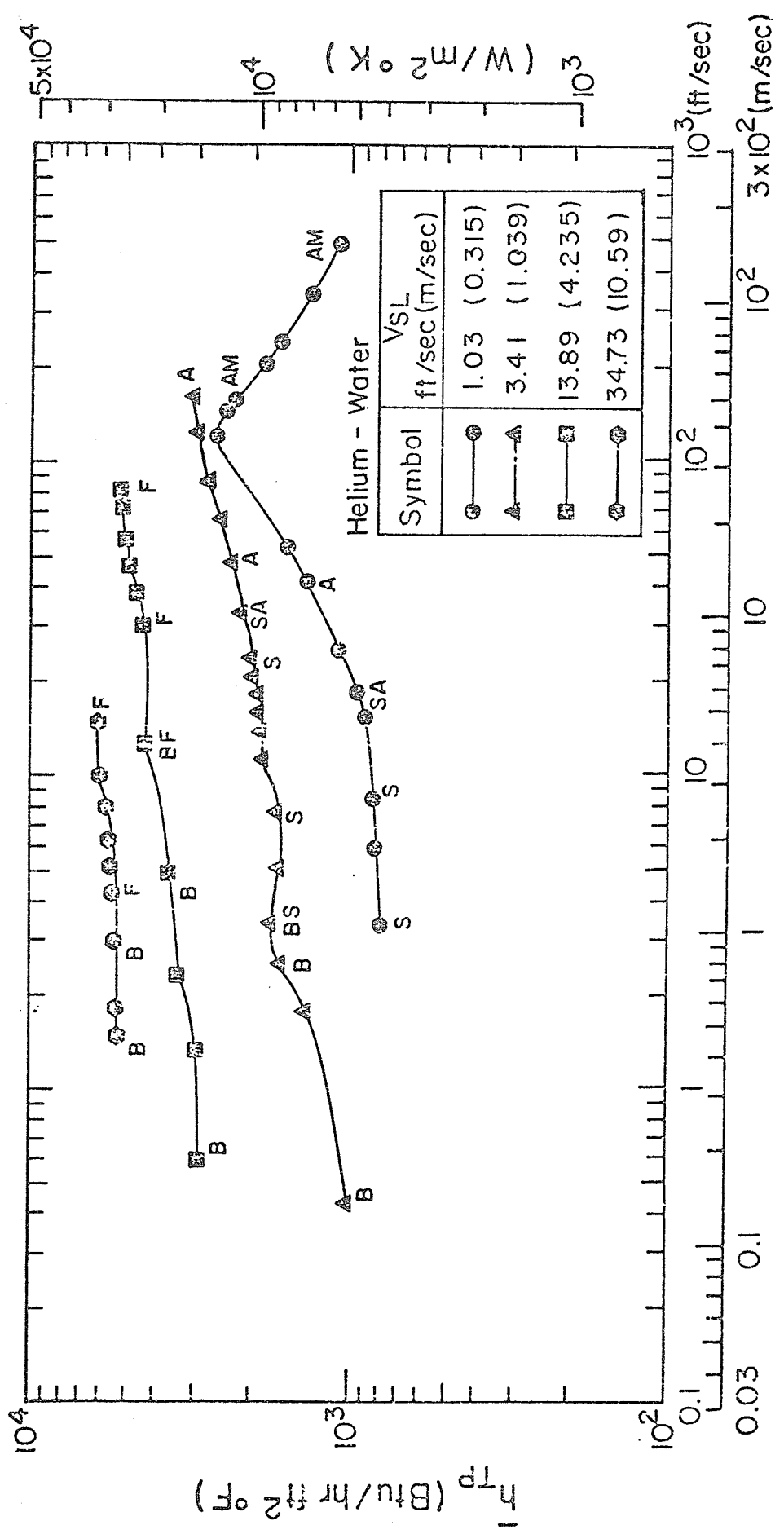


Fig. 2.8 Two-Phase Helium-Water Heat-Transfer Data of Aggour [From Reference (1)]

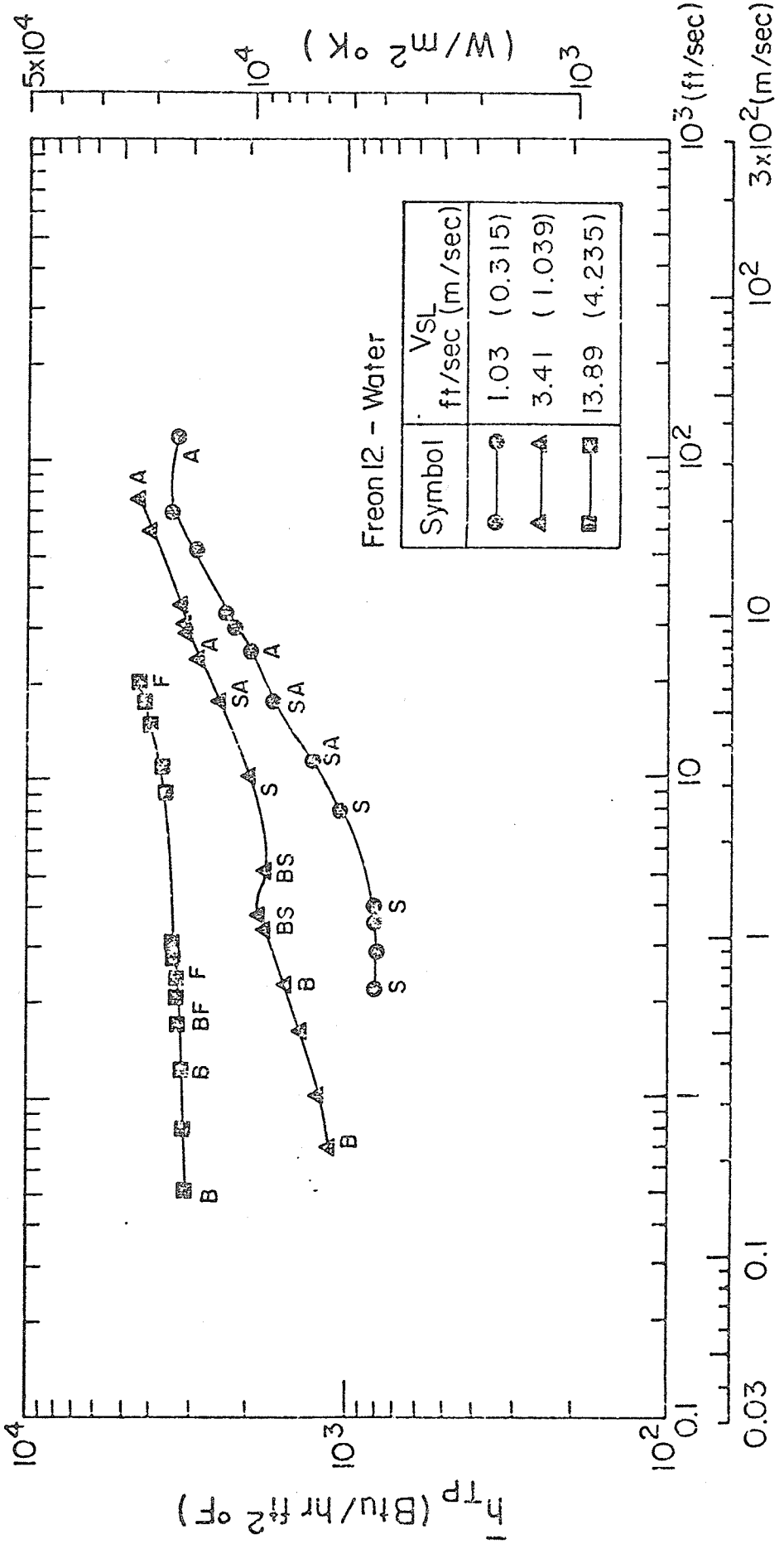


Fig. 2.9 Two-Phase Freon-Water Mean Heat-Transfer Data of Aggour [Reference (1)]

h_{SP} is the single-phase liquid mean heat-transfer coefficient based on the superficial liquid Re . The $\overline{h_{SP}}$ was calculated from the following correlations of single-phase heat transfer.

For laminar flow:

($Re_{SL} < 1000$)

($Re_L < 200$)

$$\overline{Nu}_{TP} = 1.615 \, (Re_{SL} \, Pr_L \, \frac{D}{L})^{1/3} \, (\frac{\mu_L}{\mu_w})^{0.14} \qquad (2.13)$$

For turbulent flow

($Re_{SL} > 2{,}000$)

$$\overline{Nu}_{TP} = 0.0155 \, Re_{SL}^{0.83} \, Pr_L^{0.5} \, (\frac{\mu_L}{\mu_w})^{0.33} \qquad (2.14)$$

α is the void fraction calculated from Chisholm's correlation (10).

The author compared his data with Eq. 2.12 and found that 97% were correlated within $\pm$ 50%.

The following conclusions were made on the effect of gas-phase density:

(i) In order to make a definitive statement on the effect of gas-phase density on the flow patterns, more flow pattern data are required.

(ii) gas-phase density produced no effect on heat-transfer coefficients and frictional pressure drops at low V_{SL} and low V_{SG}, and high V_{SL} and all values of V_{SG}. However, the author observed significant effects at low water flow rates and moderate-to-high V_{SG}; the trend of the results being that, for the same V_{SL} and V_{SG}, the higher the gas density, the higher the $\overline{h_{TP}}$ and frictional pressure drop and vice versa.

2.7 Ravipudi (33)

The author studied the effect of mass transfer on heat transfer rates and heat-transfer coefficients for different air-liquid mixtures in a vertical tube of 0.75 inches I.D. and heated by steam. The experiments performed at low vapour pressures of the liquid (below 310 mm Hg) were considered to have no mass transfer effects and only results of these experiments will be considered here.

The author performed single-phase heat transfer experiments with water and compared these results with the Sieder-Tate equation within + 8%. The two-phase heat transfer experiments with no mass transfer effects were carried out with water-air and toluene-air mixtures. The author measured local h_{TP} at five locations along the test section, and reported overall mean h_{TP}.

Figure 2.10 shows the mean h_{TP} data plotted against $\frac{V_{SG}}{V_{SL}}$. For each V_{SL}, the $\overline{h_{TP}}$ was observed to pass through a maximum, which was observed to occur at the transition of annular to mist flow. The $\overline{h_{TP}}$ was observed to increase as much as 5.8 times $\overline{h_{SP}}$. This enhancement in $\overline{h_{TP}}$ was attributed to the reduction of effective thickness of the laminar sub-layer with an increase in gas flow rate. The rate of heat transfer in two-phase flow increased by 200% over that of liquid flowing alone.

By employing dimensional analysis, the author proposed a correlation similar to the one proposed by Kudirka (28) and is given below

$$Nu_{TP} = 0.56 \left(\frac{V_{SG}}{V_{SL}}\right)^{0.3} \left(\frac{\mu_G}{\mu_L}\right)^{0.2} Re_{SL}^{0.6} Pr_L^{0.33} \left(\frac{\mu_L}{\mu_w}\right)^{0.14} \qquad (2.16)$$

$$8{,}554 < Re_{SL} < 89{,}626; \quad 1 < \frac{V_{SG}}{V_{SL}} < 90 \ .$$

The author correlated his $\overline{h_{TP}}$ data with Eq. 2.16 and found that data upto the maximum in $\overline{h_{TP}}$ were correlated within $\pm$ 8%.

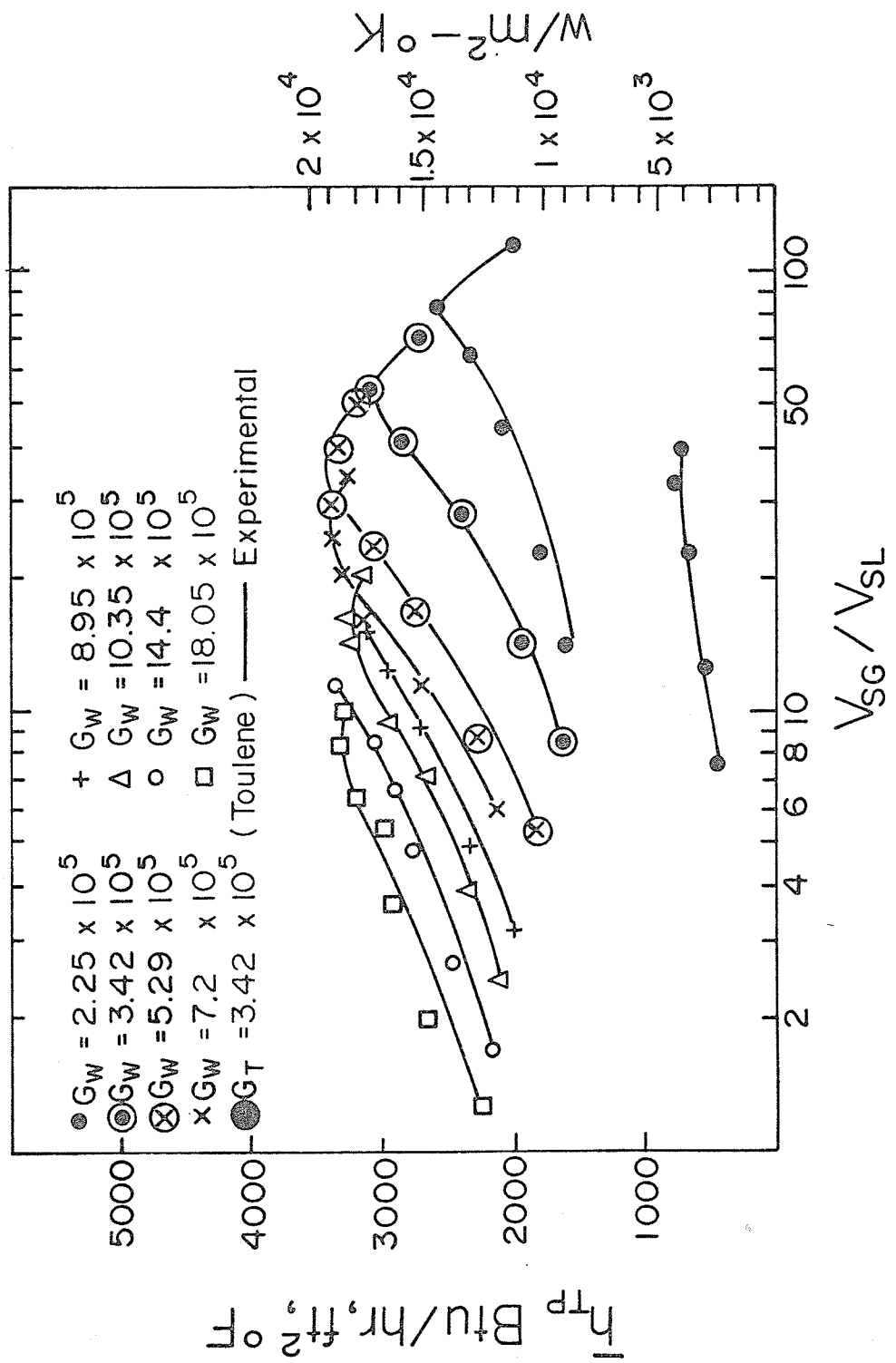


Fig. 2.10 Mean Heat-Transfer Results of Ravipudi

CHAPTER 3

EXPERIMENTAL APPARATUS

3.1 Introductory Remarks

This chapter describes the experimental apparatus used in the present work. As mentioned earlier, the present investigation was a continuation of previous work (48, 1) to determine the effect of fluid properties on the heat transfer and hydrodynamics in two-phase, two-component flow. Therefore, the same experimental facility, with some slight modifications, used in the previous work (1) was used in the present work. These slight modifications were the replacement of some control valves with better ones, the addition of some drain points in the liquid flow loop and the replacement of the DVM with a new one (Keithly 191).

The material presented in this chapter is essentially the same as that in References (48) and (1) and is presented here for the sake of completeness. The circled numbers appearing in the figures correspond to the components used in the system which are described in detail in Appendix A.

3.2 Liquid-Air Flow System

3.2.1 General Description

The flow schematic of the liquid-air loop is shown in Fig. 3.1. To indicate the main features of liquid and air flow loops, more details are given later in this section.

Test liquids from the storage tank, after passing through the heat exchanger, were pumped by a positive displacement gear pump to the gas-liquid mixer through a selected rotameter. The flow was by-passed to the storage tank at the pump discharge and a large pressure drop was maintained across the control valve which allowed stable operation in two-phase flow. The air was obtained from the central compressor in the Mechanical Engineering Laboratory. The pressure of the air was controlled and set by a combination of pressure regulators and a by-pass valve on the supply line. The air flow rate was measured by a set of orifice meters or a rotameter. The air was injected through the porous tube in the mixer. The back flow of liquid in the air supply line was prevented by a check valve installed on the air feed line. The liquid-gas mixture then passed through the heated test section and transparent visualization section. The mixture then passed through the separator where air escaped to the atmosphere and the liquid returned to the storage tank.

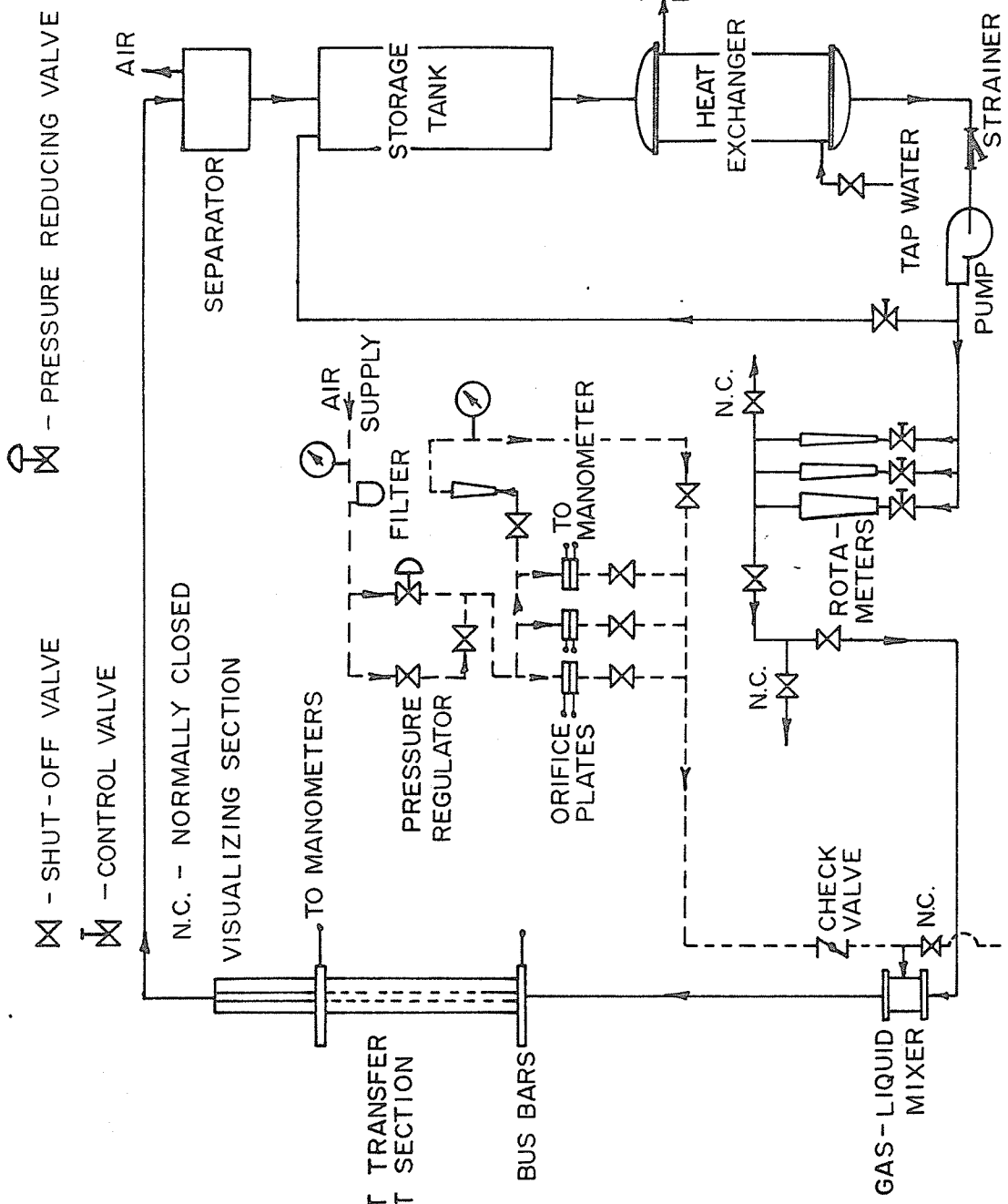


Fig. 3.1 SCHEMATIC DIAGRAM OF LIQUID-AIR FLOW SYSTEM

The details of the liquid flow loop and the air flow circuit are given in the following sections.

3.2.2 Liquid Flow Loop

Distilled water and (tap) water-surfactant solutions were the liquids used in the present work. The test liquids were stored in a 40 gallon (U.S.) storage tank. The details of the liquid loop are given in Fig. 3.2. It consisted of the following:

(i) A stainless steel liquid storage tank of 40 gallon (U.S.) capacity,

(ii) a heat exchanger connected in series to control the temperature of the liquid entering the test section,

(iii) a positive displacement gear pump. A by-pass line at the discharge of the pump to allow setting the desired flow rates through the rotameters,

(iv) three rotameters of varying ranges with control valves, in parallel, for measuring the liquid flow rates,

(v) the test section consisting of the mixer a calming length, the heated test section and the visualization section,

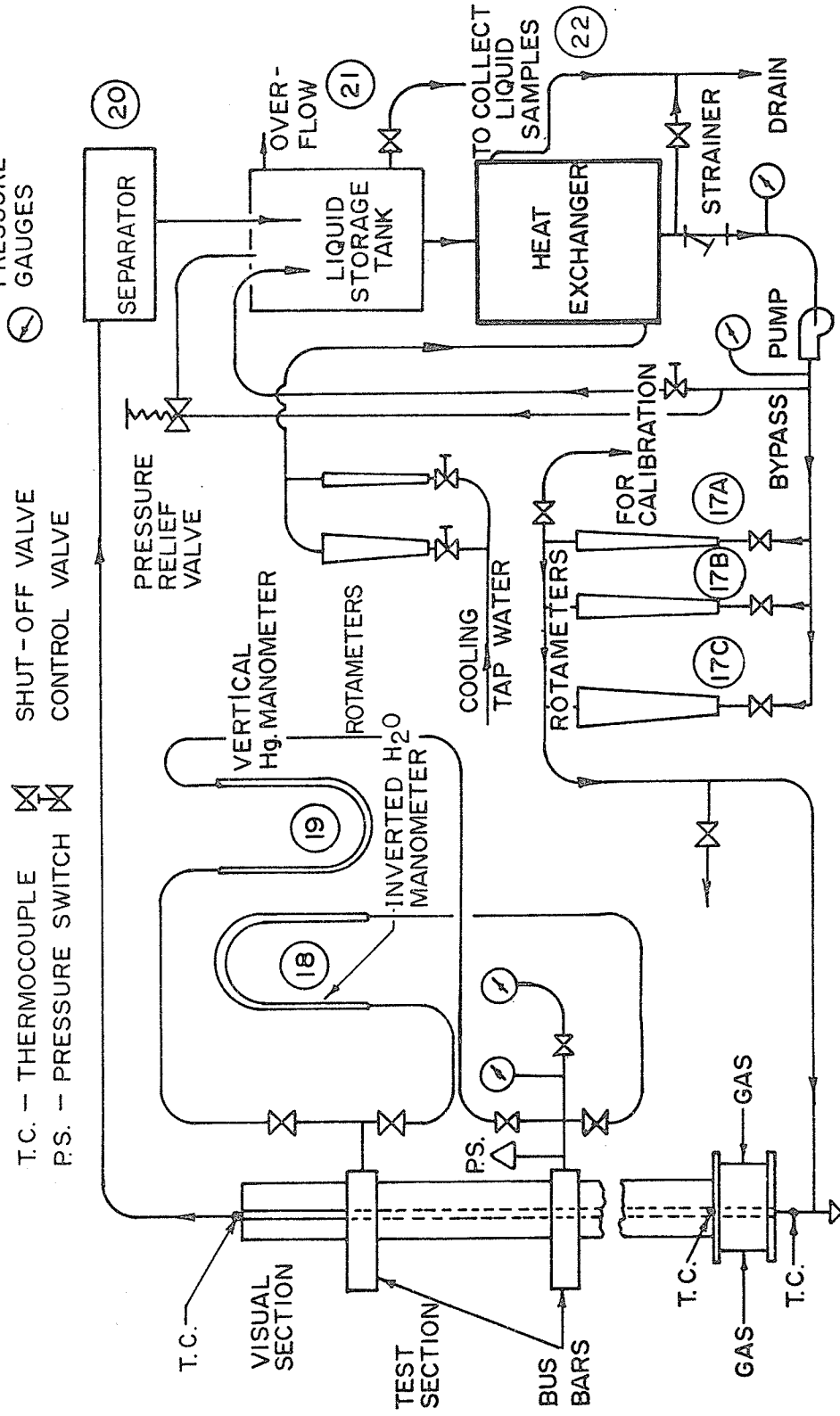


Fig. 3.2 DETAILED SCHEMATIC OF LIQUID FLOW LOOP

(vi) the liquid-gas separator, which drained the liquid into the storage tank and vented air to the atmosphere,

(vii) a heat exchanger cooling water system consisting of two parallel rotameters and control valves to set the cooling tap-water flow rates,

(viii) an upright mercury manometer and an inverted liquid manometer to measure the total pressure drop across the test section,

(xi) other elements including control valves, pressure gauges, a pressure relief valve, a strainer and provision for calibration as shown in Fig. 3.2.

The material used in constructing the liquid circuit and those of control valves and strainer were stainless steel, brass and copper. Rubber hoses were also used wherever required for flexible joints.

3.2.3 Air Flow Circuit

The details of the air flow loop are shown in Fig. 3.3. It consisted of the following:

(i) A main gas supply line having a shut-off valve, a gas filter, a coarse pressure-regulator, a by-pass line with a shut-off valve and a fine pressure regulator,

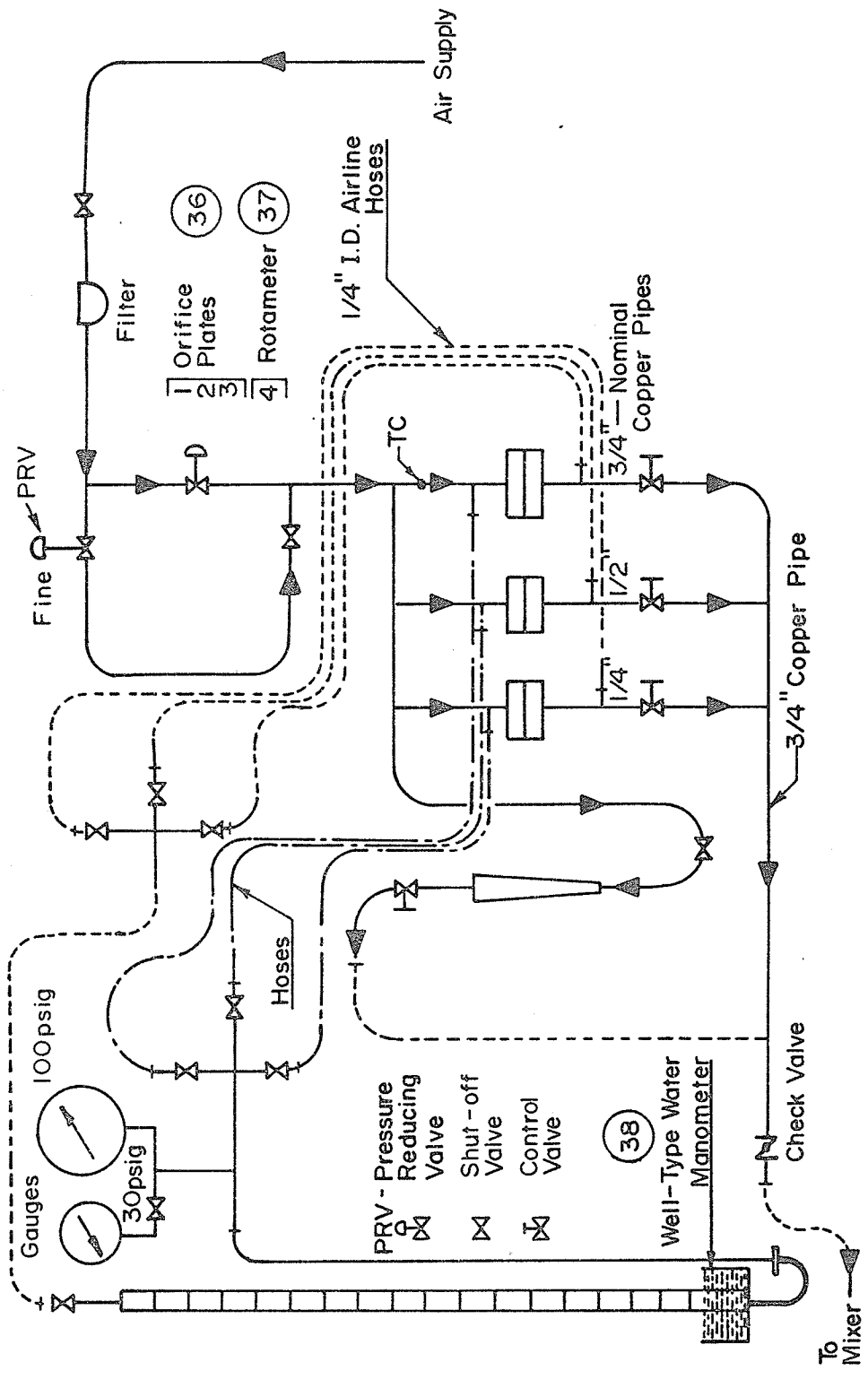


Fig.3.3 DETAILED SCHEMATIC OF THE AIR FLOW LOOP

(ii) a set of three orifice meters and a rotameter, all connected in parallel through four needle valves, for measuring air flow rates,

(iii) a well-type water manometer to measure the pressure drop across the orifice plates,

(iv) the air-line leading to the mixer, equipped with a check-valve to prevent any back flow of water into the air lines.

Flexible pressure hoses were used in the air-supply system. Standard pressure gauges were installed at appropriate locations as shown in Fig. 3.2.

3.2.4 Fluid-Temperature Measurements

Six copper-constantan AWG#30,0.010 in. (0.254 mm) diameter (T/G-30-DT) thermocouples were used to measure the temperature of the fluid at the following locations:

(i) One for measuring the temperature of the air at the inlet to the orifice meters,

(ii) one for the liquid temperature at the inlet to the mixer,

(iii) two for the mixture at the exit of the mixer,

(iv) two at the outlet of the transparent section.

3.3 Test Section

The principal components of the test section were the gas-liquid mixer, downstream of which was a 5 ft long calming section (L = 130D), the heated tube and the transparent visualization section. All the sections were flange-connected and sealed with rubber O-rings. The test section is shown in Fig. 3.4

3.3.1 Gas-Liquid Mixer

The details of the gas-liquid mixing section are shown in Fig. 3.5. It consisted mainly of a grade E porosint bronze tube (supplied by Sintered Products Limited, Sutton-in-Ashfield, Notts, England) of the same inside diameter as the test tube, contained in a brass cylinder and equipped with a stainless steel strainer.

The chamber was designed such that the gas or liquid could be forced through the porous tube; however, in the present investigation the liquid flowed axially upwards while the gas was forced to flow through the porous tube.

3.3.2 Heated Test Section

The heated test section was made of type 304 stainless steel tube, 0.460 in. (1.168 cm) I.D., 0.500 in. (1.270 cm) O.D. and 2 ft (60.96 cm) long. As shown in Fig. 3.4, two

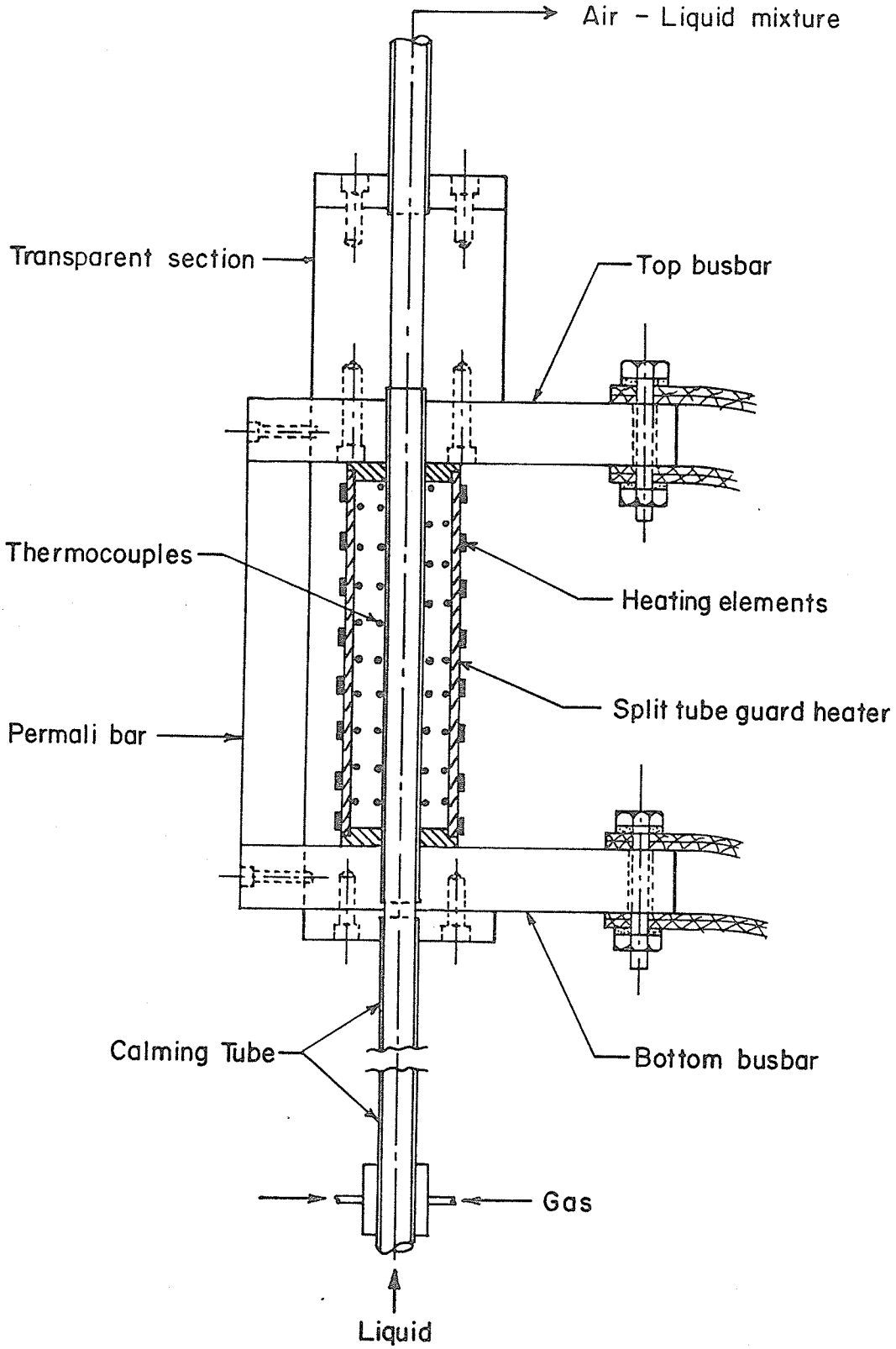


Fig. 3.4 Test Section

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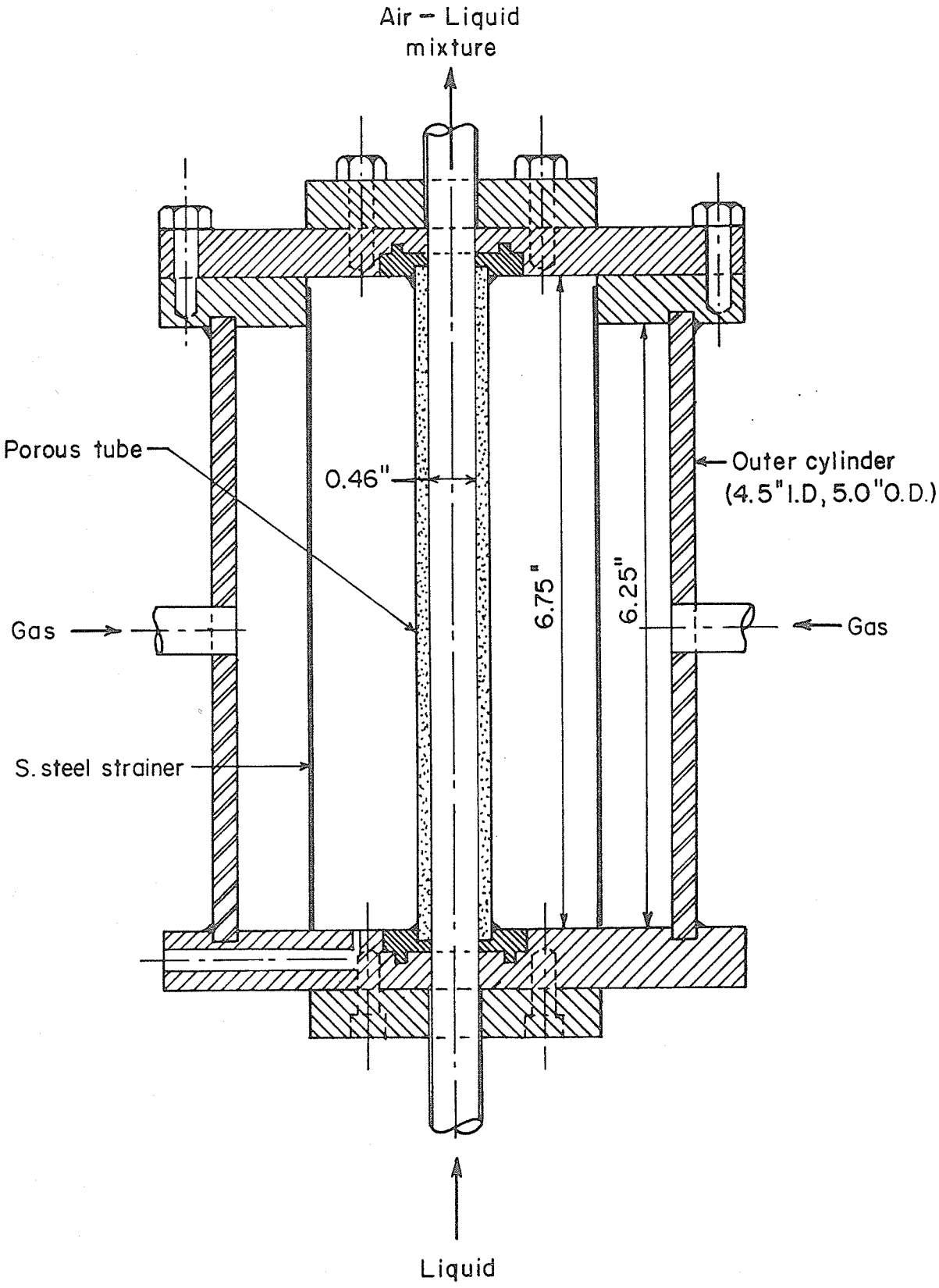


Fig. 3.5 The Mixer

bus bars were silver soldered to the tube. A 1 in. x 1 in. x 2 ft. (2.54 x 2.54 x 61 cm) long Permali electrical insulator bar was firmly attached vertically between the bus bars to avoid buckling of the heated tube due to the weight of the bus bars and the power cables. Alternating-current Joulean heating, using the test tube as an electrical resistor, was employed because this method offered a simple and accurate means of measuring and controlling the local heat flux.

As shown in Fig. 3.4, a guard heater made of a split copper tube (lower and upper guard heaters) was installed around the heated tube. The main purpose of the guard heater was to maintain a zero temperature-gradient at the outer surface of the heated wall and to prevent thermal losses from the heated test section to the surroundings. More details can be found in Reference (48).

3.3.3 Wall-Temperature Measurements

In the experiments, outer-wall temperatures of the test section were measured by means of thermocouples. The inner wall temperatures were calculated from these measurements by employing a well-established method (4, 29). In this method, the temperature drop across the tube wall was calculated from the knowledge of the tube wall thickness,

its properties and the electric current. This method is explained in detail in Appendix C.

The location of thermocouples on the outer wall of the heated test tube and the inner wall of the guard heater is shown in Fig. 3.6. Forty-three thermocouples (Nos. 5-47) were used to measure the wall temperature at 16 elevations along the test section; however, temperature readings only at Plane Nos. 2, 4, 6, 8, 11, 14 and 15 were used to calculate the local heat-transfer coefficients (see section C.1 (b), Appendix C). Eighteen thermocouples (Nos. 48-65) were used to measure the guard heater wall temperature at nine elevations. Thermocouple numbers 1 to 4 measured the temperature of the bus bars.

Copper-constantan AWG#36, 0.005 in. (0.127 mm) diameter (T/G-36-DT) thermocouples were installed on the test tube wall and AWG#30, 0.010 in. (0.254 mm) diameter (T/G-30--DT) thermocouples were installed on the inner wall of the guard heater. The thermocouple wires, supplied by Thermoelectric Canada Ltd., were calibrated in the laboratory at the time of installation over the temperature range involved in the present investigation (48). Scotch electrical tape No. 27 was used to insulate the thermocouples from the tube and also to attach them to the tube wall. A layer of tape was wrapped around the tube at the desired location, the thermo-couple head was placed in position and two or three turns

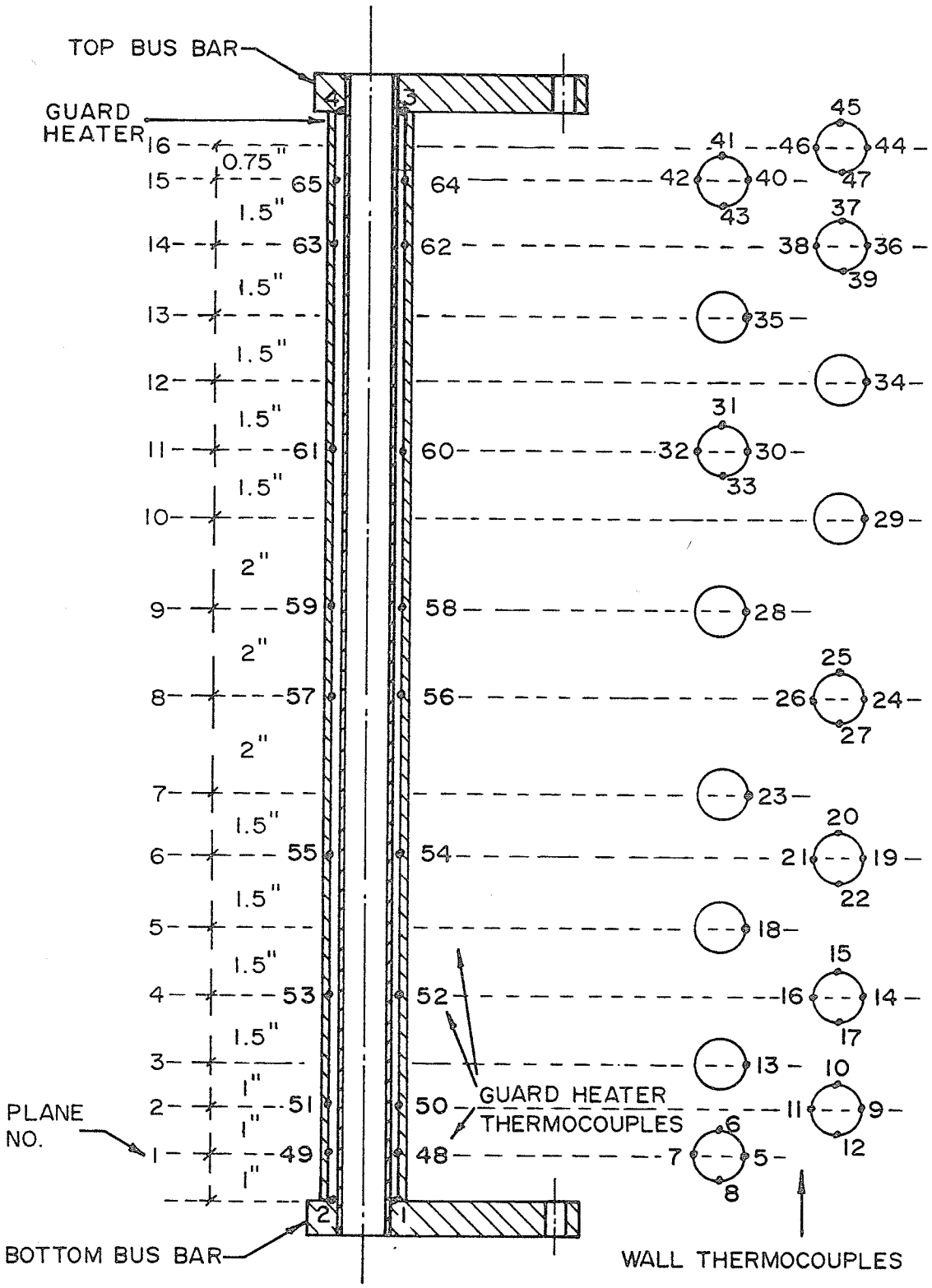


Fig. 3.6 LOCATION OF THERMOCOUPLES

of the wire were wrapped around the tube in order to minimize any possible conduction errors.

3.3.4 Observation Section

The observation section was made of a transparent cast acrylic rectangular block, 3 in. x 3 in. x 1 ft. (7.62 x 7.62 x 30.48 cm) long. A precision, highly polished hole of 0.46 in. (1.168 cm) I.D. was drilled through the block. As shown in Fig. 3.4 the block was placed right on top of the heated section. The visual and photographic observations were made through this transparent section. It was assumed that the character of the flow pattern in this section was the same as that existing in the heated test section.

3.4 Temperature Measuring System

The previous sections described the location of all the thermocouples to measure the wall temperature the heated test tube, the guard heater and the fluid temperatures. This section describes the system employed to measure the emf of the thermocouples. The original temperature-measuring system (48) as modified by Aggour (1) was used in the present work and is shown in Fig. 3.7.

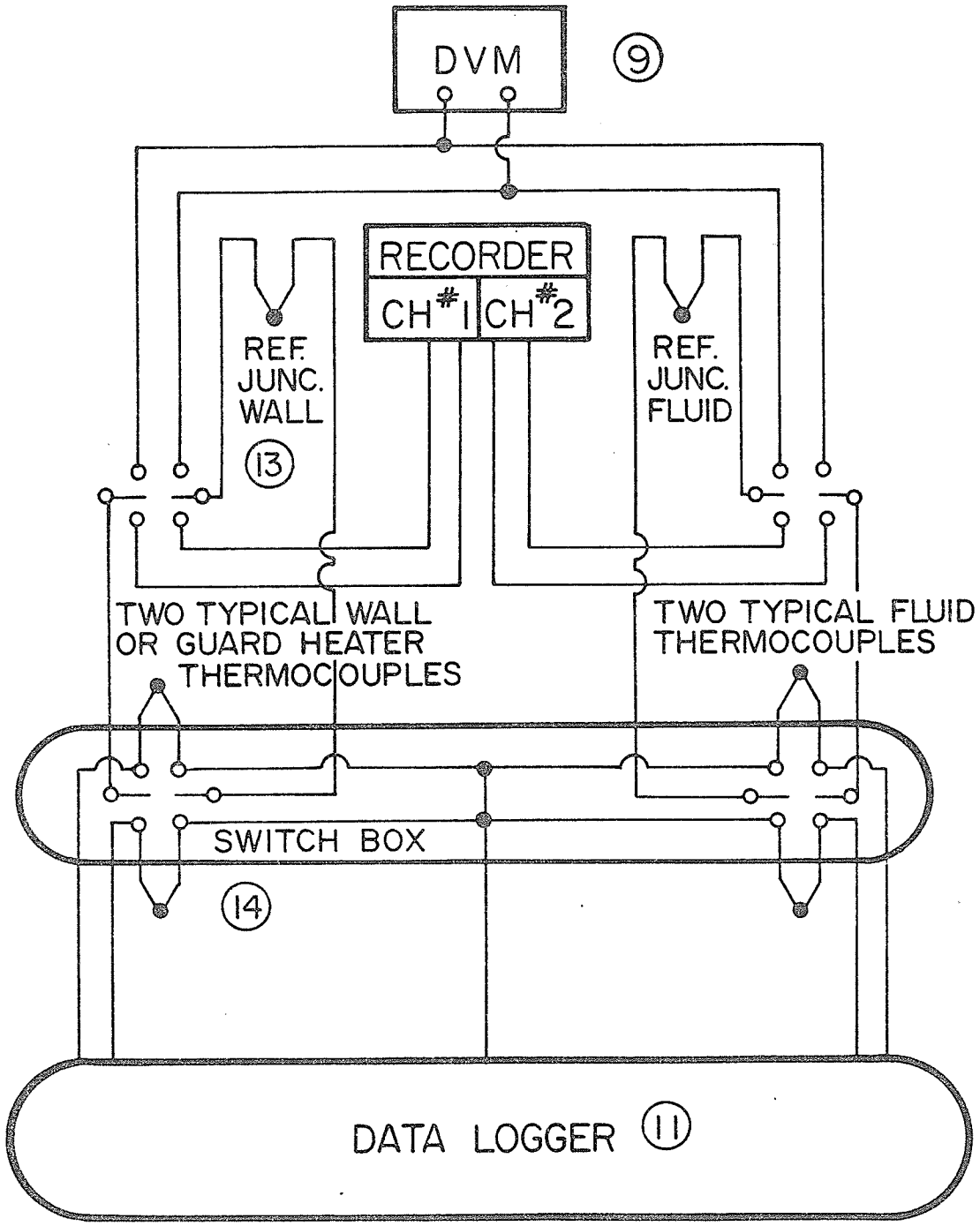


Fig. 3.7 Thermocouple emf Measuring Circuit

The emf of thermocouples was measured by any one or combination of the following temperature recording devices by selecting the appropriate switches:

(i) The Fluke 2240A data logger,

(ii) the Keithley 191 DVM,

(iii) the Honeywell two-pen strip chart recorder.

The Fluke data logger had 60 analog inputs and a scanning speed up to 15 channels per second. The first channel was connected to a 1 mv standard potential source while the remaining 59 channels were used to record the emf of all the wall thermocouples, fluid thermocouples and six of the guard heater thermocouples.

The correspondence between the data logger inputs and inputs of the multiple-point selector switch are given in Table 3.1.

A high-precision Fluke 335A DC voltage standard was used frequently to check accuracy and to calibrate the DVM, the recorder and the data logger.

Table 3.1 Correspondence between the Data Logger Inputs and the Multiple-point Selector Switch

TC No.	To measure the temperature of	Fluke Data Logger Channel No.	DVM/Recorder Selector Switch No.
1-4	lower & upper bus bars	1-4	1-4
5-47	the outer wall of the heated test tube*	5-47	5-47
52	the inner wall of the guard heater*	48	52
53	"	49	53
56	"	50	56
57	"	51	57
62	"	52	62
63	"	53	63
66	the water at the inlet to the mixer	54	73
67-68	the mixture at the outlet of the mixer	55-56	74-75
69-70	the mixture at the outlet to the test section	57-58	76-77
71	the gas at the inlet to the orifice plate assembly	59	79

*Location of thermocouples given in Fig. 3.6

3.5 Power Supply Circuit

A power supply system was designed and constructed by Vijay (48), and, as mentioned earlier, the same was employed in the present work. The function of this system was to supply, control and measure the electric power to the stainless steel test section. The power supply circuit is shown in Fig. 3.8 and consisted of the following items.

(i) A 240 volts, 100 amp, AC mains power source,

(ii) a power variac for control of electrical power to the test section,

(iii) a 24 KVA transformer,

(iv) power measuring circuit, which consisted of a calibrated current transformer, a potential transformer, voltmeter, ammeter and a wattmeter. The ammeter readings were used to calculate the heat flux while the voltmeter and the wattmeter readings were used only as a check,

(v) the stainless steel test tube which served as an electric resistor,

(vi) a pressure flow switch to shut off the power in case of flow failure,

(vii) a temperature controller (sensing the temperature of the middle-point on the test section) to shut off the power in case of accidental over-heating of the test section.

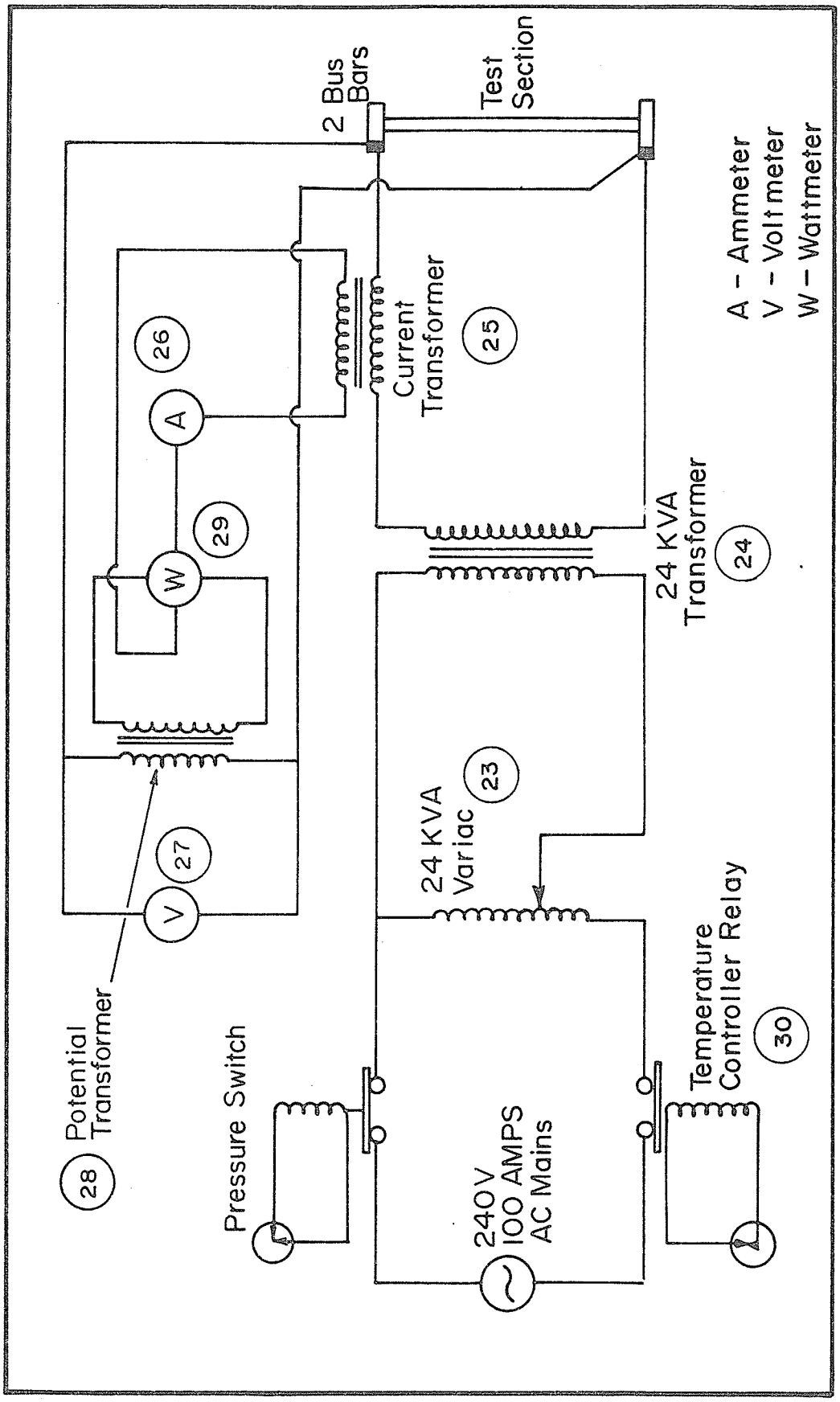


Fig. 3.8 Power Supply Circuit

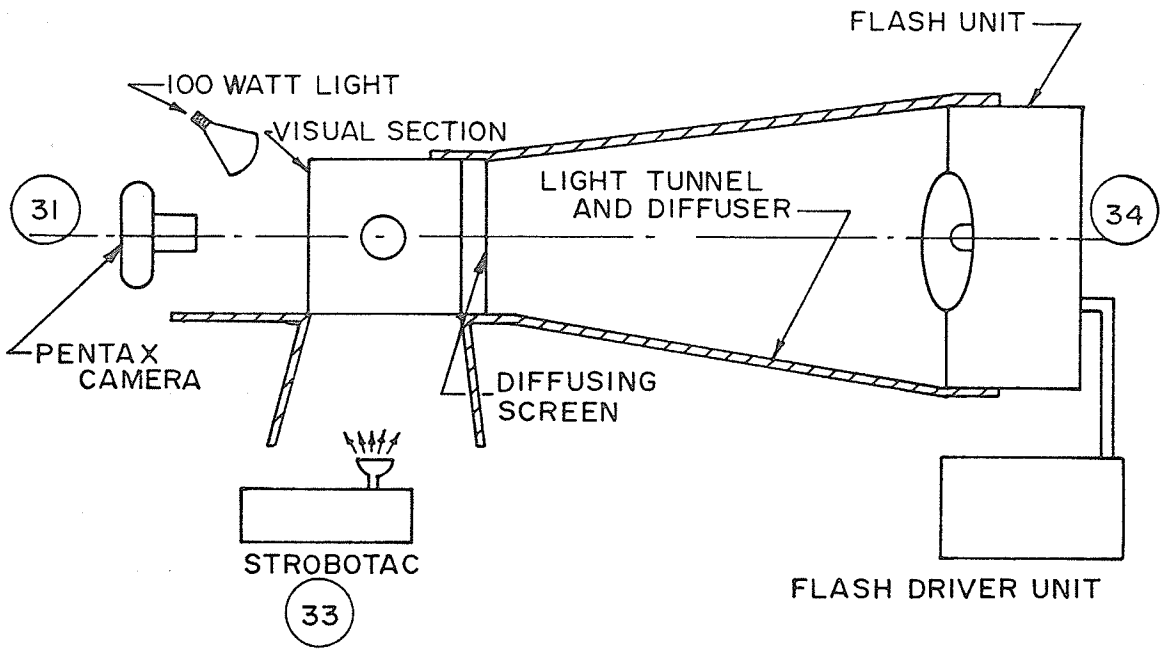
3.6 Photographic Section

An extensive testing of various settings and arrangement of the cameras was done in order to obtain good-quality photographs of flow patterns. The two arrangements shown in Figs. 3.9(a) and (b) were found most appropriate. It should be noted that the Strobotac and lamp light shown in Fig. 3.9(a) were used only to observe the flow patterns and are not part of photographic equipment. The arrangement shown in Fig. 3.9(a) was used for tests having V_{SL} up to 10.4 ft/sec (3.18 m/sec). At V_{SL} > 10.4 ft.sec (3.18 m/sec) the flow was slightly opague and the arrangement shown in Fig. 3.9(b) was useful in the sense that both sides of the tube were illuminated. The parabolic reflector was designed to give the focal point at the center of the tube. For some photographs, a diffusing screen close to the observation section was also used; however, most of the pictures were taken without the screen. The photographic equipment consisted of the following:

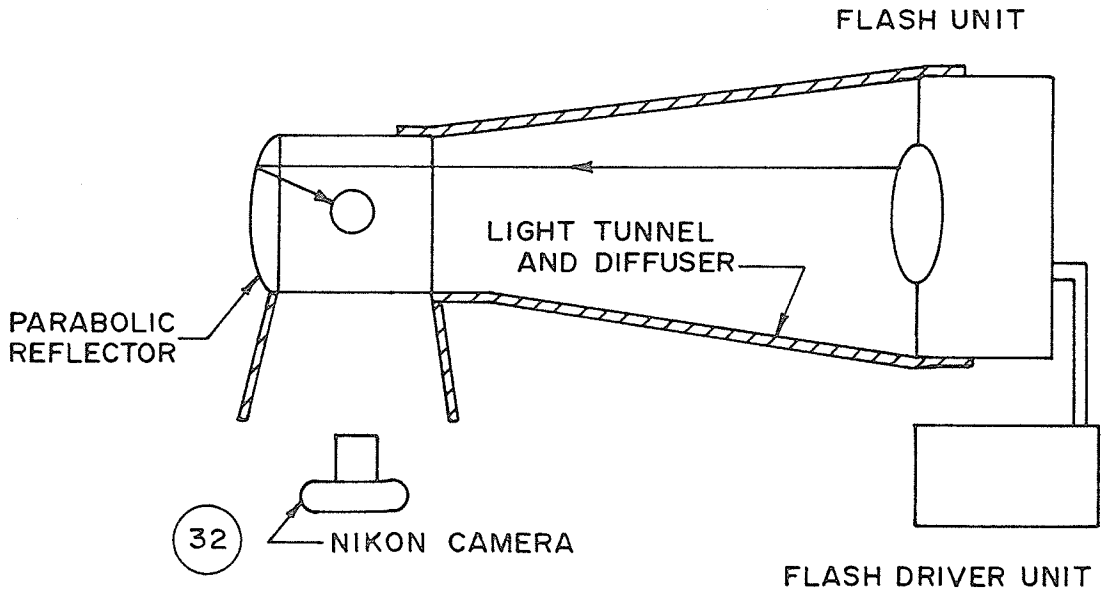
(i) A Pentax Spotmatic camera equipped with super Takumar & 50 mm f/4.0 close up lens,

(ii) a Nikon Photomatic FTN camera equipped with a Nikkor-s, 50 mm f/1.4 close up lens,

(iii) an EG&G Microflash Electronic Flash unit (flash duration ≃ 0.5 μsec) with the driver unit (which produced a 2-KV pulse to trigger the flash). The



(a) Arrangement with Pentax 35 mm Camera



(b) Arrangement with Nikon 35 mm Camera

Fig. 3.9 SET – UP OF PHOTOGRAPHIC SECTION

flash unit was covered with a mylar diffuser,

(iv) a light guide made of cardboard lined with white paper to diffuse and direct the light towards the visual section,

(v) a parabolic reflector designed to focus light on the tube,

(vi) a General Radio type 1538-A Strobotac electronic stroboscope. Kodak Plus-X Pan (ASA 125) films were used for all photographic work.

3.7 Selection of a Surface-active Agent

As mentioned earlier, the main purpose of the present investigation was to determine the effect of reducing the surface tension on the hydrodynamics and heat transfer in two-phase two-component flow. For the experiments, it was desired to use a liquid which allows large changes in surface tension while producing insignificant changes in other properties. This can be effected by adding a surfactant to the water; a surfactant is capable of reducing the surface tension of the water at relatively low concentrations while other properties remain essentially unaltered. As mentioned in the Introduction, although static and dynamic surface tensions are not the same in this case, it is still an obvious first step to take in the investigation of the effect of surface tension. If changes in any of the measured or observed variables occur, then these are most certainly due to changes in the surface tension.

The function of the surfactant may be described as follows. The surfactant molecule consists of a hydrophilic group and a hydrophobic "tail" (37). Such surfactants can be divided into three major chemical classes, viz. hydrocarbon, silicone and fluorocarbon, depending on the tail portion of the molecule. In an aqueous solution, the hydrophobe is squeezed out of the solution and this orientation is basically responsible for reducing the surface tension. The level of reduction, therefore, depends on the surface energy (Van der Waals attraction) of the hydrophobes of the respective surfactant molecule. The aqueous surface tension of the hydrocarbon, silicone and fluorocarbon surfactants having the same water solubility have been compared by Schwarz and Reid (37). They concluded that fluorocarbon surfactants were more effective in reducing the surface tension than the silicone, which in turn were more effective than hydrocarbon surfactants. Since, for the present experiments, the main criterion was to obtain surface tensions as low as possible, a fluorocarbon surfactant was therefore selected.

Fig. 3.10 compares the surface tension vs. concentration of "FLUORAD" brand fluorochemical surfactants produced by the 3M chemical Company. Surfactants FC-134 and FC-170 were reported by the manufacturer to be substantive to the metal surfaces used in the present rig and therefore were rejected. Surfactant FC-128 was selected because it was safe to use.

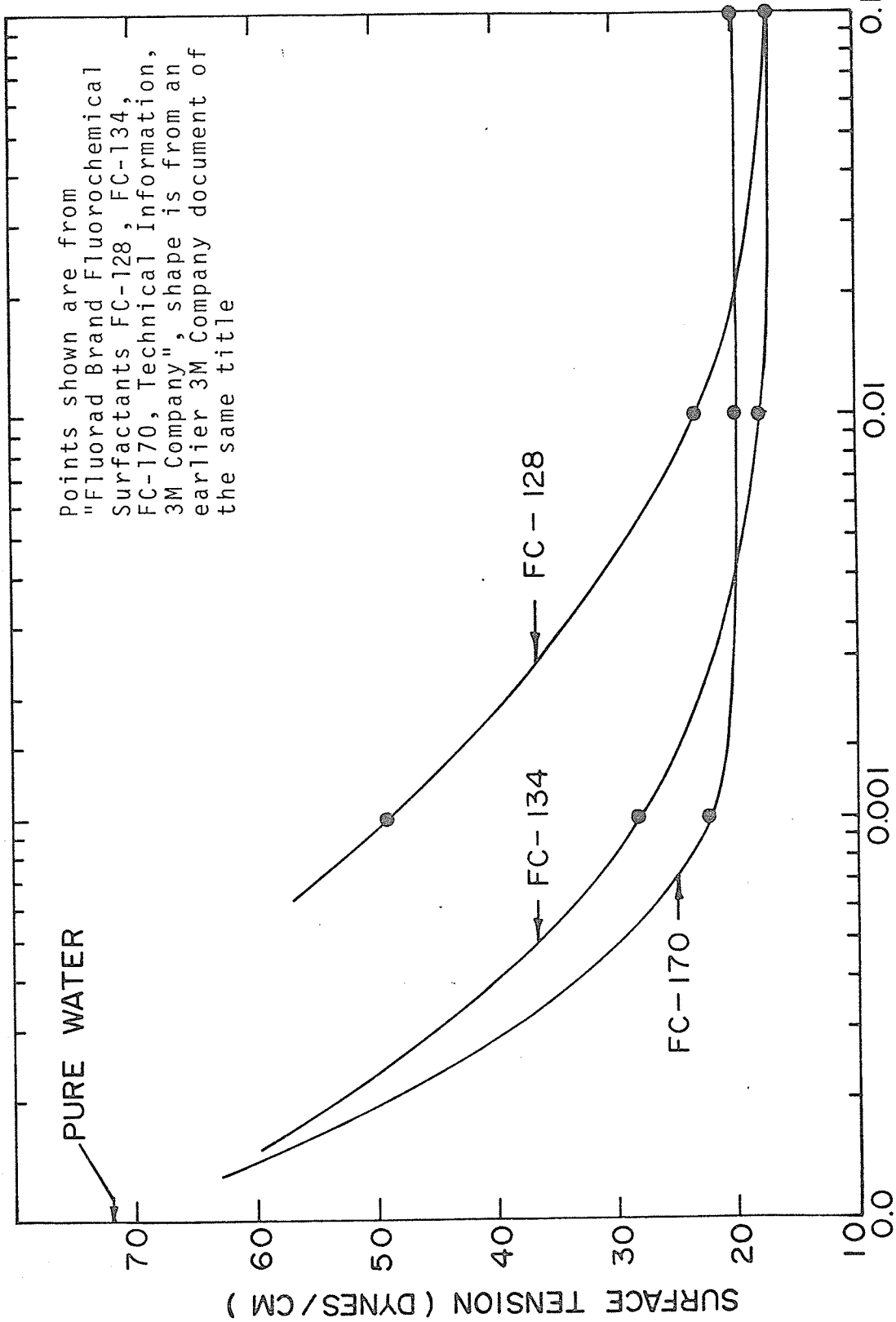


Fig. 3.10 Surface Tension Vs. Concentration of Fluoro Carbon Surfactants in Water

Samples of aqueous solution having various concentrations of FC-128 were prepared and the surface tension and viscosity were measured. Close agreement between the measured and the manufacturer's reported values was observed. The results are given below in Table 3.2.

Table 3.2 Comparison of measured and manufacturer's reported data of surface tension

Conc. of Surfactant (% wt)	Surface Tension (dyne/cm)		Viscosity		Remarks
	σ (measured)	σ_{th} (Fig. 3.10)	T (°C)	μ measured (CP)	
0.00	70.9 (typically)	72.0	21.2	0.9769	μ_w @ 21.20C = 0.9737
0.05	17.0	17.9	20.6	1.0345	du Nouy tensiometer and falling ball viscmeter were used to measure σ and μ respectively
0.10	15.7	17.0	20.7	1.0468	

3.8 Surface Tension Measurements

The equilibrium surface tension of water and water-surfactant solution was measured by means of a du Nouy tensiometer (Fisher 215 Autotensiomat Surface Tension Analyzer). The surface tension measuring system consisted mainly of the following items.

(i) A sample module containing the motor-driven elevator platform, the strain-gauge transducer-balance assembly and platinum-iridium ring,

(ii) a control module containing the operating controls and indicators,

(iii) a 1 MV one-pen strip chart recorder,

(iv) glass vessel or sterilized covered plastic Petri dishes to store the water and solution samples.

The measured apparent surface tension values were converted to the absolute values by applying the correction factor of Zuidema and Walters (57) as reported in the Fisher instruction manual and explained in Appendix C.

CHAPTER 4

EXPERIMENTAL PROCEDURE

4.1 Introductory Remarks

This chapter describes the procedure employed in performing the experiments.

In conducting the experiments, various parameters were measured to determine the heat transfer and hydrodynamic results. These variables are shown in Fig. 4.1 in the circles and are defined in Table 4.1. The other quantities were measured to monitor the experimental conditions. The calculation procedure is given in Appendix C. The calculations were performed on the University of Manitoba IBM 370 computer.

4.2 Preparation of Tests

All the temperature-measuring instruments and the surface tension measuring equipment were turned on a few hours before performing the experiment in order to allow an adequate warm-up time. The operation of the equipment and the flow circuits were checked as follows before performing the experiments. The calibration of the DVM and the recorder was checked by means of a DC voltage standard and adjusted if required. The air filter on the supply line was checked and changed if found oily or dirty. Typically, it was replaced after every two runs (In the text, the word "run" refers to an experiment in which the liquid flow rate

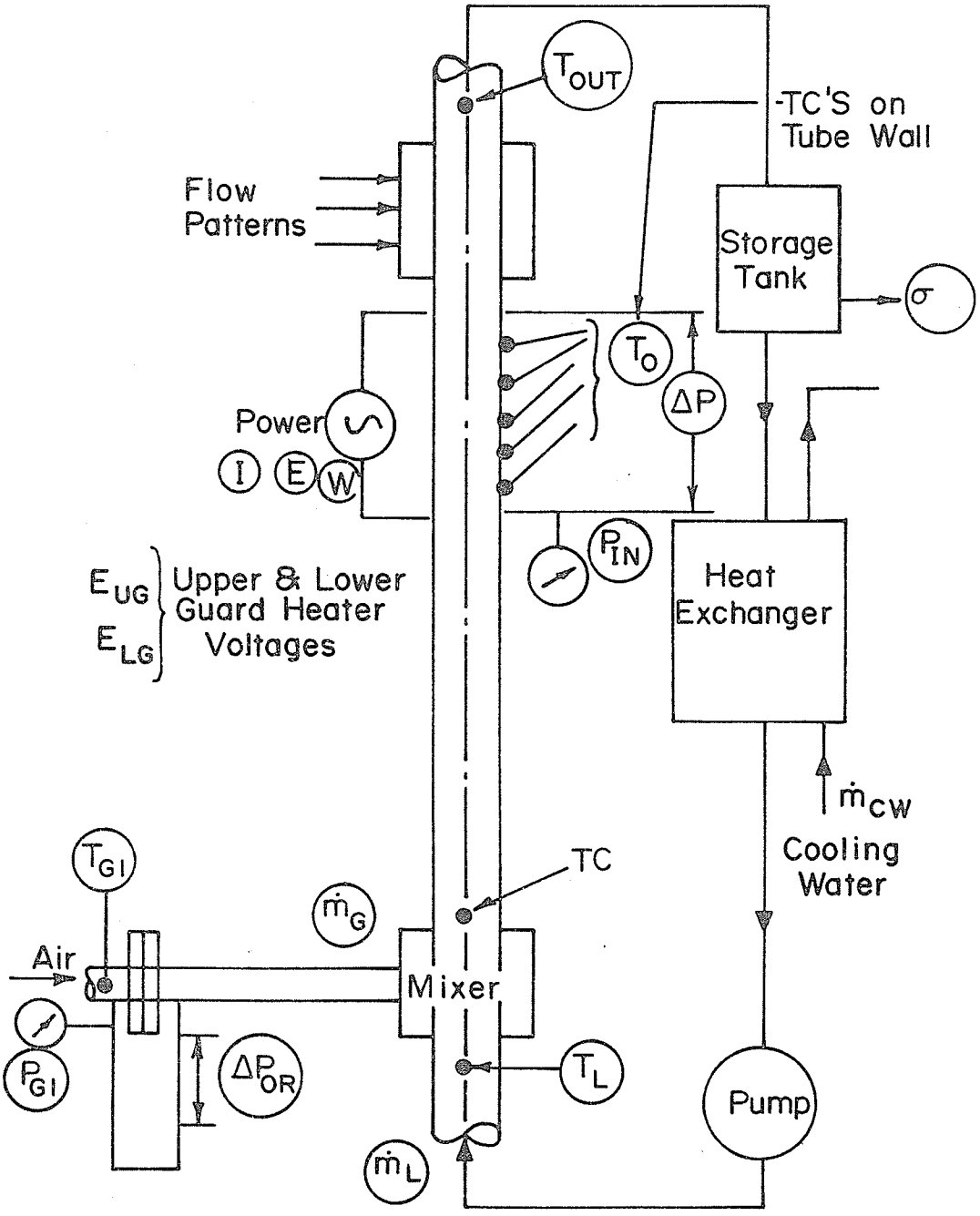


Fig. 4.1 DEFINITION OF VARIABLES COLLECTED

Table 4.1 Variables Measured in the Experiments

Power to Test Section			Power to Guard Heater		Water Flow Rate		Test Section Pressure	
(I) Ammeter Reading	(V) Voltmeter Reading	(W) Wattmeter Reading	E_{UG} volts	E_{LG} volts	Meter No.	Reading (%)	P_{IN}	ΔP
used to calculate the local heat flux	W and VI were used to check the power input to the test section		were adjusted to control the temperature of the guard heater		used with the calibration curves to calculate $\dot{m}_L$		Pressure at inlet to the test section	Total pressure drop across the test section

Gas Line Data			
O.P.N.	P_{GI}	ΔP_{OR}	P_{GL}
Orifice plate or rotameter No.	Press. at inlet to the orifice or rotameter	Press. drop across the orifice plate or rotameter reading	Gas pressure in the supply line
used, together with the gas temperature at the inlet to the orifice plate assembly (T_{GI}), to calculate the gas flow rate ($\dot{m}_G$)			used to calculate the moisture content in the gas

Other Variables	
Barometric Pressure	measured 3 times during the course of the experiment
Equilibrium Surface Tension	measured at the beginning and end of each test by du Nouy Tensiometer
Flow Pattern	Observed visually and photographed twice for each test

Thermocouple Readings	
TC No.	To measure the temperature of
1-4	Top and bottom bus bars
5 to 47	The outer wall of the heated test tube (T_o)
48 to 65	The inner wall of the guard heater
66	The water at the inlet to the mixer (T_L)
67 & 68	The mixture at the outlet of the mixer
69 & 70	The mixture at the outlet of the test section (T_{OUT})
71	The gas at the inlet to the orifice plate assembly (T_{GI})

is fixed and the air flow rate is varied; a "test" is an experiment with fixed liquid flow rate and a fixed air flow rate). The air circuit was checked for leaks. The leads from the orifice plates to the well-type manometer were checked to be clear of any water by bleeding air through them. The water level in the well-type manometer was checked and if necessary, was adjusted. The control valves were set for their proper position. For every run, the system was charged with fresh distilled water for water-air experiments. The surface tension of water was monitored during the course of the experiments and was never allowed to change by more than 5% of the literature value. In case of surfactant-solution-air experiments, the initial surface tension of the solution in the storage tank was set at the beginning of every run and this value was used to control the surface tension during all the tests for that run.

4.3 Start Up Procedure

The following steps were taken to start the rig:

(i) The cooling water to the heat exchanger was turned on,

(ii) the liquid pump was started with the by-pass valve fully opened,

(iii) all manometer and pressure gauge leads containing liquid were checked for the presence of air and purged if necessary. This step was repeated as often

as required during the course of the experiments,

(iv) the liquid flow rate was set to the desired value by a combination of closing the by-pass valve on the pump discharge and adjusting the control valve on the appropriate liquid flow meter. The rotameter was watched very carefully and adjusted whenever required. A large pressure difference across the control valves, upstream of the liquid flow meters, was maintained in order to prevent oscillations in the liquid flow rates,

(v) the valve on the main gas supply line was opened and the gas pressure at the inlet to the orifice plate assembly was set at a constant value by adjusting the pressure regulator on the gas line,

(vi) the desired gas flow rate was set by controlling the needle valve at the outlet of the appropriate orifice plate or rotameter,

(vii) the power supply to the lower and upper guard heaters was turned on,

(viii) the power supply to the test section was then turned on with the power control setting at zero input value and the power input was slowly increased to the desired value,

(ix) both channels of the recorder were then set on the monitoring position to record continuously the emf's from the inlet fluid thermocouple (T_L in Fig. 4.1) and the wall thermocouple at the mid-point of the test section,

(x) the photographic equipment was prepared for its proper operation.

For single-phase flow experiments, the same procedure was employed excluding steps v, vi and x.

4.4 Establishing Equilibrium Conditions

It was necessary to monitor and control the following variables so as to obtain steady-state conditions before taking any set of data:

1. The liquid inlet temperature to the mixer,
2. the voltage supply to the lower and upper guard heaters,
3. power supply to the test section, and hence wall temperature.

The criteria for steady-state conditions are listed below.

4.4.1 Water Inlet Temperature

The desired liquid inlet temperature was set by adjusting the cooling-water inlet temperature and the flow rate through the heat exchanger. The liquid inlet temperature

T_L to the test section was continuously recorded on one channel of the two-pen strip-chart recorder. Thermal equilibrium conditions were considered to prevail if the variation in T_L, over a period of five minutes, was not more than $\pm$ 5 μv (~ 0.2°F or ~ 0.1°C) before taking the data.

4.4.2 Power Input to Guard Heaters

A criterion for setting the power to the guard heaters so as to achieve a zero-temperature-gradient boundary condition was established in Reference (48) and its influence on the heat-transfer coefficient was reported there. The same criterion was observed in the present work. On the basis of this criterion, the power supply to the guard heater was controlled in such a way that at a given elevation, nowhere did the temperature difference between the outer surface of the test section and the inner surface of the guard heater differ by more than $\pm$ 4°F ($\pm$ 2.2°C). In the present case this temperature difference was typically in the range of 2-3°F. It was reported in Reference (48) that the effect of this magnitude of temperature difference on the heat-transfer coefficient is almost neglible in turbulent flow while it is less than 2% in laminar flow. The readings of thermocouples number 5, 25 and 40 on the tube wall and the corresponding thermocouple on the guard heaters (48, 56

and 64) were monitored successively and the power input to the guard heaters was adjusted accordingly.

4.4.3 Power Input to the Test Section

The power to the test section was supplied considering the following conditions:

(i) The temperature difference between the tube wall and the bulk fluid temperature should be low enough to minimize radial gradients in properties,

(ii) this ΔT should be large enough to determine the heat-transfer coefficients accurately.

A temperature difference of 15°F (8.33°C) was recommended (48) as adequate to meet these requirements. Therefore the following procedure, as adopted in the previous works (48, 1), was used to adjust the power to the test section:

(i) The outer wall temperature T_o at Z = 24D (TC No. 24), the liquid inlet temperature T_L (TC No. 66) and the mixture temperature at the outlet of the test section T_{OUT} (TC No. 69) were read from the DVM or recorder,

(ii) an approximate value of the inlet wall temperature T_W was estimated from a previously prepared table for the temperature drop ΔT_W as a function of current I,

(iii) an approximate value of T_B at Z = 24D was calculated from the knowledge of T_L and T_{OUT},

(iv) the difference $T_w - T_B$ was calculated and the power input was adjusted accordingly.

During the course of the experiments, it was attempted to maintain a reasonably constant temperature difference. The spread in $(T_w - T_B)$ for the entire series of tests was as follows.

Water-air:	$15^oF \begin{matrix} + 3.74 \\ - 6.44 \end{matrix}$
Surfactant Sol.-air:	$15^oF \begin{matrix} + 6.77 \\ - 6.59 \end{matrix}$

In general, the response of the wall as regards equilibrium condition was very much faster than the inlet liquid temperature.

4.5 Controlling the Surface Tension of the Solution

A serious problem concerned with the use of surfactant in the present experiments was the growth of unwanted foam in the storage tank. The surface tension of the solution was also observed to increase with running time of the tests because some amount of surfactant from the solution went into the foam. Therefore, practically, it was impossible to maintain a constant value of surface tension for all the tests. However, it was attempted to keep a minimum spread in surface tension values for all series of tests and still to have a value low enough to give large changes in the

surface-tension property. The following procedure was adopted to control the surface tension of water-surfactant solution during the course of a run:

(i) The solution sample was collected from the bottom of the storage tank (See Fig. 3.2) directly into a sterilized disposable plastic Petri dish. It was believed that the concentration of the surfactant in this sample was the same as in the solution flowing through the test section,

(ii) the plastic Petri dish was then placed gently on the tensiometer elevator platform and was left there undisturbed for at least 10-20 minutes in order to achieve a surface equilibrium. This time was found adequate just for an approximate estimate of surface tension; otherwise the samples were aged in the covered Petri dishes for 16-24 hours in order to measure the precise value of equilibrium surface tension,

(iii) the surface tension was measured and more surfactant was added to the solution in the storage tank, if an increase in the surface tension was observed,

(iv) approximately 30 minutes after the addition of the surfactant, a new sample was taken from the storage tank and the surface tension measured. Conditions were considered satisfactory to record the data if this new value was within the range of 20-30 dyne/cm,

(v) the surface tension of the solution in the storage tank was also measured at the end of each test. The data were rejected and the test was repeated if the surface tension became more than 30 dyne/cm.

The spread in σ for the entire series of tests was typically between 20-26 dyne/cm. There were only six data points (out of 98) at higher liquid flow rates for which σ was greater than 30 dyne/cm and the highest of these was 39 cyne/cm.

4.6 Taking of Data

After equilibrium conditions had been established and the surface tension of the solution maintained (for surfactant solution-air tests) at a satisfactory level, instruments were read and the value of all the variables listed in Table 4.1 were recorded.

The thermocouple readings were taken last, in all the tests. For each test, the data logger recorded the thermocouple emf's a number of times, typically 10 to 15 for highly fluctuating conditions (e.g. slug flow) and 3 to 6 under steady conditions. An average value of three to nine sets of thermocouple readings, depending upon the fluctuations in the temperature, was obtained, these average values were used to calculate the heat-transfer coefficients. If during the

recording of all the thermocouple readings, the liquid temperature varied by more than 0.2°F, the data were rejected and the test was repeated.

The test conditions and the range of variables considered in the present investigation are listed in Table 4.2. Depending upon the liquid and its flow rate, the gas flow rate was varied to obtain flow patterns from bubble to annular-mist. The maximum air flow rate obtainable was limited by the capacity of the air compressor in the laboratory. An attempt was made to collect data for all the tests of a particular run continuously; sometimesit took 20 hours to complete one run. Most of the data reported in the thesis were obtained this same way except some data at low liquid flow rates.

4.7 Flow Pattern Observation

When the required test conditions were set, the flow patterns were first observed by naked eye, using a 100-watt lamp light and then with the aid of a stroboscope. These visual observations were recorded on the data sheet. Then at least one picture of the flow pattern was taken using the camera arrangements shown in Fig. 3.9 a & b depending upon the liquid flow rate. The photographs were taken in total darkness in the laboratory while the aperture of the camera was held open and the microflash fired. The cameras were set as follows.

Table 4.2 Range of variables investigated and other information

Variables	Water-Air Experiments		Surfactant Sol-Air Experiments	
	Minimum	maximum	minimum	maximum
m_L (lbm/hr)	48	8995	48	5397
m_G (lbm/hr)	0.1	198.36	0.14	195.87
V_{SL} (ft/sec)	0.19	34.76	0.19	20.83
V_{SG} (ft/sec)	0.29	386.26	0.41	383.25
$\bar{q}_w$ (Btu/hr-ft^2)	5556	80390	5825	58103
$\bar{T}_{mix}$ (°F)	72.27	88.0	71.28	91.70
ρ_a (lbm/ft^3)	0.0716	0.3272	0.0711	0.223
σ_{abs} (dyne/cm)	68.62	72.38	19.30	38.85
Re_{SL}	710	1.53×10^5	818	0.815×10^5
Re_{SG}	77.5	1.43×10^5	107.9	1.46×10^5
Pr_L	5.37	6.56	5.17	6.65
Pr_G	0.708	0.710	0.707	0.710
We_{SL}	0.5	18420	1.8	20493

Pentax Camera: f-4.0 and 5.6

Nikon Camera: f-2.8 and 4.0 .

At least one picture was also taken after recording all the readings for that particular test. In all the tests, the same flow pattern was observed to exist before and after the taking of data for that test.

4.8 Shut-Down Procedure

The following steps were taken in sequence to shut down the rig:

(i) First the power supply to the heated tube and the guard heaters was turned off,

(ii) the by-pass valve on the pump discharge was opened fully and the control valve on the flow meter was closed and the pump was shut down.

(iii) the cooling water to the heat exchanger was turned off,

(iv) the main supply was shut off first and then the gas flow control valves were closed,

(v) finally, the test section and the mixer were drained and air was then supplied and left flowing for at least one hour to dry the mixer.

4.9 Selection of Liquid Flow Rates

For selecting the values of liquid flow rates for the present work, the flow rate settings used in the previous works (48, 1) performed on the present experimental facility were considered. It was thought to be advantageous to use the same flow rates as in the previous work (48, 1) in order to facilitate the comparison of the present results with those of References (48, 1). Also the effect of fluid properties on different variables could be observed for the same fixed liquid velocity. It was also desired to cover both laminar and turbulent flow regions in the present study. The present water-air data covered the entire range of liquid flow rates studied in References (48) and (1) except the lowest one (V_{SL} = 0.065 ft/sec, 0.02 m/sec) studied in (48). Out of seven flow rates selected for the present study, four (V_{SL} = 1.03, 3.4, 20.84 and 34.73 ft/sec) were common in References (48) and (1) while the other three (V_{SL} = 0.19, 0.37 and 10.05 ft/sec) were studied in Reference (48). It should be noted that it was not possible to work with surfactant solution at V_{SL} > 20.84 ft/sec (6.35 m/sec) because of the growth of uncontrollable foam in the storage tank which in turn continuously varied the surface tension of the solution.

CHAPTER 5

STUDY OF FLOW PATTERNS AND PRESSURE DROPS

5.1 Introductory Remarks

This Chapter deals with the hydrodynamic results observed in the present investigation. First, the single-phase pressure drop results are presented and compared with the well-known existing theories. Then the two-phase flow patterns occurring in a vertical tube are described. The samples of photographs of flow patterns for each liquid-flow rate are presented next. Then the flow pattern data observed in this work are presented and compared with the flow pattern maps of Govier and Aziz (20) and Taitel et al. (43). Finally, two-phase frictional pressure drop data are presented.

The calculation procedure for the reduction of the pressure drop data is given in Appendix C and the data are tabulated in Appendix D.

5.2 Single-Phase Pressure Drop

In two-phase flow investigations, the common procedure to test the accuracy of the instrumentation and the reliability of the experimental facility is to perform

single-phase experiments and compare these results against well-established theories and correlations. The experimental facility is assumed to be suitable for two-phase flow studies if the agreement is reasonable. Although the performance of the present experimental apparatus has been checked before (48, 1), it was important to ensure the continued satisfactory performance of the rig. Therefore single-phase experiments with water were performed. The pressure drop results are presented in this section while the heat transfer study will be discussed in the next Chapter.

In the present work, the degree of agreement between the experimental and theoretical or empirical expressions is determined by evaluating two deviations as defined below. The same parameters will be used in later chapters, wherever required.

$$\bar{e} = \text{Mean deviation} = \frac{1}{N} \Sigma \left(\frac{V_{EXPL} - V_{THL}}{V_{THL}}\right) \qquad (5.1)$$

$\bar{e}'$ = The root mean square deviation

$$= \left[\frac{1}{N} \Sigma \left(\frac{V_{EXPL} - V_{THL}}{V_{THL}}\right)^2\right]^{\frac{1}{2}} \qquad (5.2)$$

where

N is the number of data points,

V_{EXPL} is the experimental value of the variable considered,

V_{THL} is the theoretical (expected) value of the variable as determined from the equation under consideration.

5.2.1 Discussion of Results

The frictional pressure drop was calculated from the measured total pressure drop and was compared with the well-known equations listed below

Laminar flow: $(Re_{SL} < 2,000)$

$$f_{SP} = \frac{16}{Re_{SL}} \tag{5.3}$$

Turbulent flow: $(Re_{SL} > ,2000)$

$$f_{SP} = 0.079\ Re_{SL}^{-0.25} \quad (2,000 < Re_{SL} < 30,000) \tag{5.4}$$

and

$$f_{SP} = 0.046\ Re_{SL}^{-0.20} \quad (Re_{SL} > 30,000)\ . \tag{5.5}$$

The results of comparisons are shown in Fig. 5.1 and the deviations are listed below.

TABLE 5.1 Single-phase Pressure Drop Data Against Existing Correlations.

Type of Flow	$\bar{e}$	$\bar{e}'$
Laminar	45.4%	46.8%
Turbulent	-1.35%	3.5%

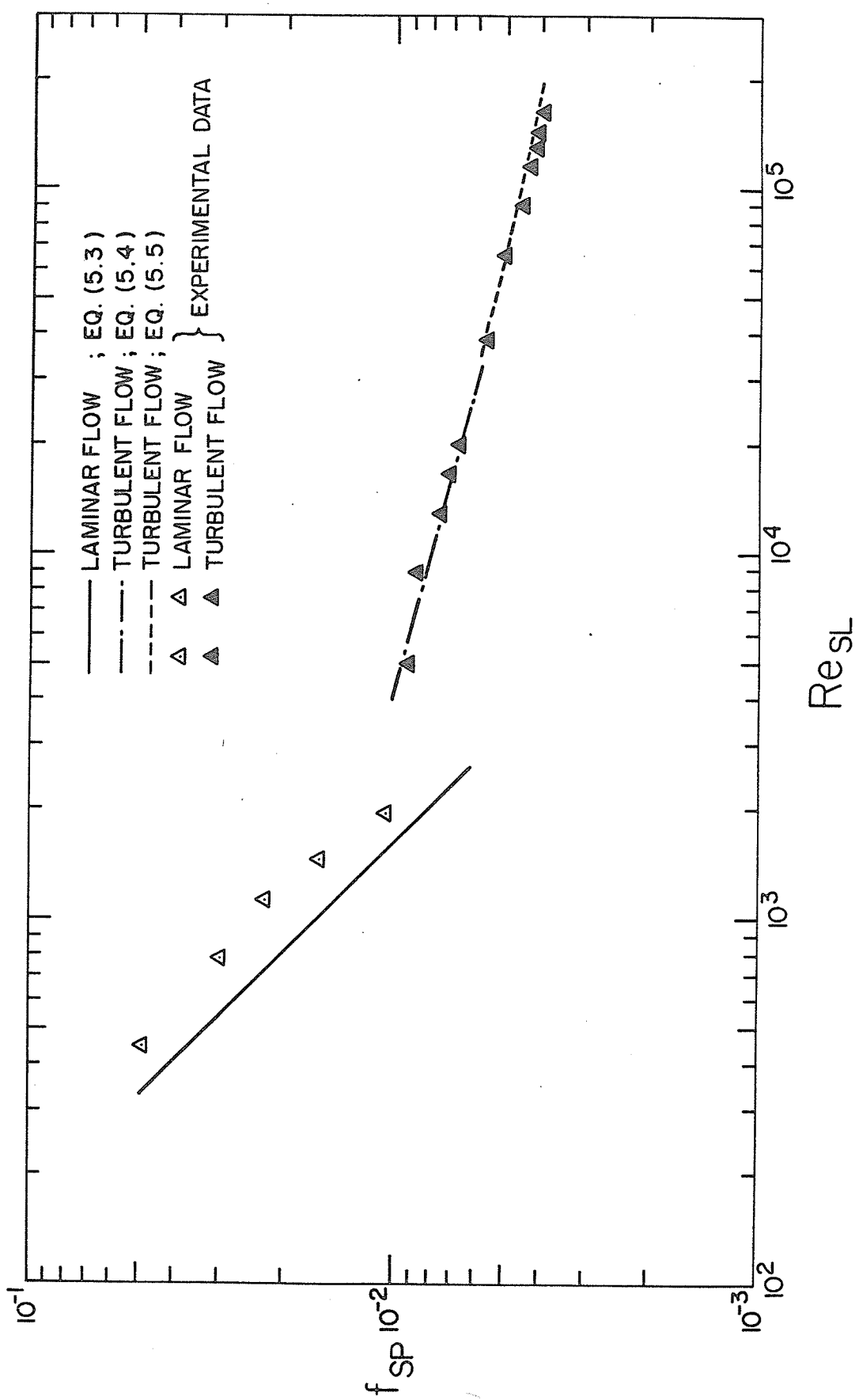


Fig. 5.1 Single-Phase Frictional Pressure Drop Results

For turbulent flow the agreement is excellent and for laminar flow, it is poor. The large deviations encountered in laminar flow are likely mainly due to the errors in reading the small deflections on the manometers.

The above equations were not corrected for variations in fluid properties (26) because the property radial gradients in the present experiments were small. It was concluded in Reference (1) that the effect of correcting the measured friction factors to constant-property values meant correction of approximately 8% for laminar flow and less than 1% for turbulent flow. Therefore these corrections were neglected.

5.3 Presentation and Discussion of Flow Pattern Data

In this section, the basic flow patterns observed in upflow of gas-liquid mixtures in a vertical tube are described; then the transitions are discussed. The samples of flow pattern photographs taken in the present work are presented next. Then the present flow pattern data are presented and compared with the flow pattern maps of Govier and Aziz (20) and Taitel et al. (43).

5.3.1 Description of Flow Patterns

When gas-liquid mixtures flow in a pipe conduit, the phases may distribute themselves in a variety of configurations depending upon the flow rates of the two individual phases, fluid properties, pipe geometry and the method of phase mixing. These flow configurations are called flow patterns. Two-phase flow patterns occurring in a vertical tube have been studied by a number of investigators and a considerable volume of literature has been published on two-phase flow patterns for upflow of gas-liquid mixtures (18, 19, 49, 7, 21, 9, 23, 32, 20, 43, 42, 31, 36, 54); some of these publications are very recent (43, 42, 36, 54). However, in spite of the volume of literature, predicting the flow patterns for upward flow of gas-liquid mixtures in vertical pipes is still an unresolved problem (43, 54). The terminology and description of flow patterns varies from author to author; however, the characterization and description proposed by Hewitt and Hall-Taylor (24) appears to be among the best (43). Their description will be generally used in the analysis of the results observed in the present work.

In the present investigation, the flow patterns were observed visually with and without the aid of a stroboscope through a transparent visualization section located immediately downstream of the heated test section as mentioned earlier

in Section 4.7. The flow patterns were also photographed by using a high-speed microflash unit in order to supplement the visual observations. Initially, experiments were run with the water-air system and visual criteria were established for each flow pattern, which were later used to identify the flow patterns of surfactant solution-air mixtures. Observations of flow patterns occurring in the water-air system indicated that the flow pattern classifications given by Hewitt and Hall-Taylor (24) generally provided a good characterization of the flow patterns. Accordingly, their description, but with some modifications or additions where appropriate, were used in identifying the flow patterns. The basic flow patterns observed are shown in Fig. 5.2 and are described below generally in the order of increasing gas flow rate for a fixed liquid rate.

1. Bubble Flow: In this flow, the gas-phase is distributed in the form of discrete bubbles in a continuous liquid phase. The two types of bubble flow, distinguished by Delhaye in Reference (3), were observed in the present work. In the "independent bubble" configuration, the bubbles are spaced while in the "packed bubble" configuration, bubbles are crowded together (see Fig. 5.2). However both types have been termed as bubble flow in the present work.

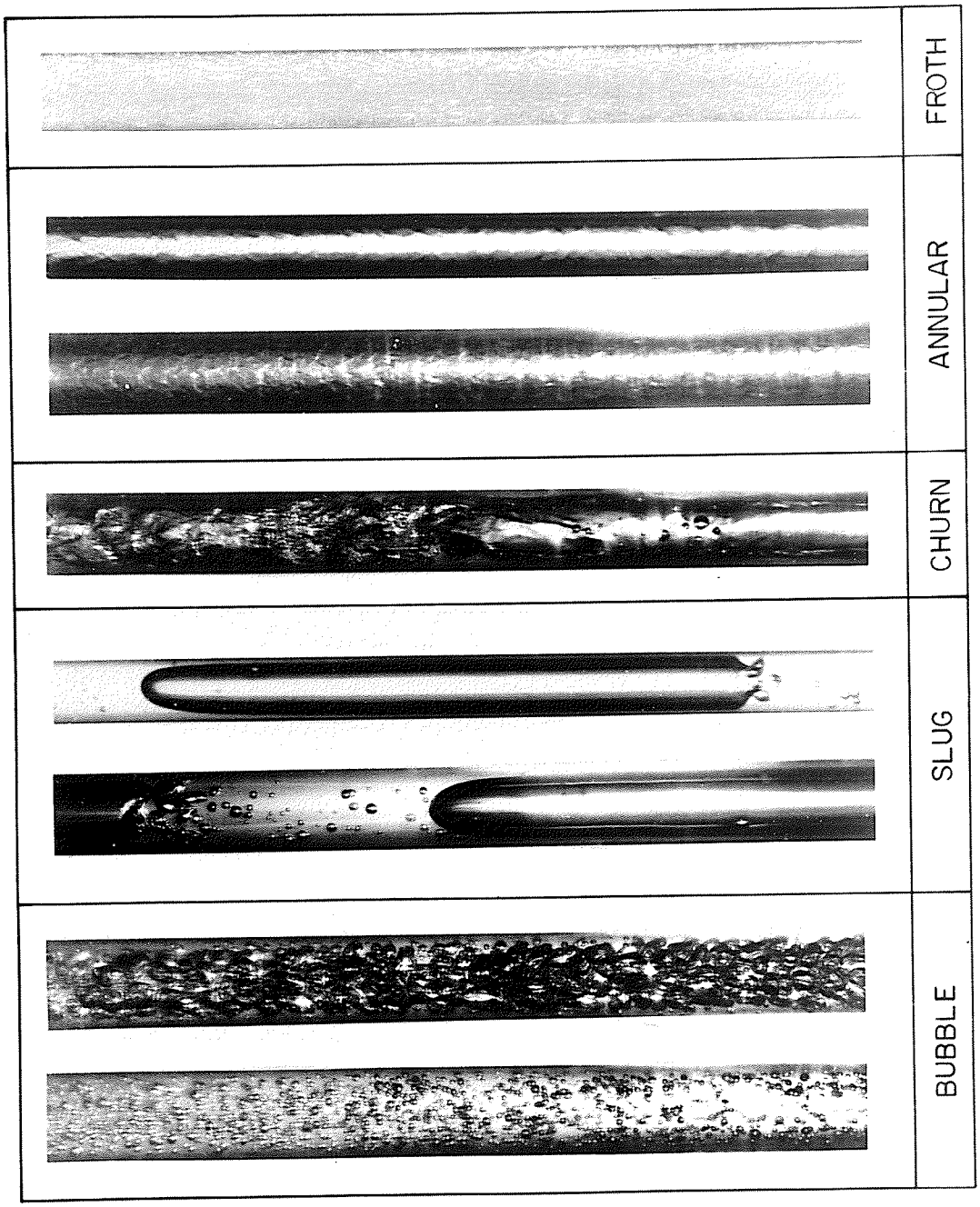


FIG. 5.2 FLOW PATTERNS IN VERTICAL CO-CURRENT FLOW

2. Slug Flow: In this type of flow, the long bullet-shaped bubbles, sometimes designated as "Taylor bubbles", have a diameter almost equal to the pipe diameter. The gas bubbles are separated by slugs of liquid which may or may not contain a dispersion of small gas bubbles. As these long bubbles move upward, liquid flows downward in the form of a thin falling film between the long bubble and the tube wall.

3. Churn Flow: As the gas flow is increased, the slug-flow structure becomes unstable and the shape of the long bubble is distorted. The continuity of the liquid slug between successive gas bubbles is destroyed by a high local gas concentration in the slug. As this happens, the liquid slug falls, accumulates and is again lifted by the gas. Typical of churn flow is this oscillatory, upward and downward motion of the liquid in the tube.

4. Annular Flow: In this type of flow, the liquid phase flows on the wall of the tube as a wavy film and the gas phase flow in the centre of the tube. The liquid may or may not contain gas bubbles and the gas core may or may not contain entrained liquid droplets.

5. Mist Flow: As the gas flow continues to increase, the liquid film on the wall becomes thinner and thinner and eventually the film is swept away by the gas phase. The liquid droplets are entrained in a continuous gas phase.

   This flow pattern was not encountered in the present work; however, the transition (annular-mist) was observed.

6. Froth Flow: This flow pattern is mainly characterized by the existence of tiny bubbles in a packed form; these bubbles are practically indistinguishable individually. One gets the impression of a homogeneous flow and the mixture has a milky appearance.

   This flow pattern occurs at high liquid and gas velocities and probably is caused by the highly turbulent fluctuations associated with the gas-liquid mixture under these conditions.

5.3.2 Flow Pattern Transitions

The transition from one flow pattern to another was observed to be smooth and gradual with respect to fluid flow rates. The sequence of the flow patterns was the same

as described above from bubble flow to annular-mist up to $V_{SL} \leq 3.41$ ft/sec (1.039 m/sec) while at $V_{SL} > 10.4$ ft/sec (3.18 m/sec), froth flow was observed just after bubble flow. Any flow configuration which contained the elements of two basic flow patterns in it was classified as a transition between those two flow patterns. Some of the transitions need some explanation and are described below:

(i) The slug-churn transition is inherently qualitative and therefore is subject to personal judgement. In the present work, the beginning of churn flow was characterized by a condition where first oscillatory motion of the liquid was observed.

(ii) In the annular-mist transition, the flow was somewhat transparent giving the impression that the tube contained a mist; there appeared to be a thin liquid film on the wall when the flow was illuminated by stroboscope light; a similar impression of liquid film was gained on examining the photographs. Based on the combination of these observations flow pattern was termed as annular-mist.

The number of tests (data points) falling under each flow pattern and transition are given in Table 5.2.

TABLE 5.2 Flow Pattern Classification in the Present Work

Flow Pattern / System	Bubble (B)[&]	Slug (S)	Churn (C)	Annular (A)	Froth (F)	Bubble Slug (B-S)	Bubble Froth (B-F)	Slug Annular (S-A)	Slug Froth (S-F)	Churn Annular (C-A)	Annular mist (A-M)	Annular froth (A-F)
Water- air	[Δ]22*	14	11	18	10	5	[Δ]5	1	3	5	16	8
Surfactant sol.-air	11	10	10	29	4	2	3	0	2	7	14	6

*Number of tests

[&]Code

[Δ]The apparatus was run under adiabatic conditions beyond its usual maximum liquid velocity in order to obtain a few more flow pattern observations in the high-liquid-velocity region. These data at V_{SL} = 41.68 ft/sec (12.70 m/sec), were limited to V_{SG} < 6 ft/sec (1.83 m/sec); seven points fell in bubble flow and one in the bubble-froth transition (the number here include these data).

5.3.3 Presentation of Flow Pattern Photographs

Different arrangements and settings of the cameras were tried to obtain good-quality photographs of the flow structure; the arrangements shown in Fig. 3.9(a) and (b) were found to be most appropriate. At least two pictures, one before and one after recording the other readings for the test, were taken for every test. A few samples of photographs covering all the flow patterns observed at each liquid flow rate are shown in Fig. 5.3 (A-H) for the water-air system and in Fig. 5.4 (A-F) for the surfactant solution-air (surfactant sol.-air) system. For each flow pattern, the photographs are arranged in order of increasing gas flow rates for a fixed liquid flow rate.

Although still-photography is a very useful tool for identification of two-phase flow patterns, it alone is not sufficient due to its own limitations, since it records only instantaneous distribution of both phases. For example, the flow pattern in Frames No. 1 of Fig. 5.3 (B) and Fig. 5.3 (C) appears superficially as annular and bubble flow respectively if reliance is placed entirely on photography. In fact, these are the pictures of slug flow. In Frame No. 1, Fig. 5.3 (B), a long gas bubble was passing by the point of observation at the time of exposure while Frame No. 1 of Fig. 5.3 (C) shows the aerated slug of liquid in the wake of a long bubble. The chaotic and oscillatory movement of the mixture in churn flow, obviously, cannot be ascertained from the photographs and it

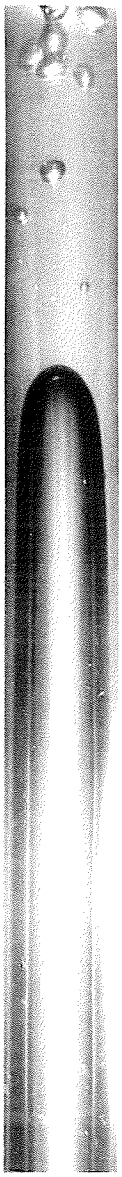
WATER - AIR	V_{SL} = 0.185 ft/sec (0.056 m/sec)			
V_{SG} ft / sec (m/sec)				
1.12 (0.34)	8.60 (2.62)	48.70 (14.84)	71.00 (21.64)	386.0 (117.65)
				
I	II	III	IV	V
SLUG	CHURN	CHURN - ANNULAR	ANNULAR	ANNULAR - MIST

FIG. 5.3(A)

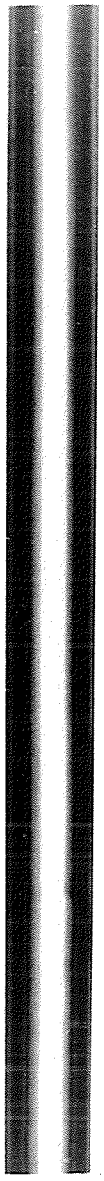
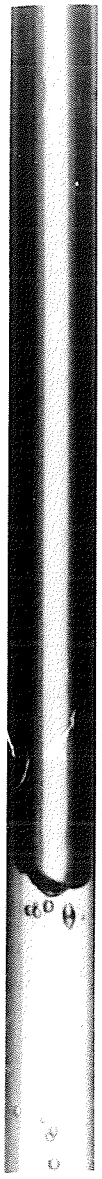
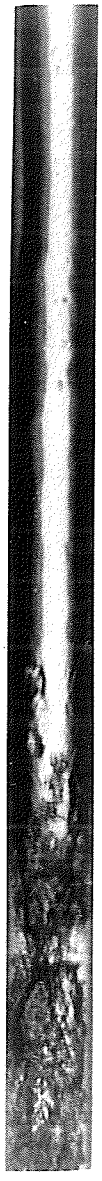
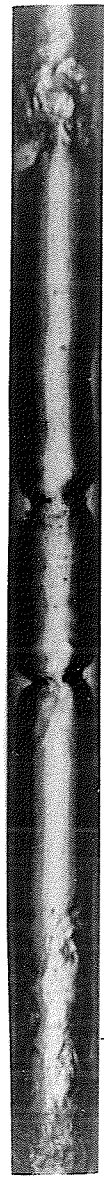
WATER – AIR	V_{SL} = 0.367 ft/sec (0.112 m/sec)			
V_{SG} ft / sec (m/sec)				
1.30 (0.40)	1.30 (0.40)	3.50 (1.07)	9.00 (2.74)	19.00 (5.79)
				
I	II	III	IV	V
SLUG	SLUG	SLUG	CHURN	CHURN

FIG. 5.3(B)

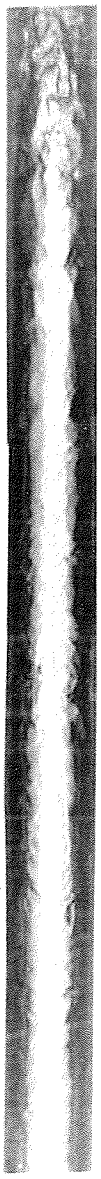
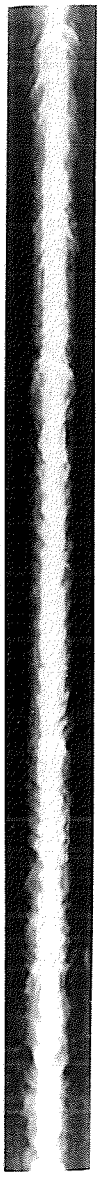
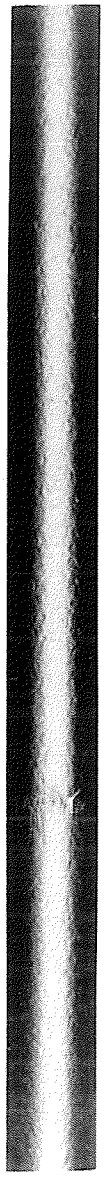
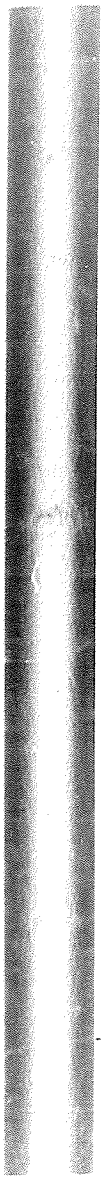
WATER - AIR	V_{SL} = 0.367 ft/sec (0.112 m/sec)			
V_{SG} ft/sec (m/sec)				
41.6 (12.68)	67.0 (20.42)	76.6 (23.34)	208.0 (63.40)	349.3 (106.47)
				
VI	VII	VIII	IX	X
CHURN - ANNULAR	ANNULAR	ANNULAR	ANNULAR-MIST	ANNULAR-MIST

FIG. 5.3(B)CONT.

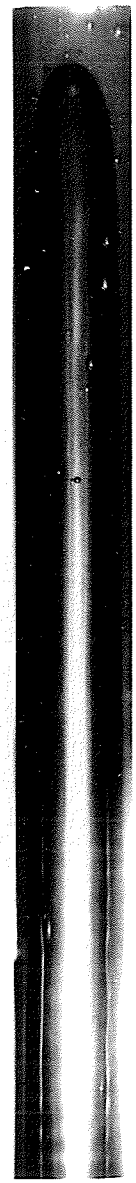
WATER – AIR	V_{SL} = 1.033 ft/sec (0.315 m/sec)			
V_{SG} ft/sec (m/sec)				
1.9 (0.58)	1.9 (0.58)	3.6 (1.10)	16.4 (5.0)	36.4 (11.10)
				
I	II	III	IV	V
SLUG	SLUG	SLUG	CHURN	CHURN-ANNULAR

FIG. 5.3(C)

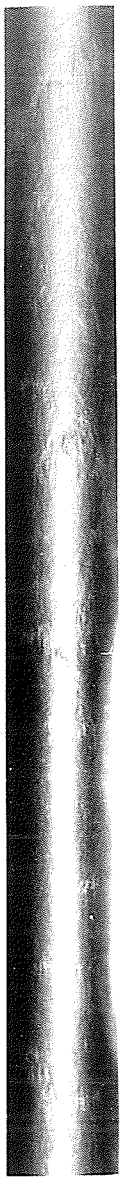
WATER – AIR	V_{SL} = 1.033 ft/sec (0.315 m/sec)			
V_{SG} ft/sec (m/sec)				
48.70 (14.84)	75.10 (22.89)	106.90 (32.58)	162.10 (49.41)	314.80 (95.95)
				
VI	VII	VIII	IX	X
ANNULAR	ANNULAR	ANNULAR	ANNULAR - MIST	ANNULAR - MIST

FIG. 5.3(C) CONT.

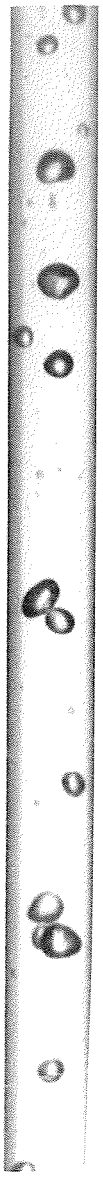
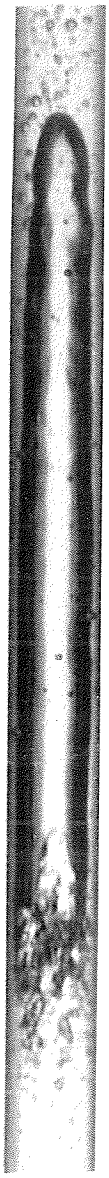
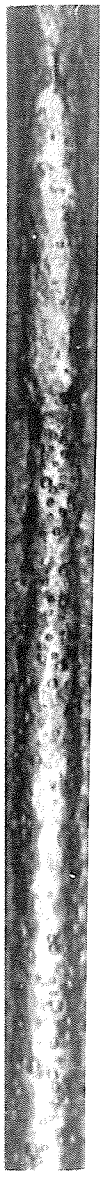
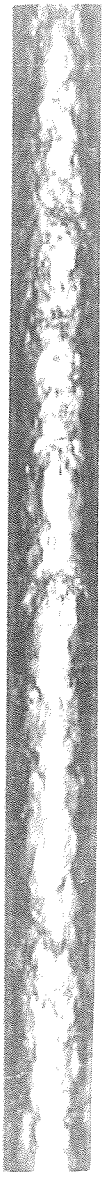
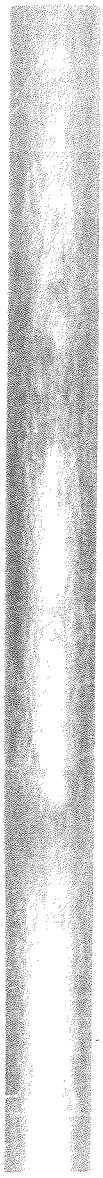
WATER - AIR	V_{SL} = 3.406 ft/sec (1.038 m/sec)			
V_{SG} ft / sec (m/sec)				
0.293 (0.09)	3.0 (0.91)	15.3 (4.66)	49.0 (14.94)	171.8 (52.36)
				
I	II	III	IV	V
BUBBLE	SLUG	SLUG - ANNULAR	ANNULAR	ANNULAR - MIST

FIG. 5.3(D)

WATER – AIR	V_{SL} = 10.40 ft/sec (3.17 m /sec)			
V_{SG} ft / sec (m /sec)				
1.0 (0.30)	2.7 (0.82)	4.6 (1.4)	6.2 (1.89)	7.0 (2.13)
				
I	II	III	IV	V
BUBBLE	BUBBLE - SLUG	BUBBLE - SLUG	BUBBLE - SLUG	SLUG - FROTH

FIG. 5.3(E)

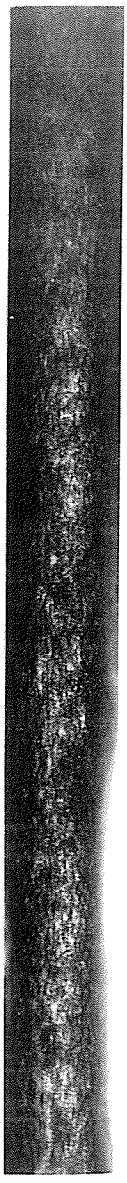
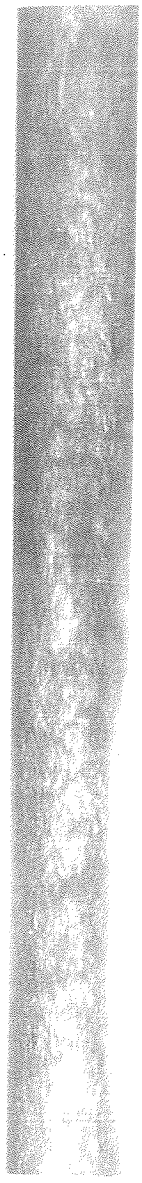
WATER - AIR	V_{SL} = 10.40 ft/sec (3.17 m/sec)			
V_{SG} ft/sec (m/sec)				
12.80 (3.90)	31.70 (9.66)	39.20 (11.95)	53.80 (16.40)	80.40 (24.51)
				
VI	VII	VIII	IX	X
SLUG - FROTH	ANNULAR - FROTH	ANNULAR - FROTH	ANNULAR - FROTH	ANNULAR - FROTH

FIG. 5.3 (E) CONT.

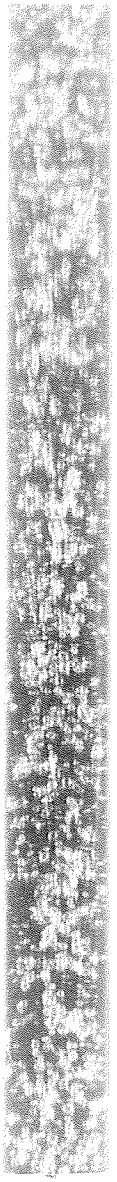
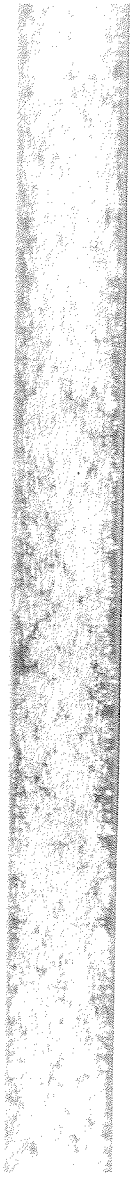
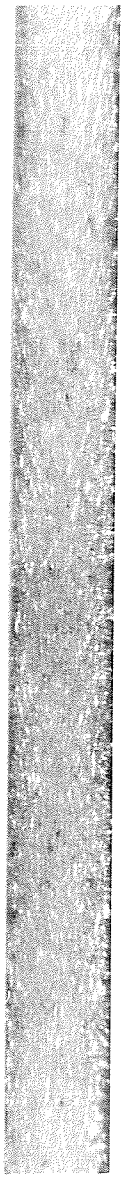
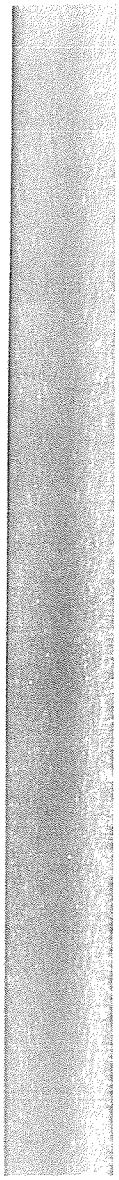
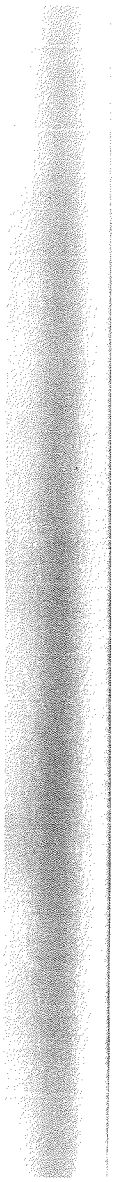
WATER - AIR	V_{SL} = 20.84 ft/sec (6.35 m/sec)			
V_{SG} ft/sec (m/sec)				
0.81 (0.25)	2.8 (0.85)	4.5 (1.37)	14.6 (4.45)	49.0 (14.95)
				
I	II	III	IV	V
BUBBLE	BUBBLE	BUBBLE - FROTH	FROTH	FROTH

FIG. 5.3(F)

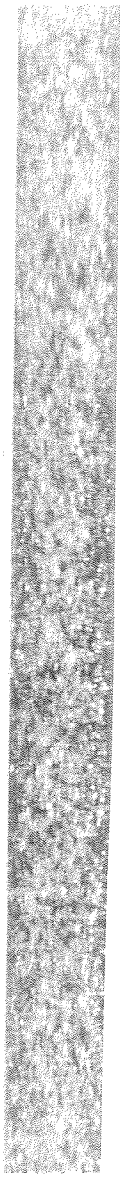
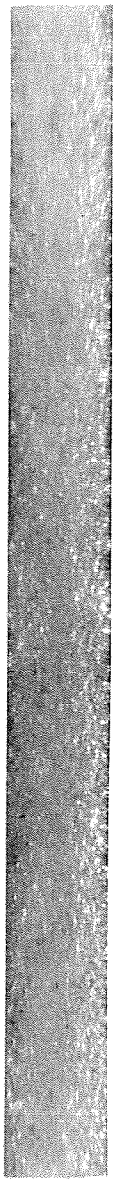
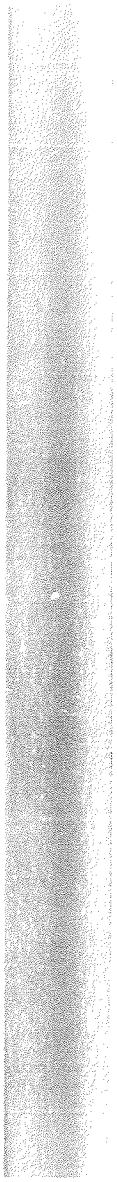
WATER - AIR	V_{SL} = 34.73 ft/sec (10.59 m/sec)			
V_{SG} ft/sec (m/sec)				
1.12 (0.34)	1.5 (0.46)	10.4 (3.17)	16.5 (5.03)	19.1 (5.82)
				
I	II	III	IV	V
BUBBLE	BUBBLE	BUBBLE - FROTH	FROTH	FROTH

FIG. 5.3(G)

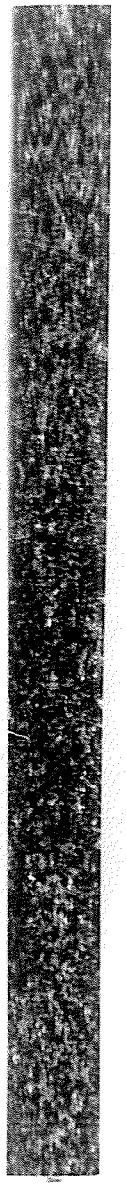
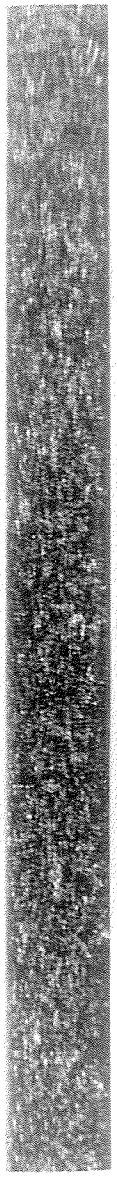
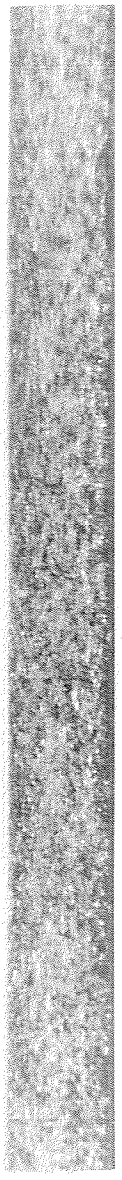
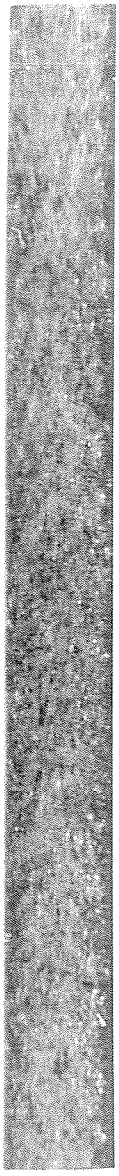
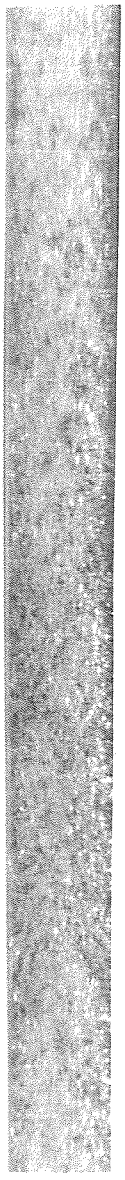
WATER - AIR	V_{SL} = 41.68 ft/sec (12.70 m/sec)			
V_{SG} ft/sec (m/sec)				
1.14 (0.35)	1.5 (0.46)	2.7 (0.82)	3.0 (0.91)	3.3 (1.00)
				
I	II	III	IV	V
BUBBLE	BUBBLE	BUBBLE	BUBBLE	BUBBLE

FIG. 5.3(H)

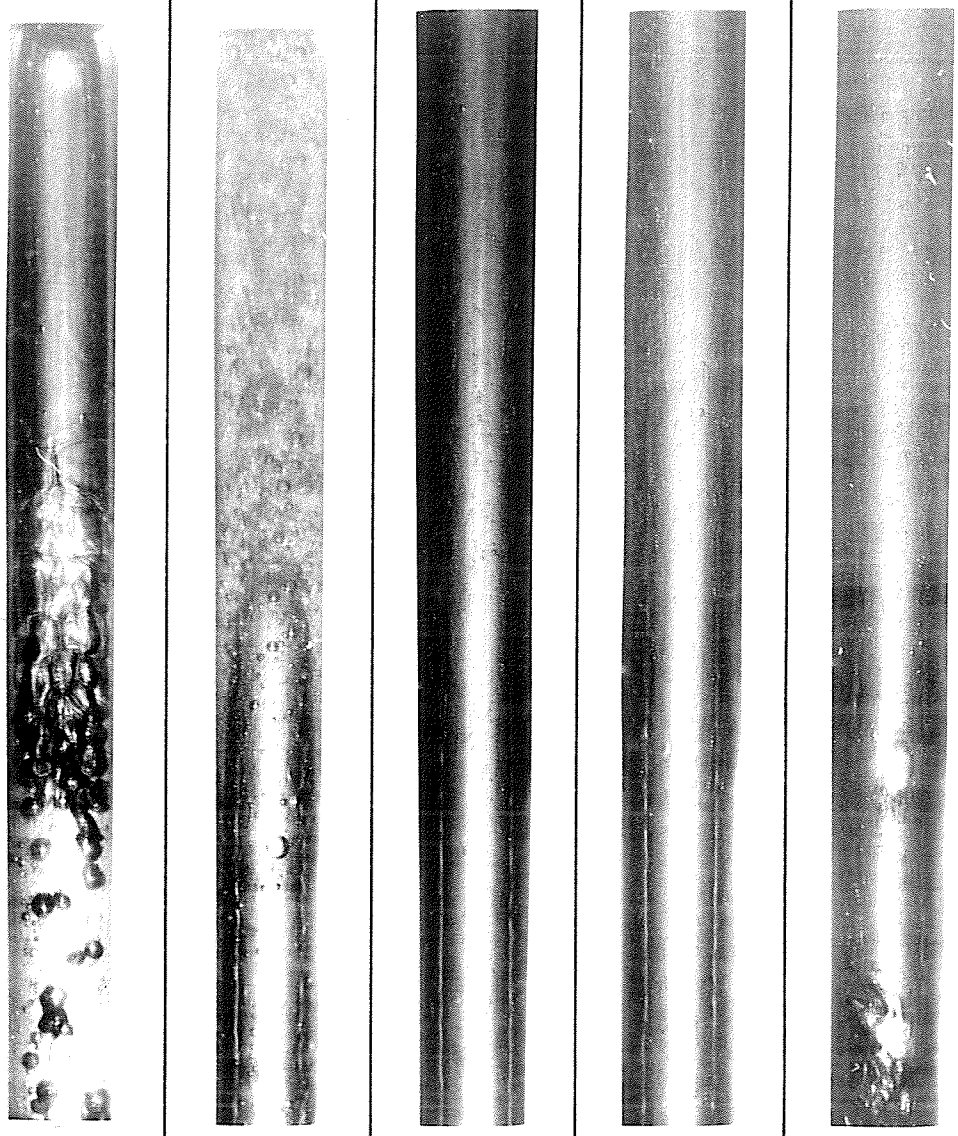
SURFACTANT SOL. - AIR	V_{SL} = 0.185 ft/sec (0.056 m/sec)			
V_{SG} ft / sec (m/sec)				
1.52 (0.46)	3.52 (1.07)	5.40 (1.65)	7.10 (2.16)	8.44 (2.57)
				
I	II	III	IV	V
SLUG	SLUG	SLUG	CHURN	CHURN

FIG. 5.4(A)

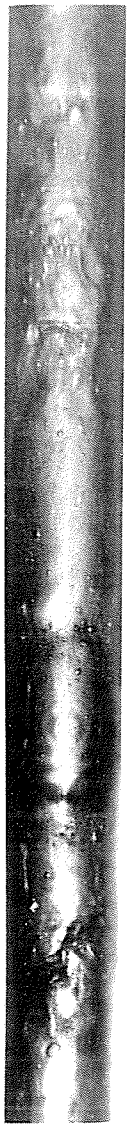
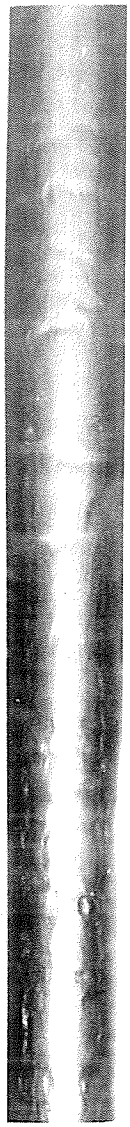
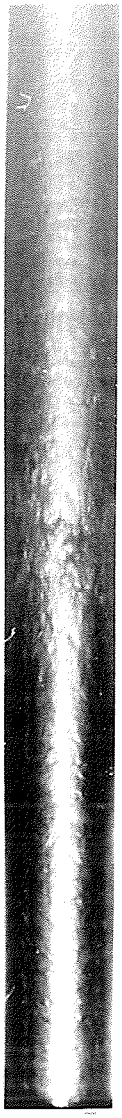
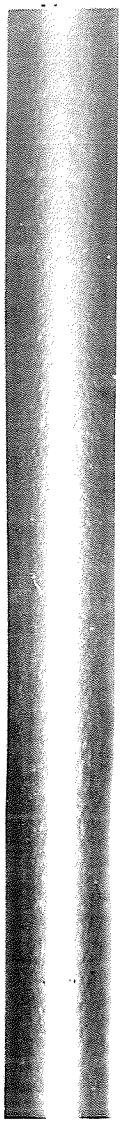
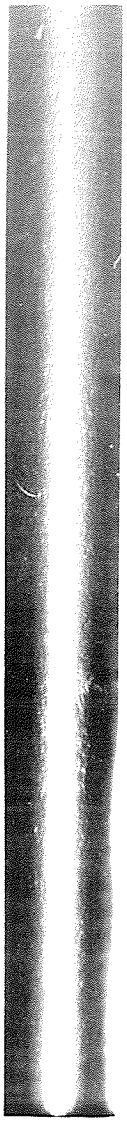
SURFACTANT SOL.–AIR	V_{SL} = 0.185 ft/sec (0.056 m/sec)			
V_{SG} ft / sec (m/sec)				
30.85 (9.40)	77.00 (23.50)	194.70 (59.34)	311.20 (94.85)	383.30 (116.83)
				
VI	VII	VIII	IX	X
CHURN–ANNULAR	ANNULAR	ANNULAR	ANNULAR	ANNULAR–MIST

FIG. 5.4(A) CONT.

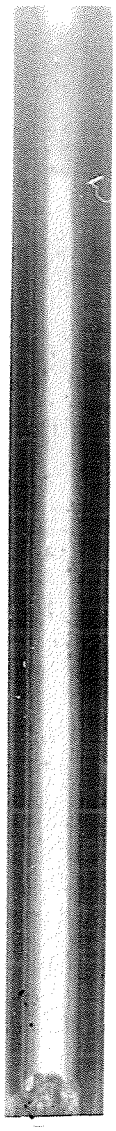
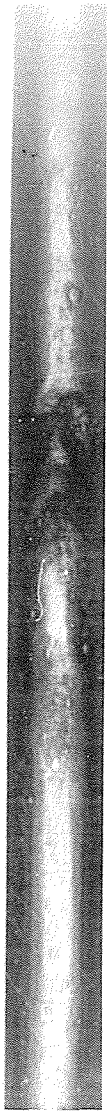
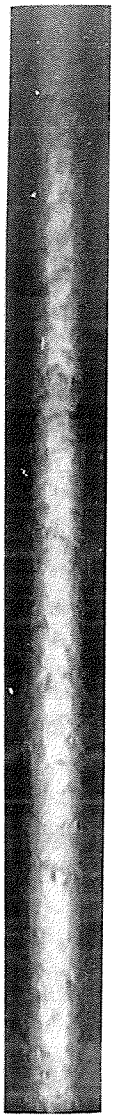
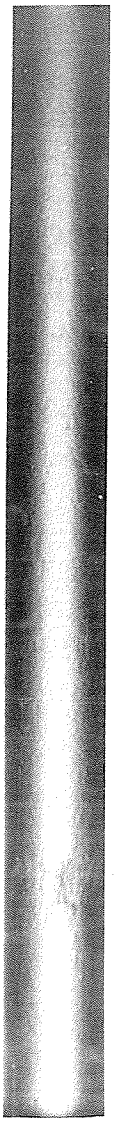
SURFACTANT SOL.- AIR	V_{SL} = 0.367 ft/sec (0.112 m/sec)			
V_{SG} ft/sec (m/sec)				
1.71 (0.52)	15.47 (4.72)	42.32 (12.90)	135.1 (41.18)	332.4 (101.32)
				
I	II	III	IV	V
SLUG	CHURN	ANNULAR	ANNULAR	ANNULAR-MIST

FIG. 5.4(B)

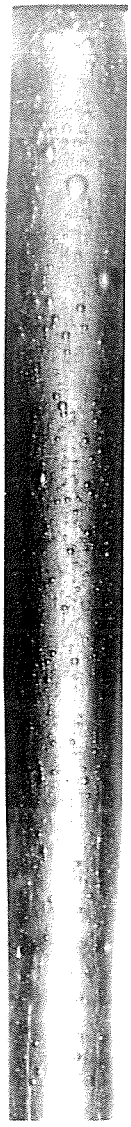
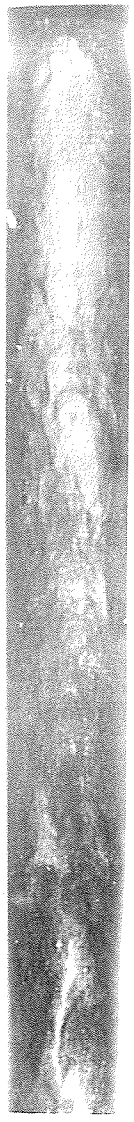
SURFACTANT SOL. - AIR	V_{SL} = 1.033 ft/sec (0.315 m/sec)			
V_{SG} ft / sec (m / sec)				
1.80 (0.55)	3.40 (1.04)	7.00 (2.13)	9.00 (2.74)	30.10 (9.17)
				
I	II	III	IV	V
BUBBLE	SLUG	SLUG	CHURN	CHURN - ANNULAR

FIG. 5.4(C)

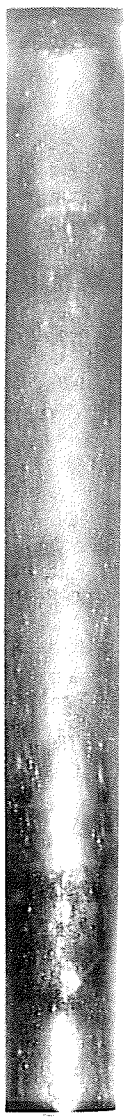
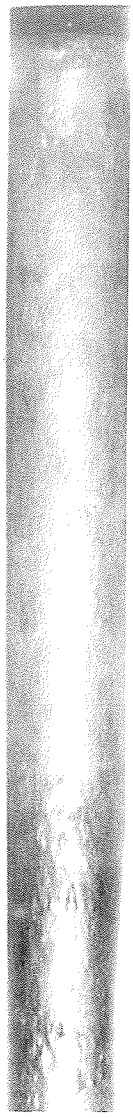
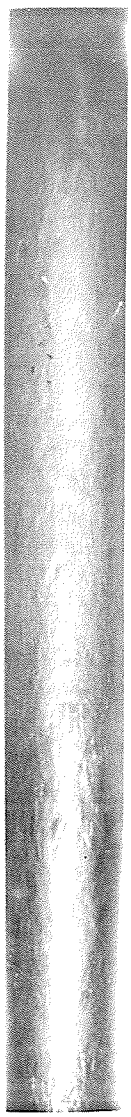
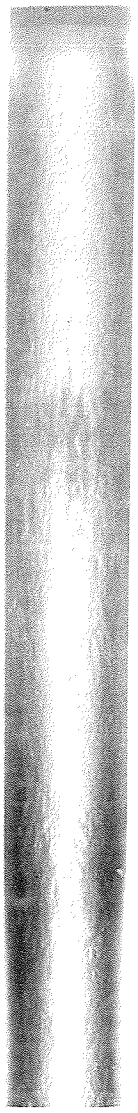
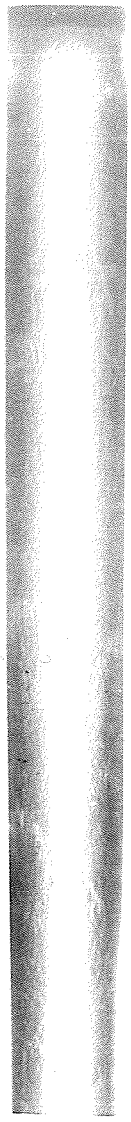
SURFACTANT SOL.-AIR	V_{SL} = 1.033 ft/sec (0.315 m/sec)			
V_{SG} ft/sec (m/sec)				
42.20 (12.86)	77.00 (23.47)	117.50 (35.81)	204.70 (62.39)	314.70 (95.92)
				
VI	VII	VIII	IX	X
ANNULAR	ANNULAR	ANNULAR	ANNULAR-MIST	ANNULAR-MIST

FIG. 5.4(C) CONT.

SURFACTANT SOL.- AIR	V_{SL} = 3.406 ft/sec (1.038 m/sec)			
V_{SG} ft/sec (m/sec)				
0.40 (0.12)	1.76 (0.54)	4.3 (1.31)	6.8 (2.07)	14.0 (4.27)
				
I	II	III	IV	V
BUBBLE	BUBBLE	BUBBLE	BUBBLE - SLUG	CHURN - ANNULAR

FIG. 5.4(D)

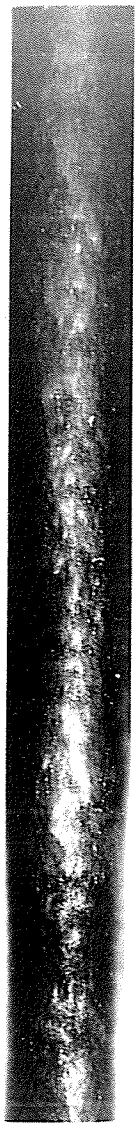
SURFACTANT SOL. - AIR		V_{SL} = 3.406 ft/sec (1.038 m / sec)		
V_{SG} ft / sec (m / sec)				
35.30 (10.76)	57.30 (17.47)	102.50 (31.24)	183.70 (56.00)	210.90 (64.28)
				
VI	VII	VIII	IX	X
ANNULAR	ANNULAR	ANNULAR	ANNULAR - MIST	ANNULAR - MIST

FIG. 5.4(D) CONT.

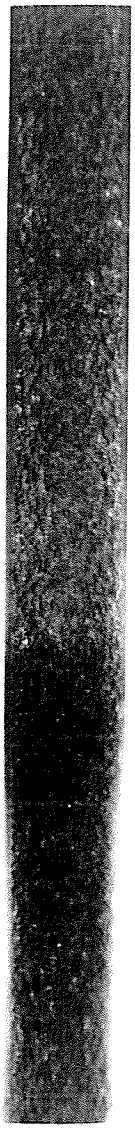
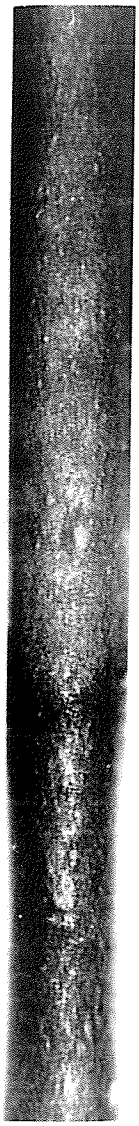
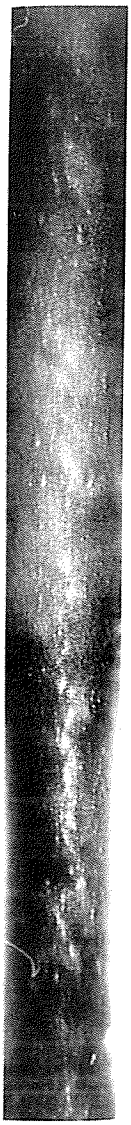
SURFACTANT SOL. - AIR	V_{SL} = 10.42 ft/sec (3.18 m/sec)			
V_{SG} ft/sec (m/sec)				
2.9 (0.9)	6.3 (1.92)	27.4 (8.35)	40.6 (12.37)	106.2 (32.37)
				
I	II	III	IV	V
BUBBLE	BUBBLE - FROTH	ANNULAR - FROTH	ANNULAR - FROTH	ANNULAR

FIG. 5.4(E)

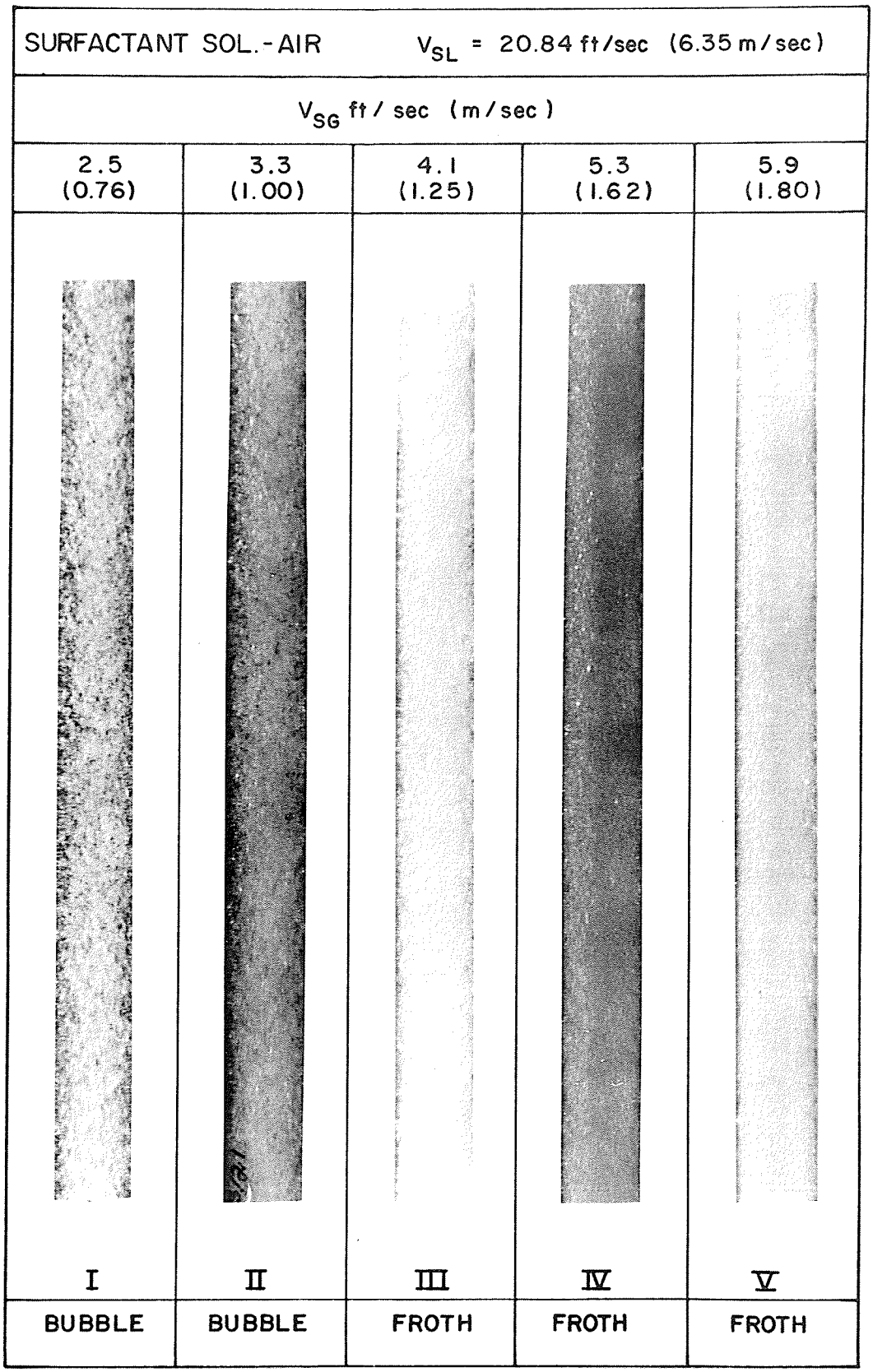

SURFACTANT SOL.-AIR
V_{SL} = 20.84 ft/sec (6.35 m/sec)
V_{SG} ft/sec (m/sec)
2.5 (0.76)
3.3 (1.00)
4.1 (1.25)
5.3 (1.62)
5.9 (1.80)
I
II
III
IV
V
BUBBLE
BUBBLE
FROTH
FROTH
FROTH

FIG. 5.4(F)

is difficult to identify the annular-mist flow transition just from the pictures because from pictures it looks like annular and by eye gives the impression of a mist. On the other hand, (at high liquid velocities) fast moving relatively long bubbles surrounded by small gas bubbles as shown in Fig. 5.3E (Frame Nos.(II-V) sometimes cannot be observed visually; the flow gives the impression of a bubble flow while the existence of long gas bubbles appear in the photographs. Therefore combination of recorded visual observations with and without the aid of stroboscope and the flow pattern photographs of each test were used to identify and report the flow patterns observed in this work. It should be noted that the appearance of a dark core in the photographs of froth flow; e.g. see Fig. 5.3 (F)-V, is due to the reflector which was employed to illuminate both sides of the tube as mentioned in Section 4.7. Therefore, these should not be confused with annular flow.

The surfactant produced significant effects on some flow pattern boundaries, which will be discussed in the following section. In addition to these changes, the surfactant also influenced the flow structure of the basic flow patterns in a number of ways. In slug flow, the number of small bubbles in the wake of the long bullet-shaped bubble as well as in the falling liquid film increased (compare Fig. 5.3 (C)-III and Fig. 5.4 (C)-II). In annular flow, more

gas bubbles penetrated the liquid film and produced a somewhat frothy film (see Fig. 5.3 (C)-VI and Fig. 5.4 (C)-VI). Also at higher liquid velocities, the surfactant sol.-air mixture was more frothy and the appearance of flow was more milky.

5.3.4 Flow Pattern Map

A flow pattern map is simply a two-dimensional coordinate system to represent different flow pattern regions along with their transition boundaries. The coordinates used to plot the map can be represented by simple measured variables such as mass flow rates and superficial velocities (23, 20, 43, 54) or by dimensionless groups (21). A wide variety of flow pattern maps for vertical upflow exist in the literature (21, 9, 23, 32, 20, 31, 43, 54), but a completely satisfactory map is still not available due to the complex mechanisms involved in two-phase flow. However, recently Taitel et al. (43) and Wiesman et al. (54) have attempted to generalize the prediction of transition boundaries. They have presented analytical expressions based on actual physical mechanisms governing these transitions.

Examination of the existing maps for vertical upflow reveals that for any given system, the major factor determining the flow pattern is the relative velocities of gas and liquid

phases. The fluid properties and pipe diameter are other parameters affecting the flow patterns. A comprehensive study on the effect of fluid properties and pipe diameter on flow pattern in horizontal lines has been made by Weismen et al. (53). On the basis of the results of this investigation and some new data obtained for vertical upflow, Weismen et al. (54) believe that liquid properties have small effects on flow patterns. Govier et al. (19) and recently Taitel et al. (43) have reported the influence of pipe diameter on flow patterns. Previous results obtained by Vijay (48) and Aggour (1) on the effect of fluid properties, using the present experimental facility, indicate that the effect of liquid viscosity is negligible (48), while Aggour (1) suggested that further data are required before a definitive statement can be made on the effect (if any) of the gas-phase density on the various transitions.

Superficial liquid velocity V_{SL} and superficial gas velocity V_{SG} were selected as mapping parameters to represent the present experimental observations of flow patterns. The maps based on the data obtained from the water-air and surfactant solution-air systems were determined and are shown in Fig. 5.5 and Fig. 5.6 respectively. It can be seen from Figs. 5.5 and 5.6 that the same liquid flow rates were selected for both systems in order to make a comparison. However, it was not possible to obtain data beyond V_{SL} = 21 ft/sec (6.48 m/sec)

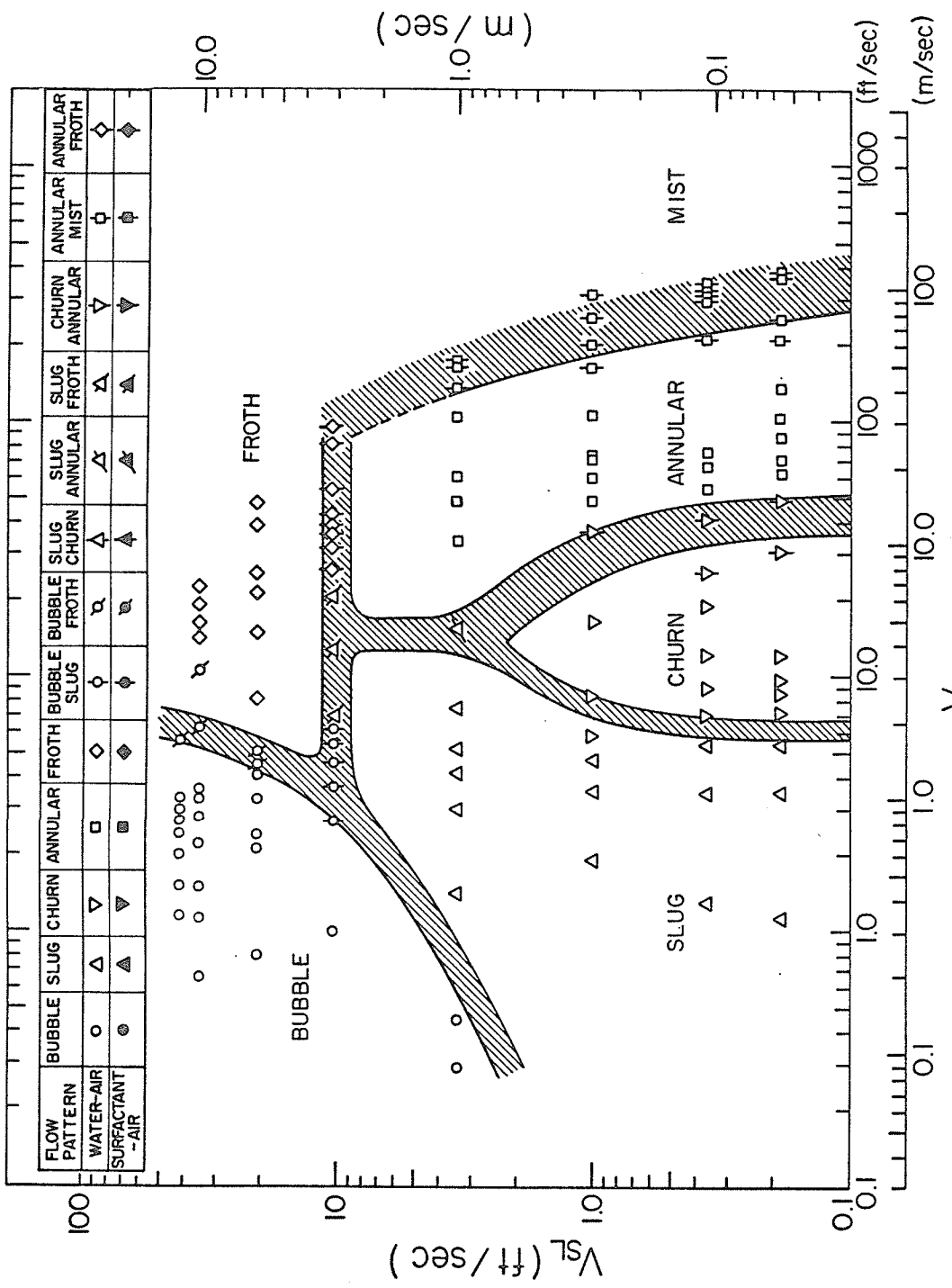


Fig.5.5 Water-Air Flow Pattern Data Based on Superficial Velocities

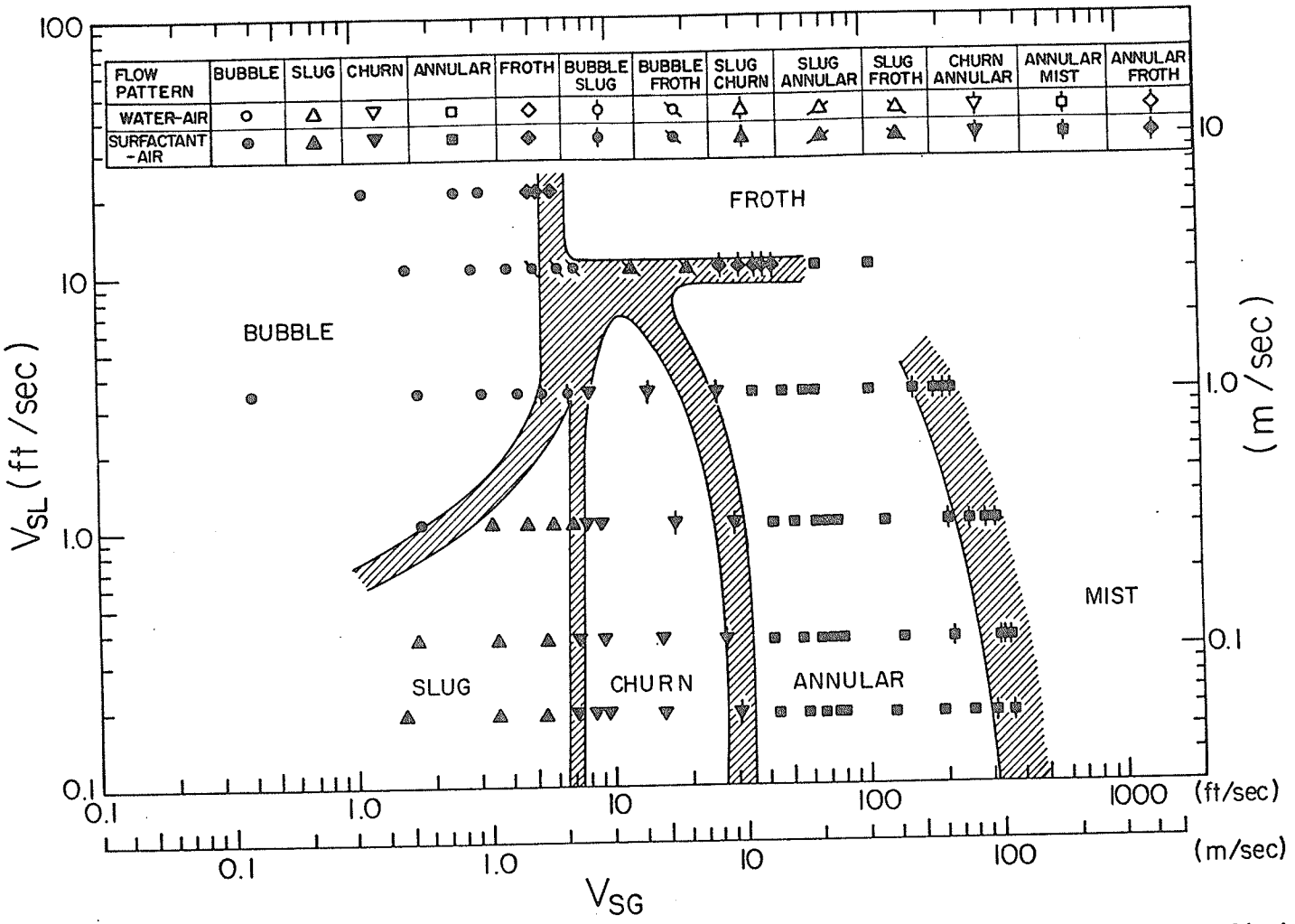


Fig. 5.6 Surfactant Solution-Air Flow Pattern Data Based on Superficial Velocities

for surfactant sol.-air system due to the foaming problem. Any individual symbol on the map corresponds to the flow pattern (or transition condition) which occurred at a particular setting of liquid and air flow rates. The transition regions have been shown by shaded bands in Figs. 5.5 and 5.6.

To demonstrate the effect of surface tension on flow pattern transitions, both sets of data are plotted on the same map and are shown in Fig. 5.7. The regions where major differences were observed have been marked with shaded lines. It can be observed from Fig. 5.7 that the slug-churn, churn-annular, annular-mist and bubble-froth transitions are essentially unchanged. The only boundary significantly affected by the addition of surfactant is the bubble-slug boundary. At V_{SL} = 1.03 ft/sec (0.314 m/sec) the first point with surfactant appears as bubble flow whereas, it was slug flow for water-air (compare Fig. 5.3 (C)-II and 5.4 (C)-I). At V_{SL} = 3.41 ft/sec (1.039 m/sec), the region formerly occupied by slug flow is now occupied by the bubble flow. Figure 5.7 indicates that the slug region has shrunk by the addition of surfactant. The appearance of bubble flow instead of slug flow by the addition of surfactant can possibly be explained by considering the physical mechanism governing the bubble-slug transition. The transition from bubble to slug flow requires a sequence of the following processes: bubble

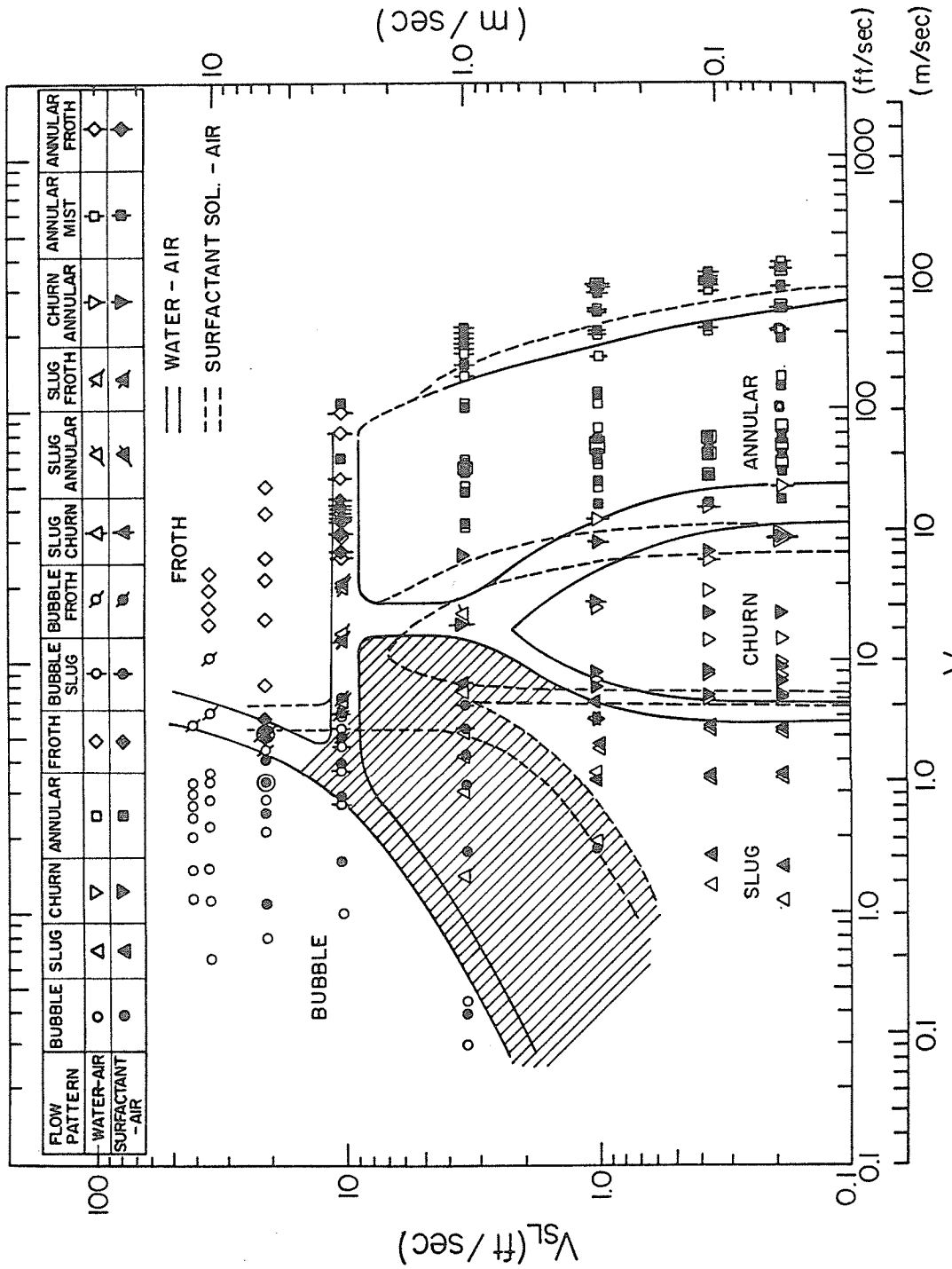


Fig. 5.7 Combined Flow Pattern Data of Water-Air and Surfactant Solution-Air Mixtures

coalescence or agglomeration results in the formation of relatively large bubbles and eventually in the formation of bubbles long enough to give stable slug flow. In the case of the presence of surfactant, an interfacial contamination is produced which tends to prevent coalescence of bubbles even if they approach each other and as a result, stable bubbles exist (see References 8, 24, 11 and 25). It has been reported by Hewitt (8, 25) that bubble flow can exist, depending on the concentration of surfactant, up to very high void fractions. Therefore it can be concluded that one would expect the location of bubble-slug boundary to depend on the concentration of surfactant. The flow pattern boundaries were insensitive to surfactant at high liquid and air velocities, a plausible explanation being that under these conditions, other forces (e.g. dispersion and inertia) are large enough to overcome the influence of the surface tension forces.

5.3.5 Comparison of Flow Pattern Maps

Some of the existing flow pattern maps for vertical upflow were studied (21, 9, 23, 32, 20, 43, 54) and a lack of agreement in the description and classification of the flow patterns was observed. Also discrepancies in the transition boundaries were noted. It was also observed that all the

flow pattern maps except (54) are restricted to lower liquid flow rates i.e. V_{SL} < 10.0 ft/sec (3.05 m/sec). Weisman et al. (54), with the exception of Vijay (48) and Aggour (1), are the first authors, who have presented a map for vertical flow which covers a region at high liquid velocities i.e. V_{SL} > 10.0 ft/sec (3.05 m/sec) which they call a dispersed flow region. This map is a modified version of their earlier map (53) proposed for horizontal flow. In order to maintain a consistency between these two maps, the authors have defined four basic flow patterns for vertical flow; these are bubble, intermittent (slug + churn), annular and dispersed ("froth of bubbles in liquid" and mist) flow. They also presented correlations for each transition.

In certain regions, the map lacks some specificity and it is felt that the utility of the map could be enhanced if the following recommendations are taken into account.

(i) The slug-churn transition is defined.

(ii) A distinction is made between the froth (which they define as a "froth of bubbles in liquid") and mist flow (mist of droplets suspended in gas), since representing these two inherently different flow patterns in one region may be confusing. By looking at their map, one gets the impression that mist flow

would appear only at V_{SL} > 10.0 ft/sec (3.048 m/sec); this may be true, but to date there is no experimental evidence available for this assumption. The present and various other studies (48, 1, 33) suggest that mist flow would appear just after annular flow for a fixed liquid flow rate. Taking this suggestion into consideration would result in defining an annular-mist transition on their map. Since this map was published very recently (during the preparation of this thesis) and also the authors' comments on the limitation of the map were unclear (explicitly probably not for use of lines smaller than 2.5 cm, implicitly it was not clear), therefore a comparison of this map with the present flow patterns was not made. However, it is recommended that in future this map should be tested against the present and previous flow pattern data (48, 1) obtained from the same facility, since these data cover a region where no other data exist.

Oya (32) reports very few flow pattern data for liquids (surfactant solution, solvent and gasoline) having lower surface tension for two-phase, two-component (gas-liquid) flow in a vertical tube. These liquids were mainly used to study a flow pattern which he calls "fish-scale-type slug flow" (the author describes nine different flow patterns for vertical flow). The flow patterns for these liquids were observed in a tube having a diameter of 0.12 inch (3 mm). A comparison between his (32) data and the present work was not made mainly

because in the present work fish-scale-type slug flow was not observed; also there was a big difference in the diameter of the tubes used by him (0.12 inch, 3 mm) and the present one (0.46 inch, 11.68 mm).

The present observation of flow patterns were compared with the Govier and Aziz map (20) and the map proposed by Taitel et al. (43). The Govier and Aziz map which is based upon the water-air data of Govier et al. (18) and correlations of Brown et al. (7) and Duns and Ros (13) was selected because the previous data (48, 1) obtained from the present experimental apparatus were compared with this map. The data of the present investigation is superimposed on the generalized flow pattern map of Govier and Aziz in Fig. 5.8 where the parameters $Y^* V_{SL}$, the modified superficial liquid velocity, and $X^* V_{SG}$, the modified superficial gas velocity, have been used as mapping coordinates, the definitions of Y^* and X^* being

$$Y^* = \left\{\frac{\rho_L \sigma_{wA}}{\rho_w \sigma_{LG}}\right\}^{1/4} \tag{5.6}$$

and

$$X^* = Y^* \left\{\frac{\rho_G}{\rho_A}\right\}^{1/3} \tag{5.7}$$

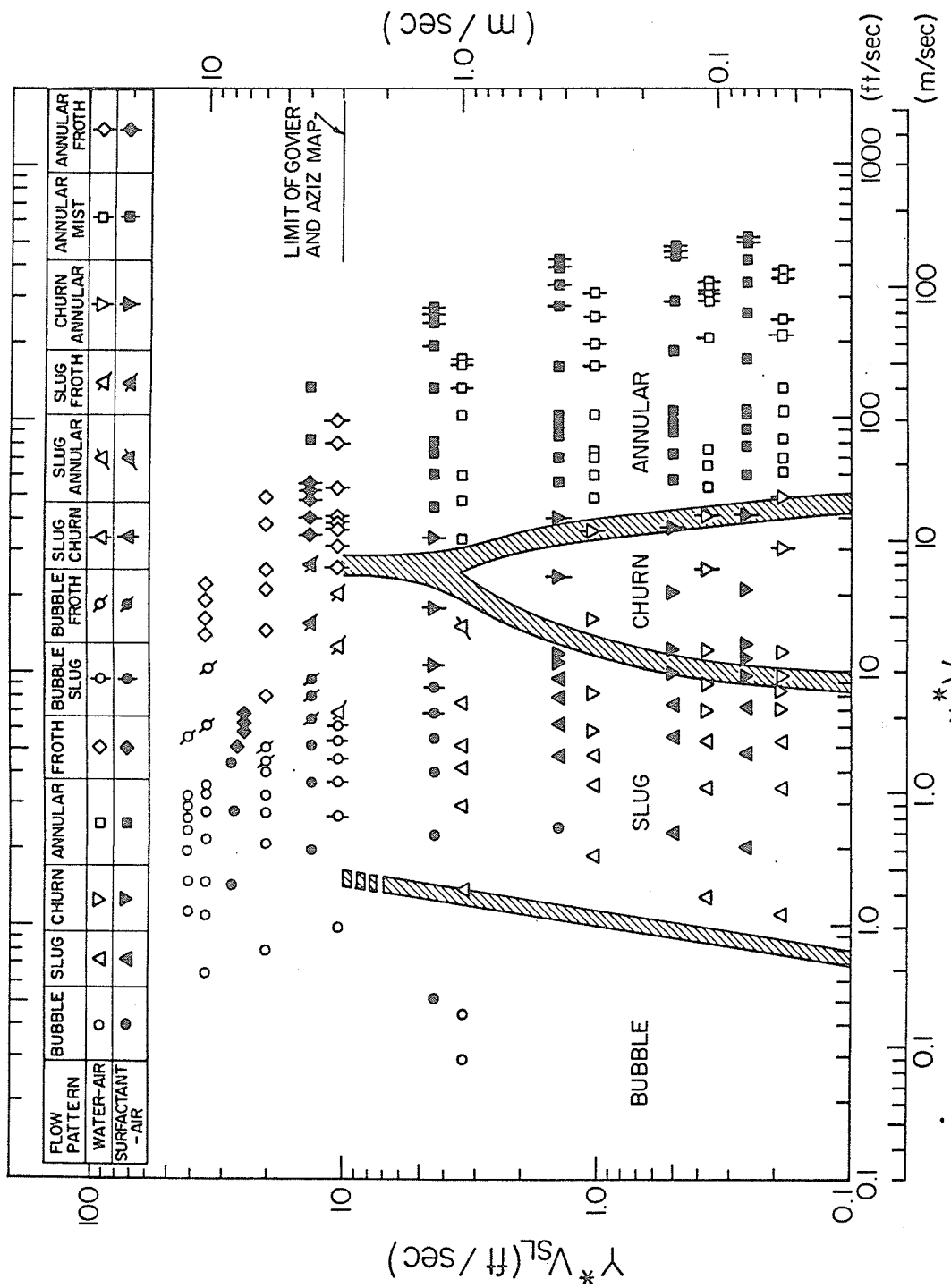


Fig. 5.8 Comparison Between Present Data and The Flow Pattern Map of Govier and Aziz for Vertical Flow

where

σ_{wA} is the surface tension of the water-air system,

σ_{LG} is the surface tension of the liquid-gas system under flowing condition,

ρ_L is the density of liquid under flowing condition,

ρ_W is the density of water at standard conditions (14.7 psia and 60°F)

ρ_G is the density of gas under flowing condition,

ρ_A is the density of air at standard conditions, (14.7 psia and 60°F).

The original map delineates four basic flow regions; these are bubble, slug, churn (they use the term "froth") and a region covering both the present annular and mist flows (they use the term "annular-mist" for the region) is the transitions are represented by shaded bands of finite width. The map is restricted to a modified liquid velocity of $Y^* V_{SL}$ = 10 ft/sec, this would be approximately 10 ft/sec in a water-air system. A comparison between the data and the map suggests that at low-to-moderate fluid rates, the mapping parameters (which include a surface tension term) do not accommodate the effect of reduced surface tension produced by adding a surfactant into the water. Based on the present water-air data, the bubble-slug boundary cannot be tested at lower fluid rates since

more data is needed at $V_{SL} < 1.0$ ft/sec (0.305 m/sec). The agreement between other boundaries and the present data could be considered as very good, especially when one considers that some of the boundaries are quite subjective.

The second map selected for the prupose of comparison is the one recently proposed by Taitel et al. (43) for vertical flow of gas-liquid mixtures. They report theoretical predictions for transition boundaries of four basic flow patterns observed in vertical flow, viz bubble, slug, churn and annular. The transition boundaries drawn in Fig. 5.9 were computed from the following Taitel et al. transition equations in order to generate their map for the present test conditions.

Bubble-Churn Transition C

$$V_{SL} = 0.923\ V_{SG} - 0.734 \left\{\frac{g(\rho_L - \rho_G)\ \sigma g_c}{(\rho_L)^2}\right\}^{0.25} \qquad (5.8)$$

Bubble-Slug Transition B

$$V_{SL} + V_{SG} = 4.0 \left[\left\{\frac{D^{0.429} \left(\frac{\sigma g_c}{\rho_L}\right)^{0.089}}{\nu_L 0.072}\right\} \left\{\frac{g\ (\rho_L - \rho_G)}{\rho_L}\right\}^{0.446}\right] . \qquad (5.9)$$

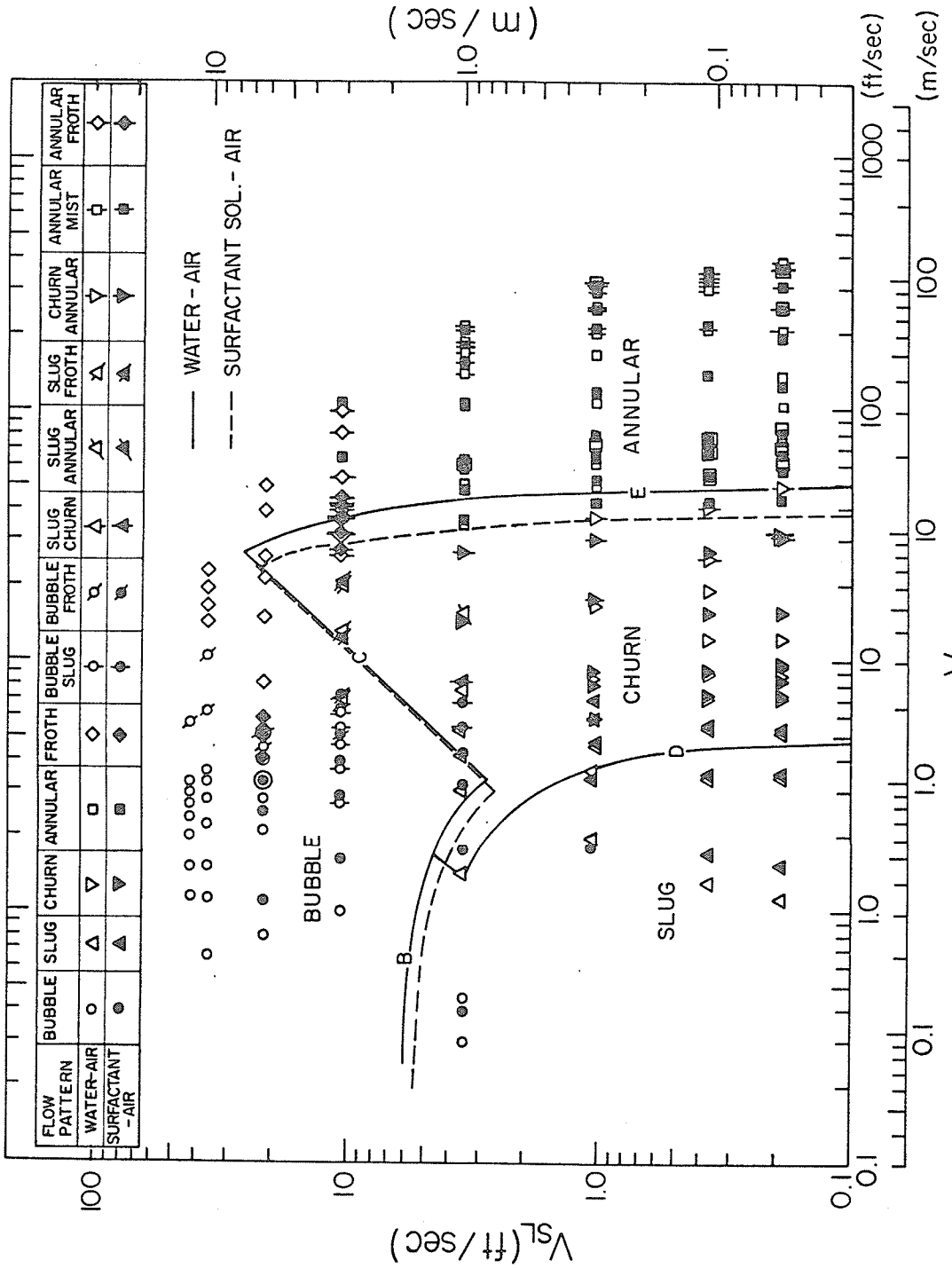


Fig. 5.9 Comparison Between Present Experimental Data and The Flow Pattern Map of Taitel et al. for Vertical Upflow

Slug-Churn Transition D

$$\frac{\ell_E}{D} = 40.6 \left\{\frac{V_{SL} + V_{SG}}{\sqrt{gD}} + 0.22\right\} \qquad (5.10)$$

$\frac{\ell_E}{D}$ = 182.6 for present visualization section.

Churn-Annular Transition E

$$\frac{V_{SG}\ \rho_G^{0.5}}{[\sigma\ g\ (\rho_L - \rho_G)\ g_c]^{0.25}} = 3.1 \qquad (5.11)$$

The solid lines in Fig. 5.9 represent transition boundaries for the water-air system while the dashed lines represent those for the surfactant solution-air system. The experimental data observed in the present work is also superimposed on the Taitel et al. (43) map in Fig. 5.9.

For bubble-slug transition, Taitel et al. suggest that bubble flow cannot exist below the curve B (see Fig. 5.9) in systems having small-diameter tubes, the criterion for "small diameter" being that

$$\left\{\frac{\rho_L^2\ g\ D^2}{g_c\ (\rho_L - \rho_a)\ \sigma}\right\}^{0.25} \leq 4.36 \ . \qquad (5.12)$$

According to Eq. (5.12) the present experimental facility falls in the category of "small diameter tube", however, it can be observed from Fig. 5.9 that a few data points for bubble flow, admittedly close to the transition B, exist below curve B. The earlier work (48) conducted on the present experimental facility also reports a few data points for bubble flow which fall below this curve. The present investigation does not cover data at the lower end of V_{SG} for V_{SL} < 3.41 ft/sec (1.039 m/sec), therefore, more data are needed at the lower end of V_{SG} to confirm the existence or non-existence of bubble flow below curve B. The slug-churn transition gave a moderate agreement with the data at low liquid velocities while large differences were observed at V_{SL} > 1.0 ft/sec (0.305 m/sec). It should be noted that similar observations were made by Taitel et al. (43) when they attempted to correlate their own experimental data with this transition. They attributed this discrepancy to the difficulty in discriminating between slug and churn flow at high liquid flows. Present data suggest that the oscillatory motion of churn flow reduces as the liquid velocity is increased. Their data suggest that this slug-churn transition is independent of liquid flow rate.

The agreement between the transition E for annular flow and the present data is excellent provided the changes

appearing in the gas phase density with increasing liquid flow rates are considered. In Eq.(5.11), ρ_G appears to the power of 0.5 and therefore, at least theoretically, has a significant effect. In the paper (43), to compare their data, Taitel et al. have plotted this transition as if ρ_G were constant during the experiments. They evaluated ρ_G at 14.7 psia and 77°F which may not be the real value, since the pressure in the test section, no doubt, would be higher than the atmospheric pressure. The conditions for a constant ρ_G can be achieved if the inlet pressure to the test section is controlled and ρ_G is calculated at the mean pressure.

At higher liquid velocities, their bubble region also contained the present froth flow.

It can be concluded from the material presented in this section that to date no satisfactory map exists for vertical flow of gas-liquid mixtures. Maps based on experimental data are restricted to lower liquid flow rates while the analytical correlations are not sufficient to predict the transition boundaries accurately. Based on the present experimental data which covers high liquid flow rates where few other data exist, it is suggested that if a single map is to be desired for vertical flow, it should generally have the shape for the transition lines shown on Fig. 5.5

5.4 Two-Phase Frictional Pressure Drop

The total pressure drop during two-phase flow in a vertical tube can be regarded as the sum of three components, i.e.

$$\Delta P = \Delta P_{TPF} + \Delta P_{TPG} + \Delta P_{TPA} \tag{5.13}$$

where

ΔP is total pressure drop,

ΔP_{TPF} is the frictional component,

ΔP_{TPG} is the gravitational component, and

ΔP_{TPA} is the accelerational pressure drop.

The accelerational pressure drop can be assumed negligible (48). Then effectively the total pressure drop is made up of two components, i.e.

$$\Delta P = \Delta P_{TPF} + \Delta P_{TPG} \quad . \tag{5.14}$$

The gravitational component is simply the static head in the test section and is given by

$$\Delta P_{TPG} = \{\rho_L (1 - \alpha) + \rho_G (\alpha)\} L \frac{g}{g_c} \tag{5.15}$$

where

α is the void fraction.

The void fraction correlation of Chisholm (10) was used to predict the void fraction as explained in Appendix C. The total pressure drops were measured on manometers also as explained in Appendix C; then Eq.(5.14) was employed to calculate ΔP_{TPF}.

5.4.1 Discussion of Results

The two-phase frictional pressure drop data are plotted in Fig. 5.10 for water-air and in Fig. 5.11 for surfactant solution-air system. In the figures, the frictional pressure drop is plotted against V_{SG} with V_{SL} as the parameter. The code letters (see Table 5.2) appearing beside the data points in Figs. 5.10 and 5.11 indicate the observed flow pattern. In general, $\Delta P_{TPF} \sim V_{SG}$ profiles are similar to those already reported in References (18, 19, 7, 48, 1). The changes in the slope of the curves are generally associated with the flow pattern transitions observed in the present work.

At low liquid and gas flow rates, in slug and churn flow, the fluctuations in the inverted manometer were so high that it was not possible to read the total pressure drop with reasonable accuracy. Also under the same conditions, the total pressure drop became almost equal to the static head and the frictional pressure drop was then extremely small and in some cases gave negative values, probably due to the

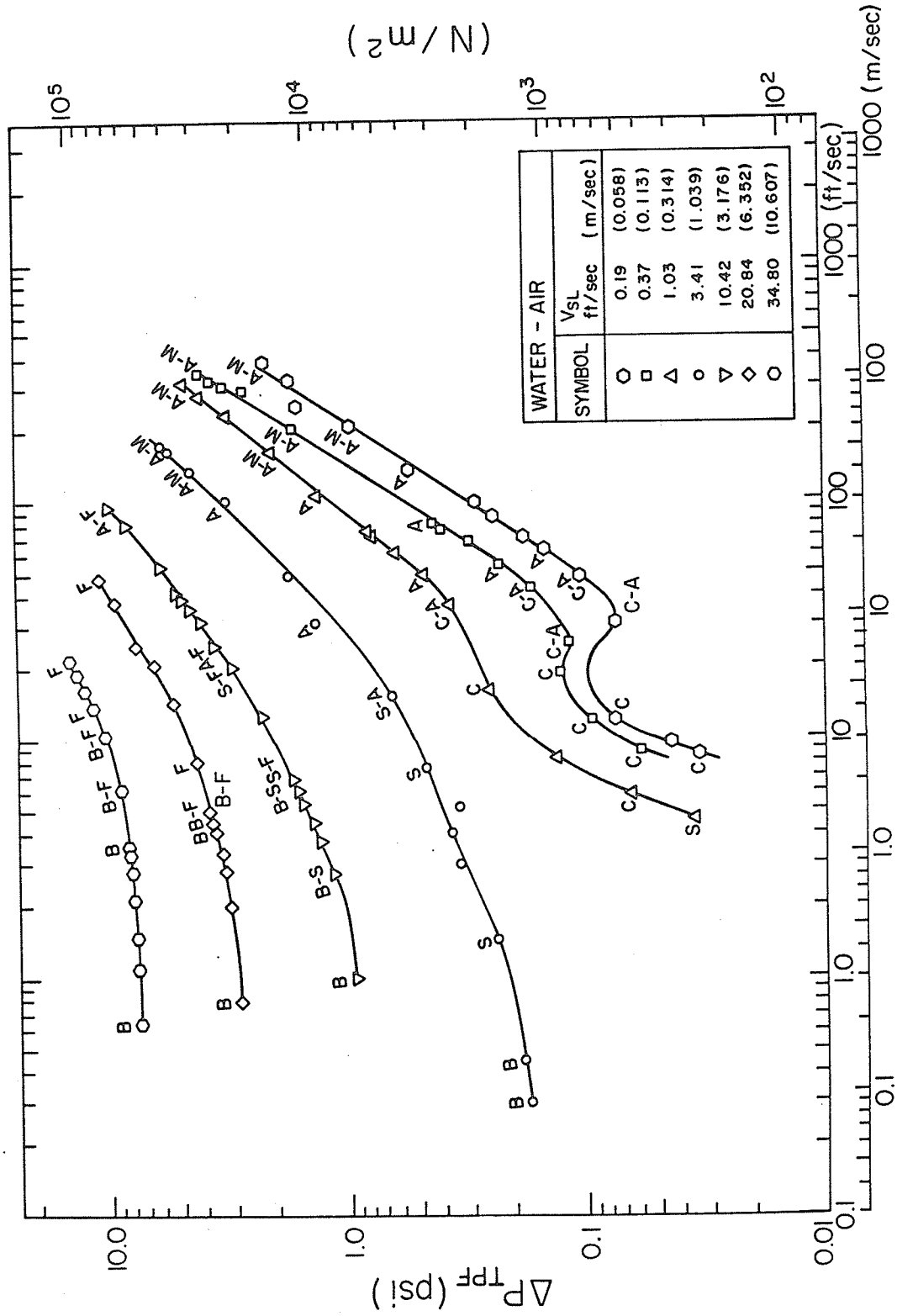


Fig. 5.10 Frictional Pressure Drop Data for Water-Air System

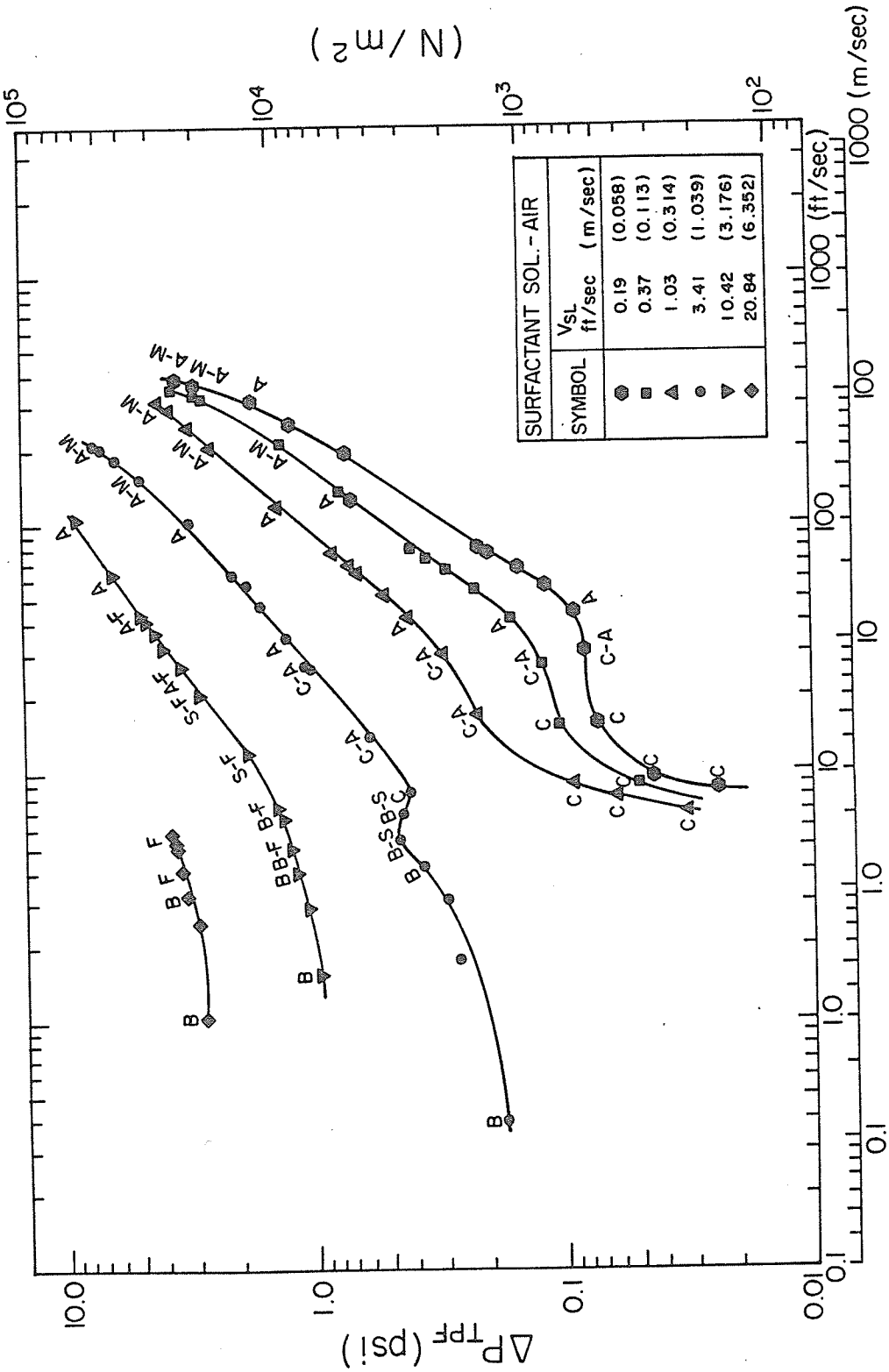


Fig. 5.11 Frictional Pressure Drop Data for Surfactant Solution-Air System

downflow of liquid film on the wall in these flow patterns (48, 1, 40, 45). The frictional pressure drop data under these conditions for which $\Delta P_{TPF} < 0.2$ in (0.51 cm) of water (approximately 0.01 psi) were regarded as unreliable and therefore were excluded.

In order to demonstrate the effect of surface tension on frictional pressure drop, both sets of data for water-air and surfactant solution-air are included in Fig. 5.12. Examination of Fig. 5.12 indicates that at low liquid flow rates, i.e. V_{SL} = 0.19, 0.37 and 1.03 ft/sec (0.058, 0.113 and 0.314 m/sec), some differences exist at the lower end of V_{SG} (approximately up to V_{SG} = 25 ft/sec) between both sets of data and no, or very little, effects are observed for $V_{SG} > 25$ ft/sec (7.62 m/sec). These differences appearing at low liquid and air flow rates could be real because under these conditions, among various forces, surface tension forces may be more influencing. However, under these conditions of low liquid and air flow rates (slug flow), the pressure drop measurements may not be very accurate because of the large fluctuations in the manometer reading; therefore, it would be risky to attribute these changes to the surface tension. In the present investigation frictional pressure drop is obtained by subtracting the static head from the measured total pressure drop, an error might be introduced due to void

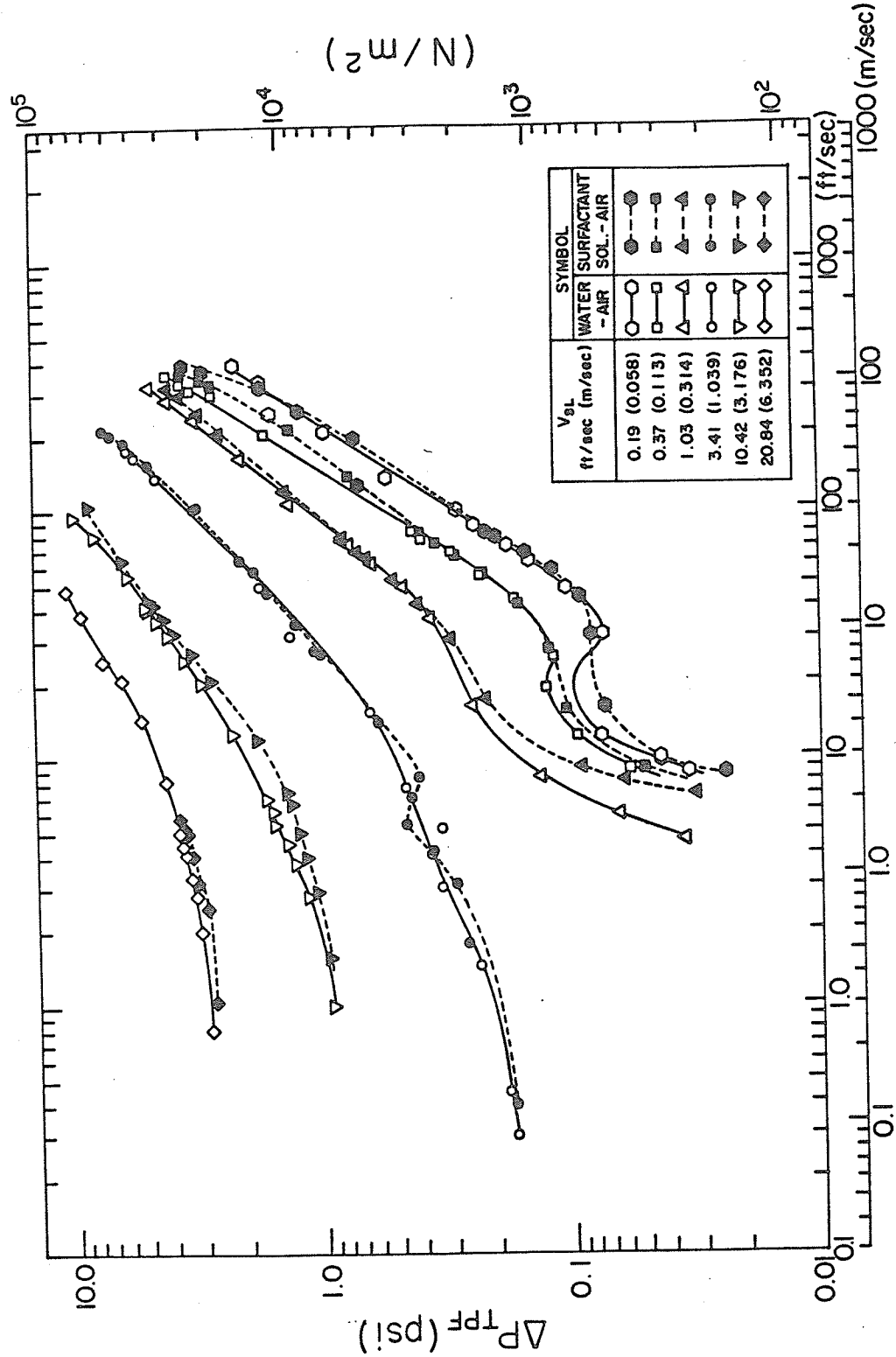


Fig. 5.12 Combined Plot of Frictional Pressure Drop Results for Both Liquid-Air Mixtures

fraction since a calculated value obtained from the same equation is used for both liquid-air systems as opposed to a measured value. The difference appearing at V_{SL} = 3.41 ft/sec (1.039 m/sec) and $V_{SG} \approx$ 5.2 ft/sec (1.676 m/sec) just based on a single point cannot be attributed to the surface tension, especially when these points lie in a region where conditions are highly unsteady. Examination of Fig. 5.12 indicates that in general there is a tendency in the surfactant data to be lower than that of water-air data, which suggests a reversed trend in the water-air data point at V_{SL} = 3.41 ft/sec (1.039 m/sec) and $V_{SG} \approx$ 5.2 ft.sec (1.59 m/sec). At V_{SL} = 10.42 ft/sec (3.176 m/sec), significant differences appear mainly where a change in the flow pattern was observed

So far as the present author is aware, very limited (55, 45) study has been made on the effect of surface tension on the frictional pressure drop for two-phase, gas-liquid mixtures flowing in vertical tubes. Whalley et al. (55) used a liquid (Genklene) having lower surface tension than that of water in order to study the effect of surface tension on various hydrodynamic aspects and quoted values for total pressure drop. Ueda (45) studied the effect of surface tension on frictional pressure drop by using an aqueous-surfactant-solution. The lowest value obtained for surface tension was 33.94 dyne/cm. For a fixed V_{SL} = 1.55 ft/sec

(0.472 m/sec), the range of V_{SG} was 1.15 ft/sec (0.35 m/sec) - 14.24 ft/sec (4.34 m/sec). Ueda (45) concluded that surface tension has very little effect on frictional pressure drop. Examination of his data plotted on a small scale in the paper (45) indicated that, if anything, there is a tendency in the surfactant solution data to be slightly lower than that of the water-air data. In the present investigation a similar trend was observed in general (see Fig. 5.12). Therefore it can be concluded that surface tension produced little effect on the frictional pressure drop, ΔP_{TPF} being slightly lower for the surfactant solution than for the water-air system where differences exist.

CHAPTER 6

PRESENTATION AND DISCUSSION OF HEAT TRANSFER RESULTS

6.1 Introductory Remarks

This Chapter deals with the heat transfer results obtained in the present investigation. The single-phase heat transfer results are presented first and compared with the well-known theories and correlations. Then the two-phase heat transfer results are presented and discussed. The local heat transfer data are then compared with the modified theory of Spalding (41) in the manner proposed in Reference (48). The mean heat transfer data are then tested against some of the existing correlations. As a result of this comparison, a correlation proposed by Aggour (1) is recommended for use.

The calculation procedure is given in Appendix C and the complete set of data are tabulated in Appendix D.

6.2 Single-Phase Heat Transfer Results

As already mentioned in Section 5.2, single-phase experiments were performed in order to ensure the continued satisfactory performance of the experimental apparatus. The

single-phase heat transfer results are presented in this section. The local heat-transfer coefficients are presented first and compared with the theories of Worsoe-Shmidt (56) and Siegel et al. (38) for laminar flow and the Spalding theory (41) and Hausen's correlation (14) for turbulent flow. The mean heat transfer data are presented next and compared with the well known Seider-Tate correlation (39) and semi-theoretical solution (2) for laminar flow and with the empirical correlation recommended by Kays (26) for turbulent flow.

6.2.1 Local Heat Transfer Results

The local heat-transfer coefficients were calculated at seven different elevations along the test section by the following equation, as discussed in Appendix C.

$$h_{SP} = \frac{q_w}{T_w - T_B} \tag{6.1}$$

where q_w, T_w and T_B are measured variables.

These local heat-transfer coefficients are shown in Fig. 6.1, plotted as a function of location along the test section with Re_{SL} as a parameter. The $h_{SP} \sim Z$ profiles appear to have the same shape as predicted by the single-

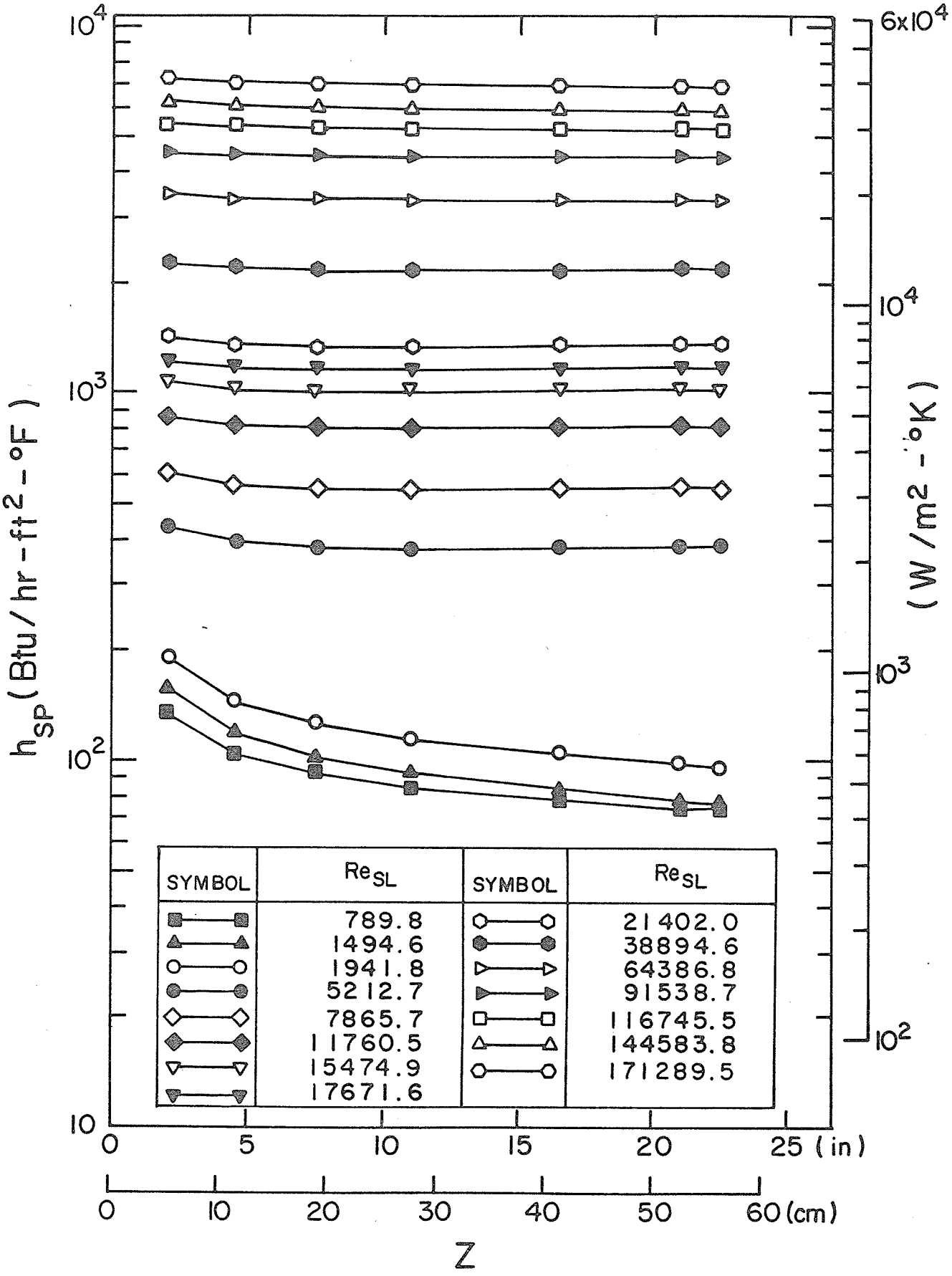


Fig. 6.1 Single Phase Local Heat Transfer Data

phase heat transfer theories, therefore suggesting a qualitative agreement between the experimental data and the single-phase heat transfer theory.

The single-phase heat transfer data were compared with the following theories and this quantitative comparison is given below.

1. Laminar Flow: ($Re_{SL} < 2,000$)

(i) Worsoe-Schmidt (56)

In the paper, the governing differential equations were solved by using finite differences and the solutions were presented in the form of tables, listing Nu_{SP} against $\bar{Z}$, where

$$\bar{Z} = \frac{4\ (Z/D)}{Re_{SL} Pr_L} \tag{6.2}$$

(ii) Seigel et al. (38)

The solution was presented in the form of infinite series as given below.

$$Nu_{SP}\ (Z') = \{\frac{11}{48} - \frac{1}{2} \sum_{m=1}^{\alpha} \frac{\exp\ (-\gamma_m^2\ Z')}{A_m\ \gamma_m}\}^{-1} \tag{6.3}$$

where

$$Z' = \frac{2\ (Z/D)}{Re_{SL}\ Pr_L} \quad . \qquad (6.4)$$

The constants and the eigenvalues for the infinite series are tabulated below.

TABLE 6.1 Values of A_m and γ_m in Equation 6.3

m	A_m	γ_m
1	7.630×10^{-3}	25.68
2	2.058×10^{-3}	83.86
3	0.901×10^{-3}	174.2
4	0.487×10^{-3}	296.5
5	0.297×10^{-3}	450.9
for larger m,	$\gamma_m = 4\ m + \frac{4}{3}$ $A_m = 0.358\ \gamma_m^{-2.32}$	

2. Turbulent Flow:

(i) Spalding's Theory (41)

The following expression is recommended by Spalding to be valid for the entire range of Z^+ to evaluate

local heat-transfer coefficients.

$$S_q\ (Z^+) = \left[\left\{\frac{Pr_L/Pr_T}{6.64(Z^+/Pr_T)^{1/9} + P_{FN}}\right\}^4 + \{0.651(Z^+/Pr_L)^{-1/3}\}^4\right]^{1/4} \qquad (6.5)$$

where

$$Z^+ = (Z/D)\ Re_{SL}\ (f_{SP}/2)^{1/2} \qquad (6.6)$$

Sq (Z^+) is the Spalding function given by

$$Sq\ (Z^+) = \frac{Nu_{SP}\ (Z)}{Re_{SL}\ (f_{SP}/2)^{1/2}} \qquad (6.7)$$

P_{FN} is the "P-function" and is given by

$$P_{FN} = 11.57\ \left\{\left(\frac{Pr_L}{Pr_T}\right)^{0.75} - 1\right\} \qquad (6.8)$$

Pr_T is the turbulent Prandtl number

Pr_T = 0.887 (recommended by Spalding).

(ii) Hausen's Correlation (14)

The following correlation is recommended by Hausen to evaluate local heat-transfer coefficients.

$$Nu_{SP} = 0.116 \{(Re_{SL})^{2/3} - 125\} \{1 + (1/3)(D/Z)^{2/3}\} Pr^{1/3} \{\mu_L/\mu_W\}^{0.14} . \quad (6.9)$$

The results of comparison of the single-phase experimental data with the above-noted theories for laminar and turbulent flow are shown in Fig. 6.2 and are summarized in Table 6.2. The agreement is excellent for turbulent flow and reasonable for laminar flow. The results for laminar heat transfer are believed to be influenced by natural convection and therefore are higher than those predicted by the theories. In Fig. 6.2, only the theoretical line of Worsoe-Schmidt is shown because it almost coincides with the line of Siegel et al. Also the theoretical line of Hausen's correlation is not shown because it was not possible to indicate this expression by a single line for the entire range. It can be observed from the deviations given in Table 6.2 that the theory of Spalding and Hausen's correlation bound the range of turbulent data.

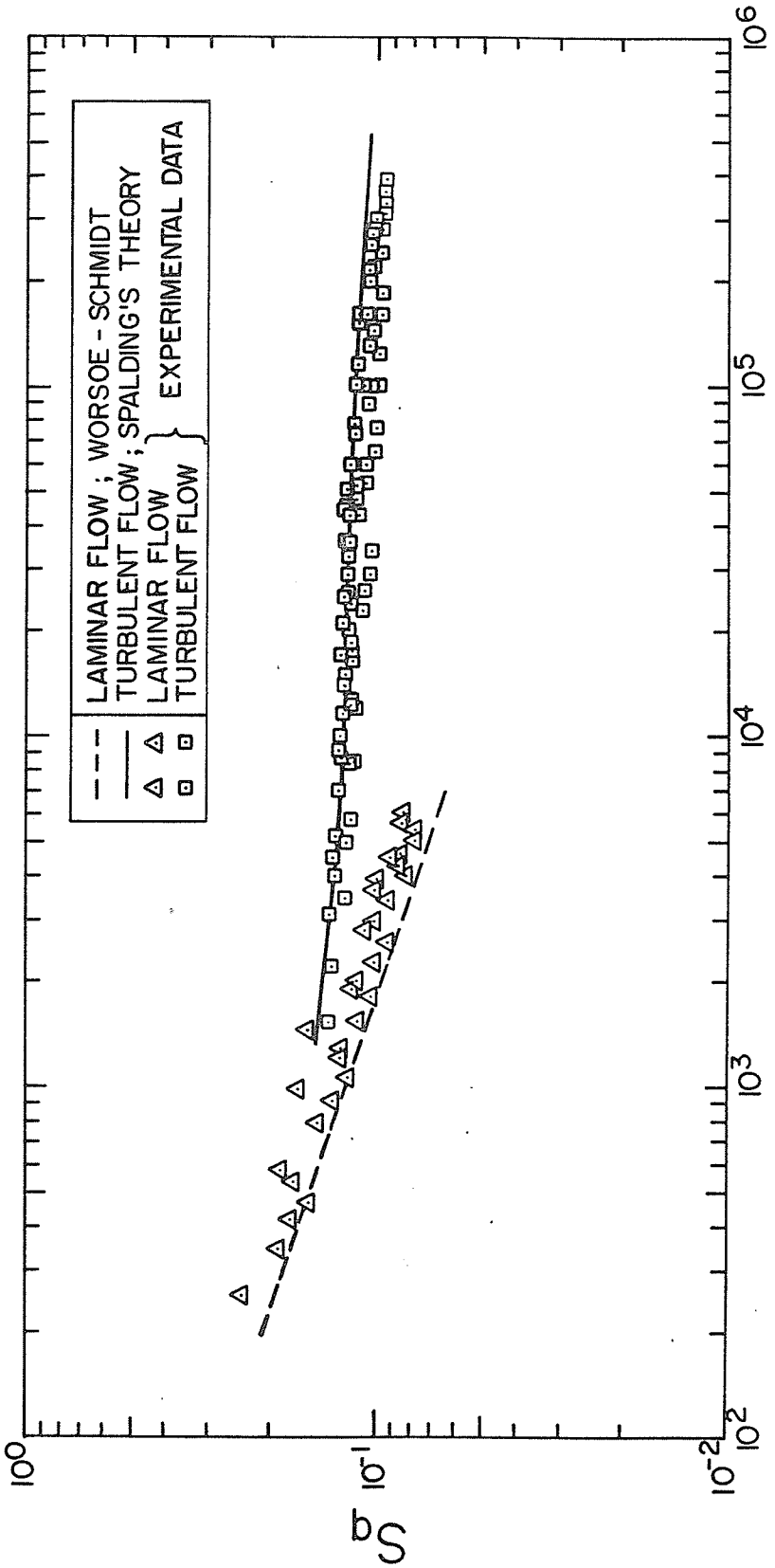


Fig. 6.2 Comparison of Single-Phase Local Heat-Transfer Data with Some Existing Theories

TABLE 6.2 Comparison of single-phase local heat transfer data with some existing theories

Type of Flow	Theory of	No. of data Points	$\bar{e}$ (%)	$\overline{e'}$ (%)
Laminar	Worsoe-Schmidt	32	15.47	18.36
	Seigel et al. Eq. 6.3	32	16.76	21.1
Turbulent	Spalding Eq. 6.5	91	-4.55	6.63
	Hausen Eq. 6.9	91	4.351	6.92

6.2.2 Mean Heat Transfer Results

As discussed in Appendix C , the overall length mean heat transfer coefficients were calculated by the following expression

$$\overline{h_{SP}} = \frac{1}{\Delta L} \int_{L_1}^{L_2} h_{SP}(Z)\, dz \qquad (6.10)$$

where

ΔL is the length of the heated test section over which the average heat-transfer coefficients were evaulated.

1. Laminar Flow

The following expressions given by Sieder and Tate (39) and in Reference (2) were corrected for property variations, although the variations in the water properties in the radial direction were small (the temperature difference between the wall and the bulk was typically 15°F)

$$\overline{Nu_{SP}} = A\ (Re_{SL}\ Pr_L\ \frac{D}{L})^{0.33}\ (\frac{\mu_L}{\mu_W})^{0.14} \qquad (6.11)$$

$$A = 1.86 \text{ (Sieder-Tate)} \qquad (6.11A)$$

$$A = 1.615 \text{ (Reference 2).} \qquad (6.11B)$$

The mean heat-transfer data for laminar flow were compared with Eq. (6.11) and the results are shown in Fig. 6.3 and summarized in Table 6.3. For laminar flow, the factor F appearing in the ordinate is given by

$$F = (Pr_L\ \frac{D}{L})^{0.33}\ \ (\mu_L/\mu_W)^{0.14}\ .$$

The agreement between the data and Eq. (6.11) was better with A = 1.86 as compared with when A = 1.615. Therefore the Sieder-Tate equation will be mostly used later in this Chapter, wherever required to predict the single-phase mean heat transfer coefficients.

2. Turbulent Flow

The correlation recommended by Kays (26) for fully developed turbulent flow in water and light liquids ($1.0 < Pr_L < 20$) was corrected for variable fluid properties and used for comparison with the mean heat-transfer coefficients and is given below:

$$\overline{Nu_{SP}} = 0.0155\ Re_{SL}^{0.83}\ Pr_L^{0.5}\ \left(\frac{\mu_L}{\mu_W}\right)^{0.33} . \qquad (6.12)$$

The mean heat-transfer data for single-phase flow, obtained in this work were compared with Eq. (6.12). The results of comparison are shown in Fig. 6.3 and are summarized in Table 6.3; Fig. 6.3 and Table 6.3 illustrate an excellent agreement between the data and Eq. (6.12).

For turbulent flow, the factor F appearing in the ordinate is given by

$$F = Pr^{0.5}\ (\mu_L/\mu_W)^{0.33} .$$

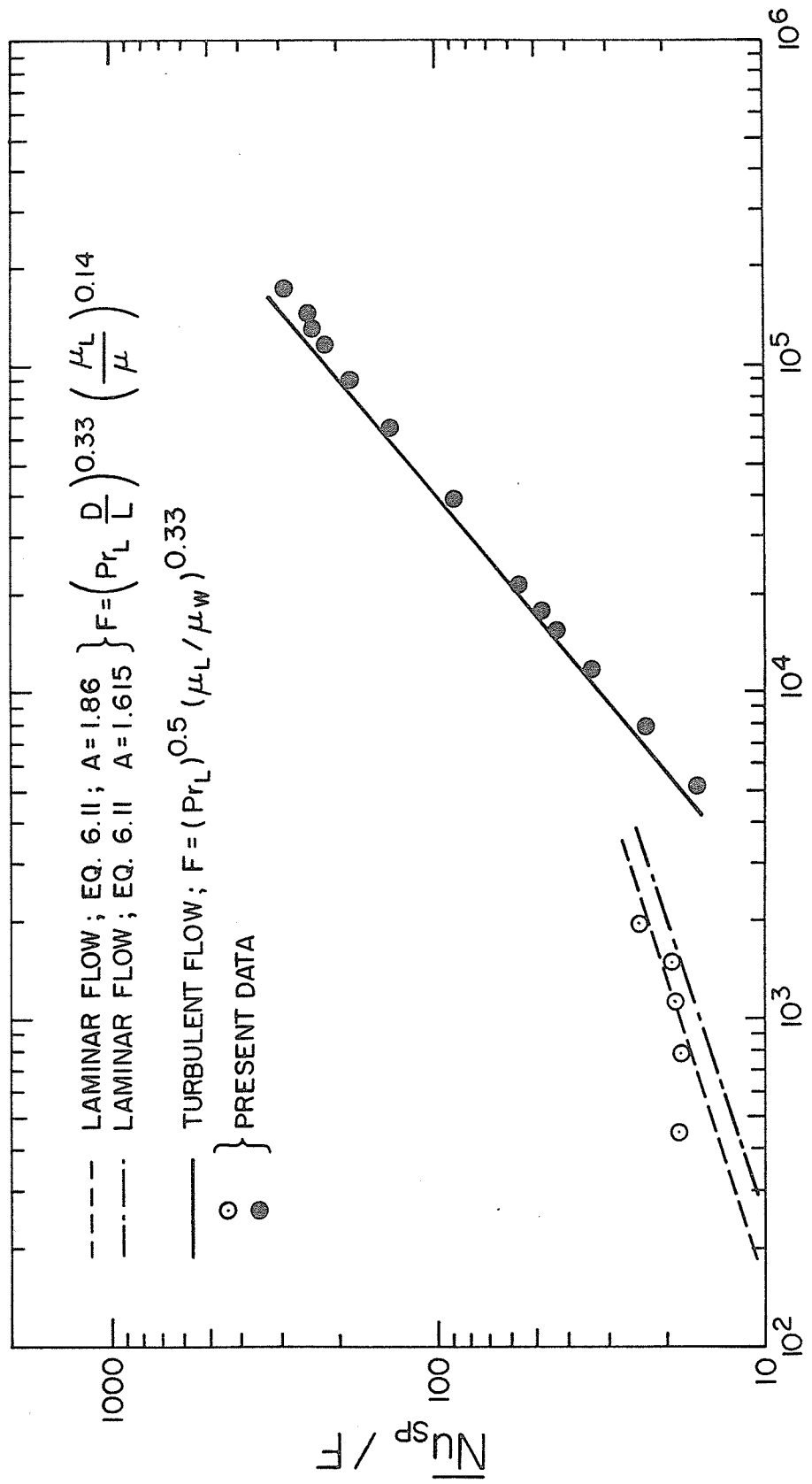


Fig. 6.3 Comparison of Single-Phase Heat-Transfer Data with Correlations

TABLE 6.3 Comparison of $\overline{h_{SP}}$ with some existing correlations

Type of Flow	$\bar{e}$ (%)	$\overline{e'}$ (%)	Equation(s) Compared
Laminar	6.89	14.03	Eq. (6.11) A = 1.86
	23.10	27.25	Eq. (6.11) A = 1.615
Turbulent	-13.23	12.36	Eq. 6.12

The following conclusions could be drawn on the basis of the material presented in this section.

i. That the experimental equipment continues to function satisfactorily.

ii. That the results obtained for two-phase heat transfer would be accurate and reliable.

6.3 Two-Phase Heat Transfer Results

This section presents the two-phase local and mean heat transfer results obtained in the present investigation.

Experiments with water-air mixtures were performed first, prior to collecting heat transfer data for the

surfactant sol.-air system, mainly because of two reasons: to check the performance of the experimental apparatus and secondly to obtain baseline experimental data for the purpose of comparison. The water-air mean heat-transfer coefficients were compared with the data previously obtained from the same experimental facility by Vijay (48) and Aggour (1). The results of this comparison are shown in Fig. 6.4 which reveals generally an excellent agreement between the present and previous data (48, 1). The continued satisfactory performance of the rig was therefore established and it was believed that any data obtained further would be accurate and reliable. However a comment should be made concerning the results in the annular-mist region for the two velocities (V_{SL} = 0.19 ft/sec (0.058 m/sec) and V_{SL} = 0.37 ft/sec (0.113 m/sec)) with the laminar superficial liquid Reynolds number (Re_{SL} = 836 and 1512) respectively. In this region original data taken by the present investigator and repeated data showed more scatter when compared with Vijay's (48) results and internally than anywhere else tested (see Appendix C for further comments on what was otherwise good repeatability). The data shown encompass the extremes of data for the laminar superficial Reynolds number tested in this region (lowest at V_{SL} = 0.19 ft/sec (0.058 m/sec) and highest at V_{SL} = 0.37 ft/sec (0.113 m/sec)).

6.3.1 Local Heat Transfer Coefficients

The two-phase local heat-transfer coefficients, h_{TP} were measured as explained in Appendic C. The raw data are

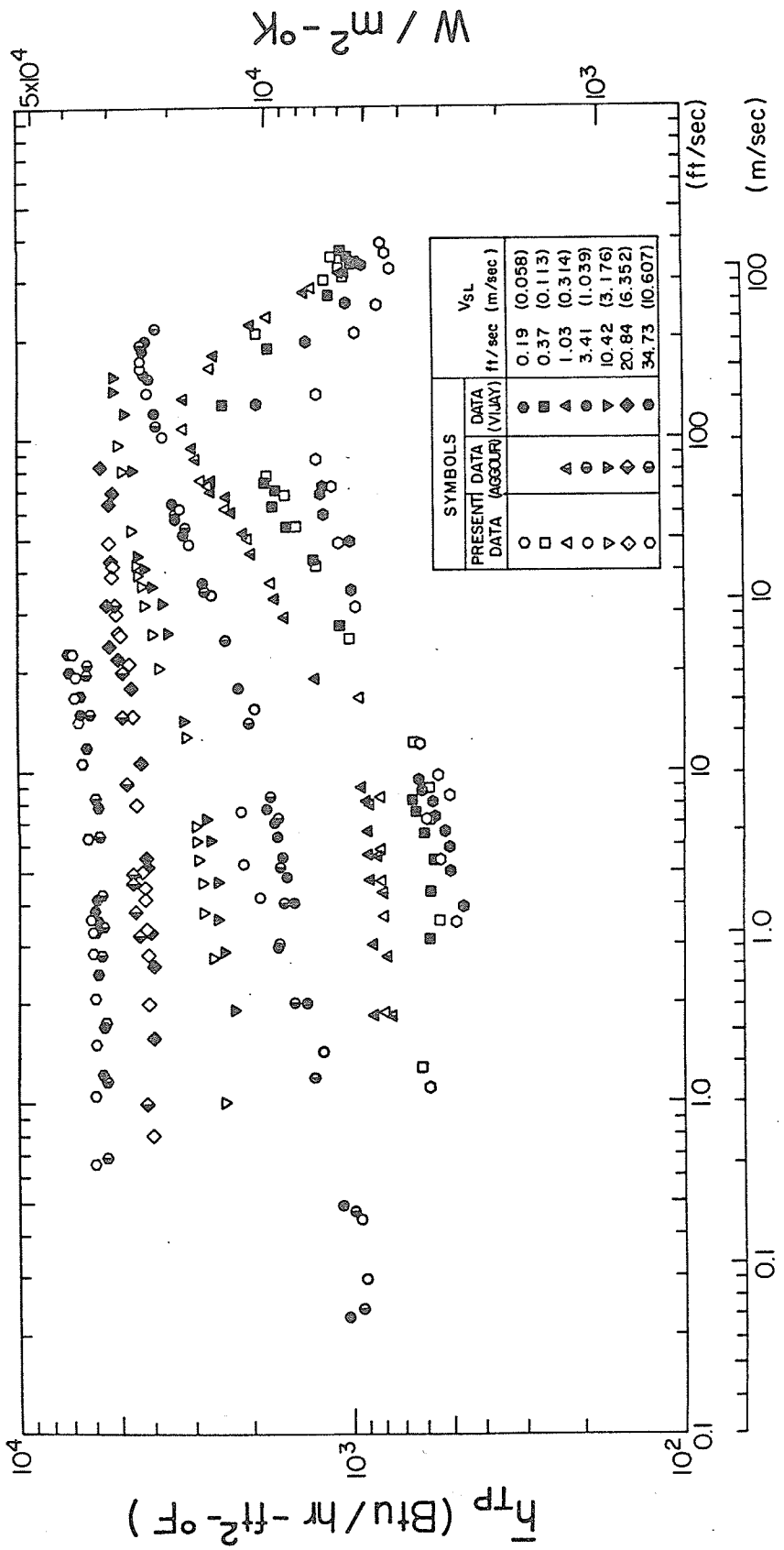


Fig. 6.4 Comparison of present Water-Air htp Data with the Data of Aggour and Vijay.

presented in Figs. 6.5(A-G) for water-air and Figs. 6.6(A-F) for surfactant sol-air. In each figure h_{TP} is plotted against Z, the distance from the beginning of the heated section, for a fixed liquid flow with the superficial gas velocity being a parameter. It should be noted that all the data obtained are not included in the figures for the sake of clarity; however, complete data are tabulated in Appendix D.

Examination of the $h_{TP} \sim Z$ plots indicates that at moderate-to-high liquid flow rates i.e., $V_{SL} \geq 3.41$ ft/sec (1.039 m/sec) the shape of the $h_{TP} \sim Z$ profiles is similar to those of single-phase local heat-transfer coefficients (see Fig. 6.5; D to G and Fig. 6.6, D to F) as shown in Fig. 6.1. At low liquid flow rates and low-to-moderate gas velocity, h_{TP} increased along the distance Z in the bubble, slug, churn and annular flow while in the annular-mist h_{TP} decreased along Z (see Fig. 6.5, A to C and Fig. 6.6, A to C). A comparison of Fig. 6.5, A to G for the water-air system and Fig. 6.6, A to F for the surfactant-air system suggests that the behaviour of local heat-transfer coefficients with respect to distance along the test section remain unaffected by reducing the surface tension of water. Similar behaviour of h_{TP}, in that it increases with the distance, has also been reported in the literature (15, 16) and was also observed in the earlier work (48,1) conducted on the present experimental facility. Fedotkin and Zarudnev (15) reported that for some flow regimes in vertically upward flow the mean values of heat-transfer coefficient were higher in the top section than they were in the bottom section of their test section.

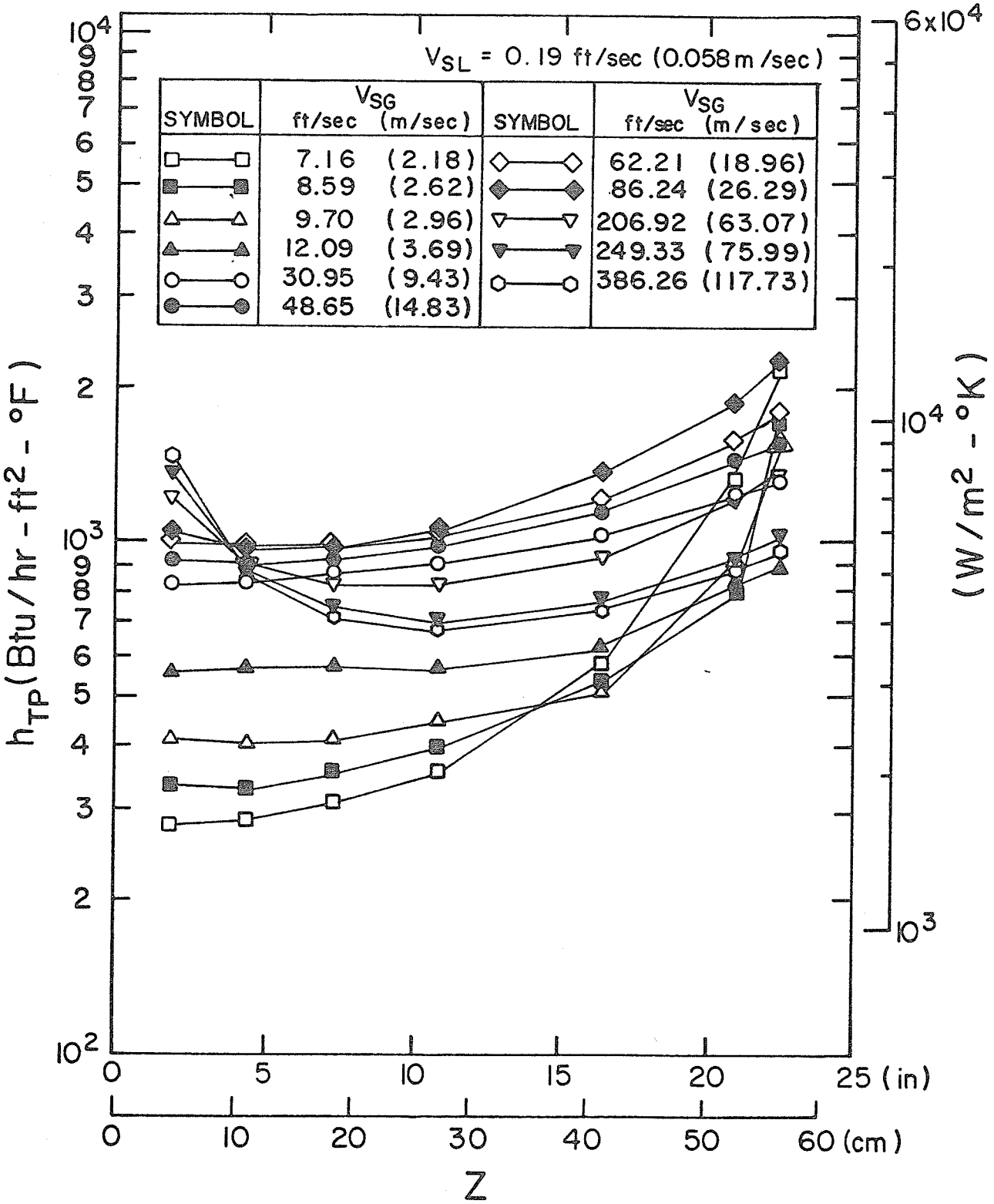


Fig. 6.5A Two-Phase Water-Air Local Heat-Transfer Data

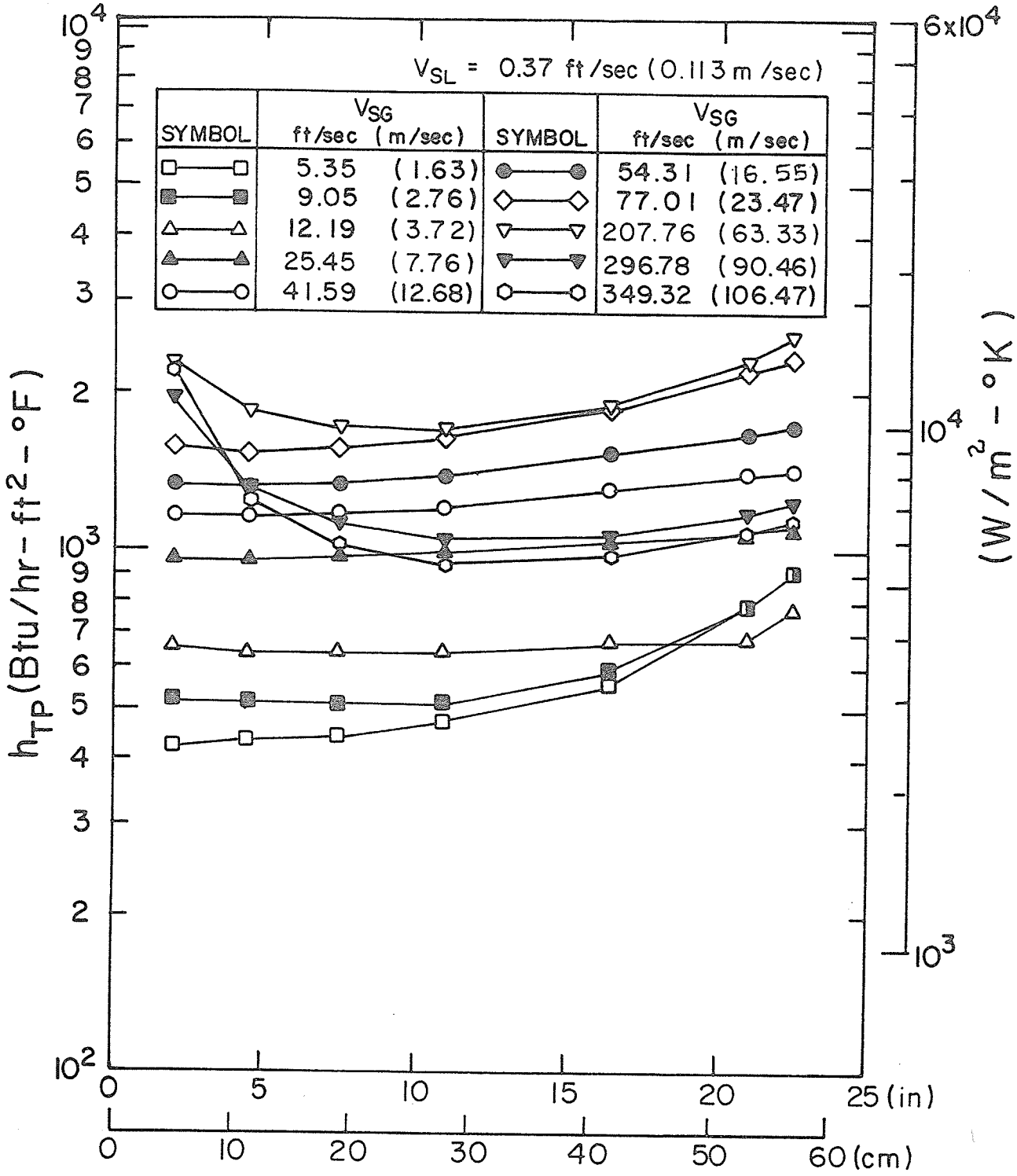


Fig. 6.5B Two-Phase Water-Air Local Heat Transfer Data

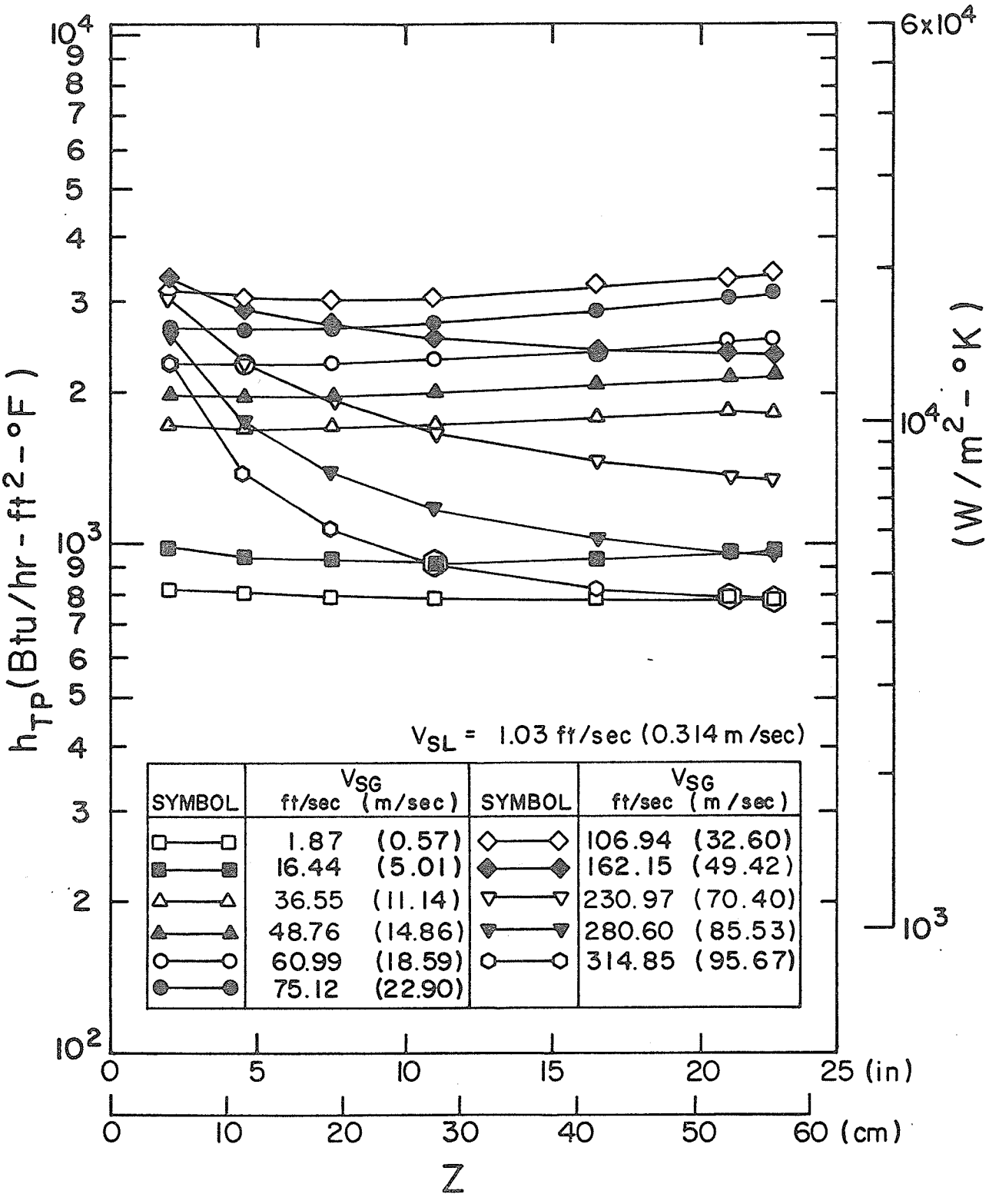


Fig. 6.5C Two-Phase Water-Air Local Heat-Transfer Data

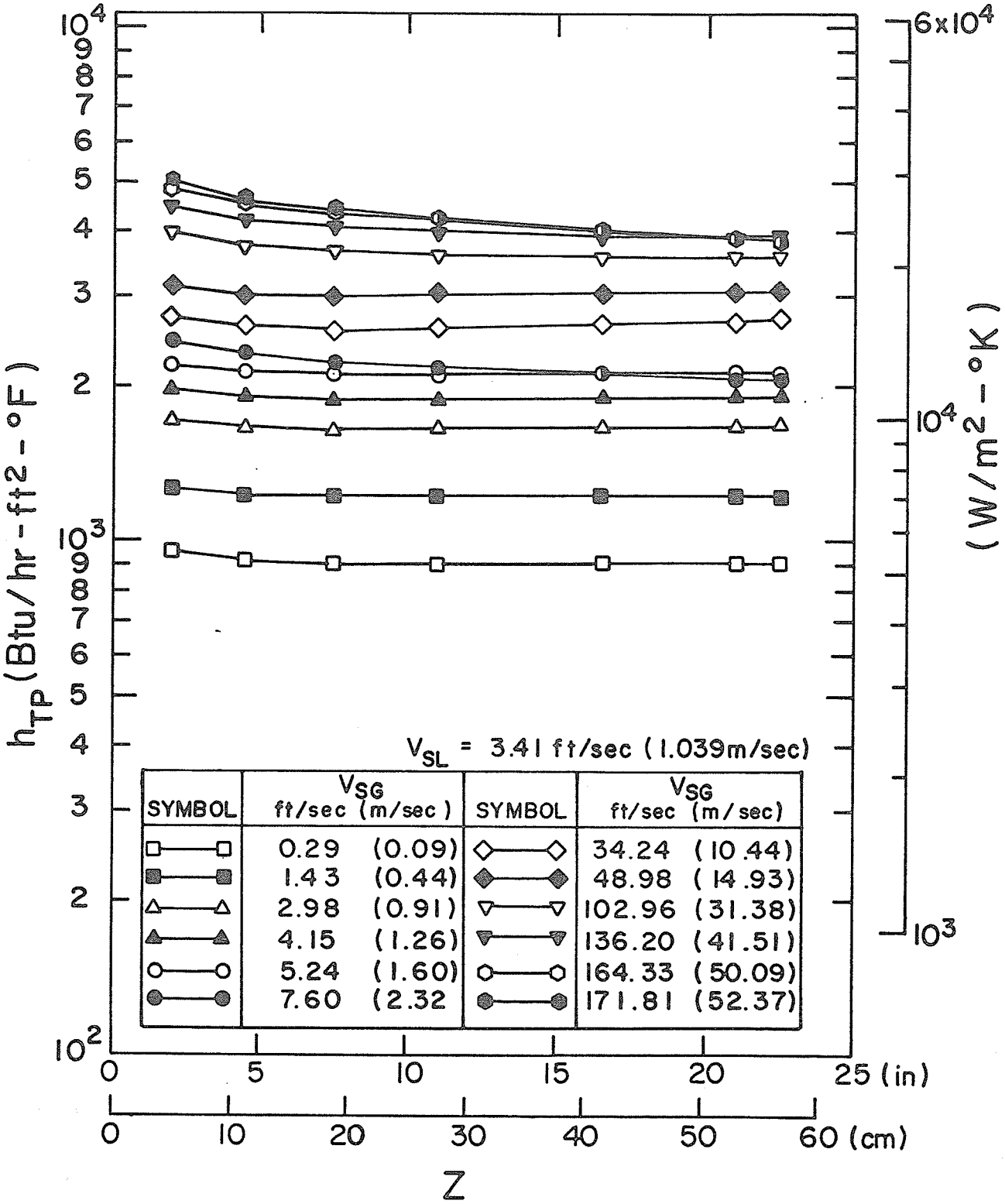


Fig. 6.5D Two-Phase Water-Air Local Heat-Transfer Data

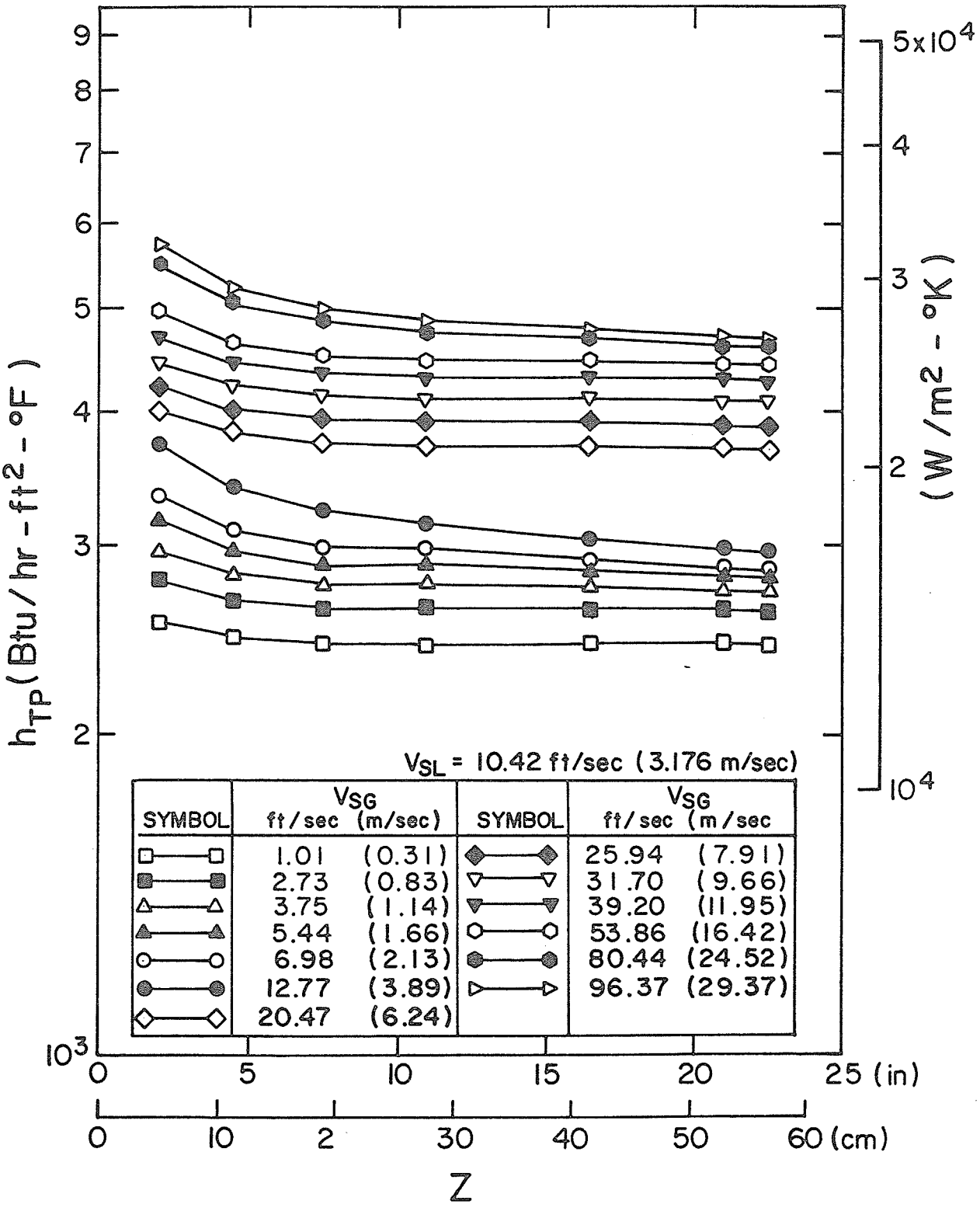


Fig. 6.5E Two-Phase Water-Air Local Heat Transfer Data

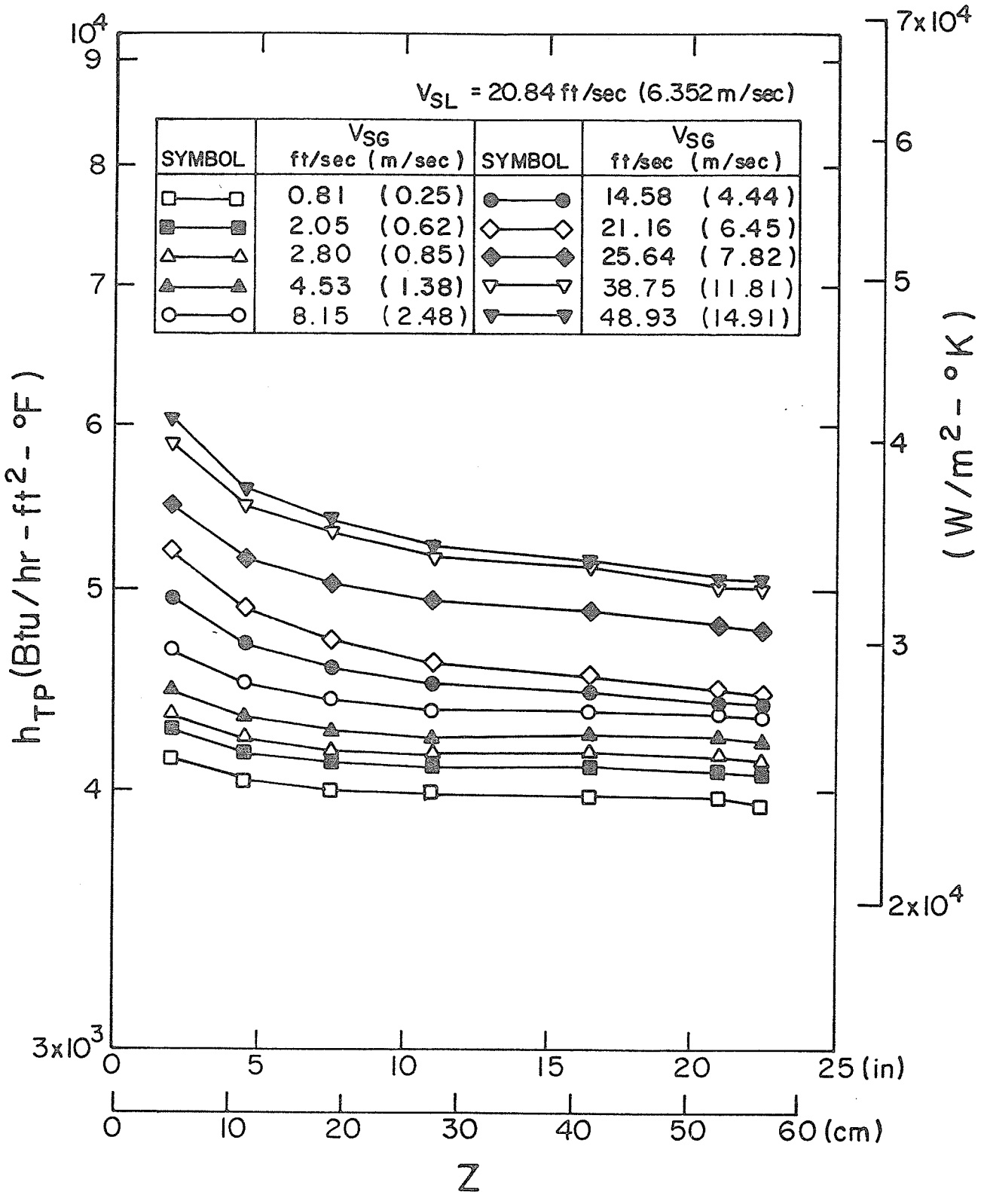


Fig. 6.5F Two-Phase Water-Air Local Heat Transfer Data

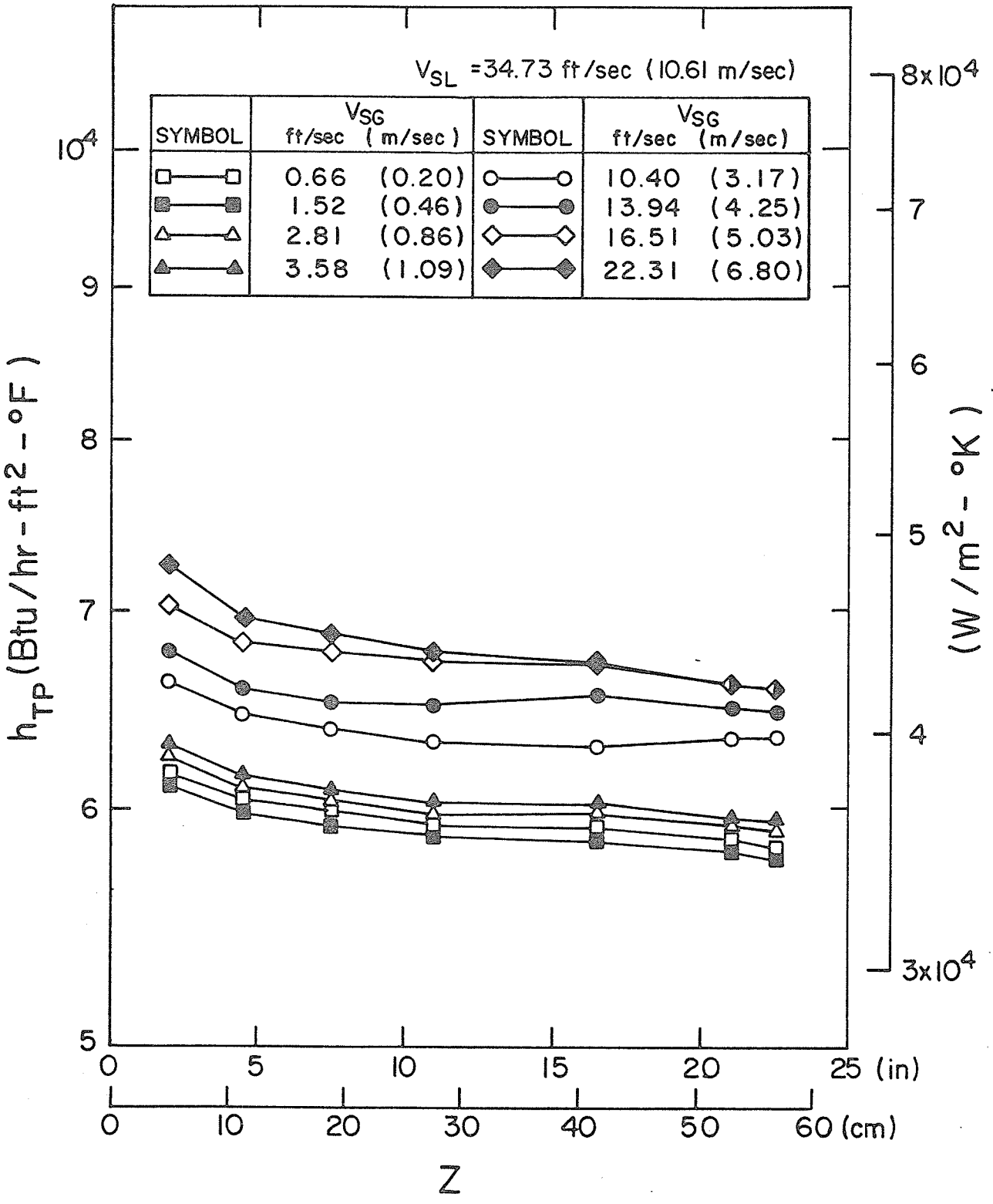


Fig. 6.5G Two-Phase Water-Air Local Heat Transfer Data

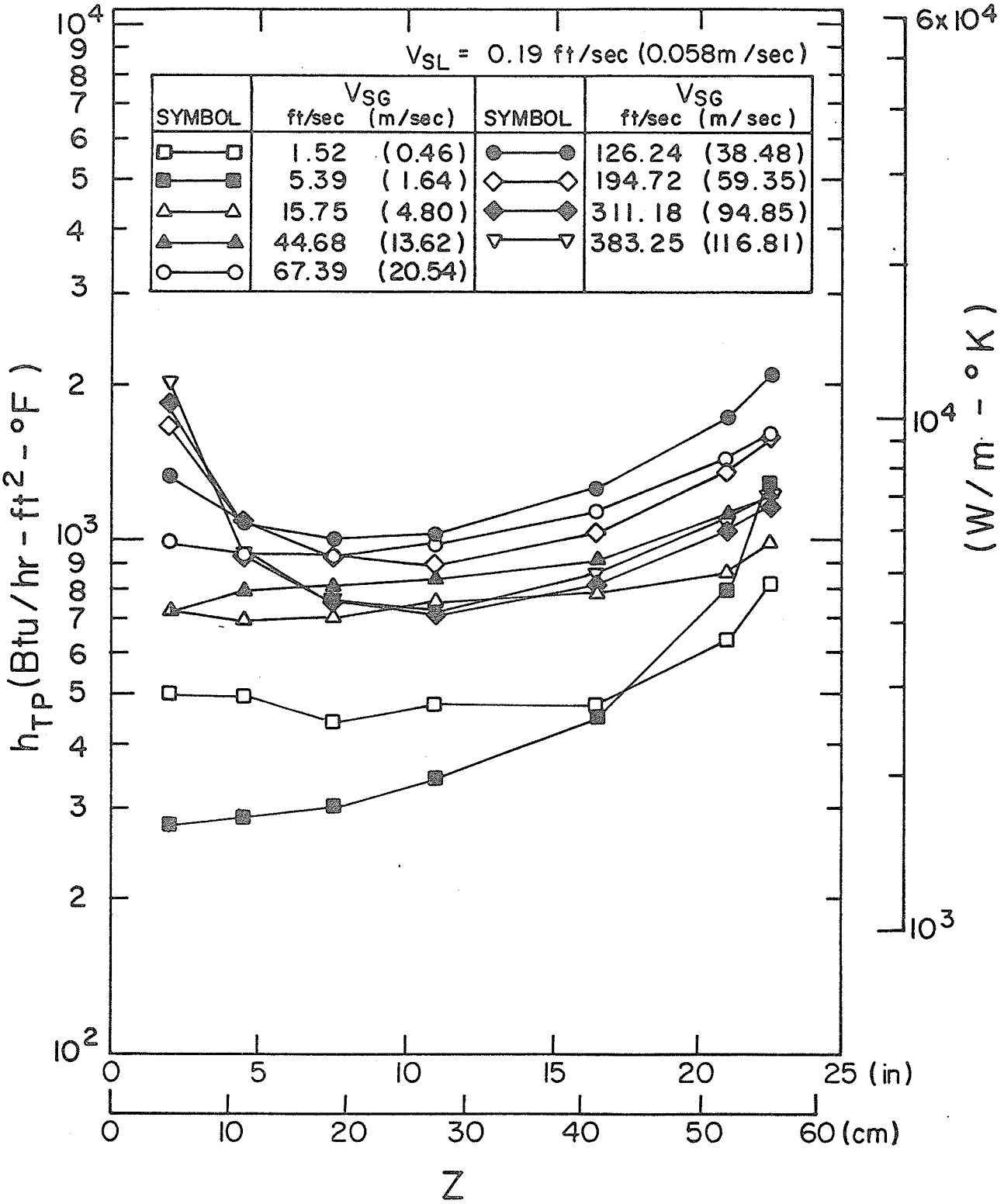


Fig. 6.6A Two-Phase Surfactant Solution-Air Local Heat-Transfer Data

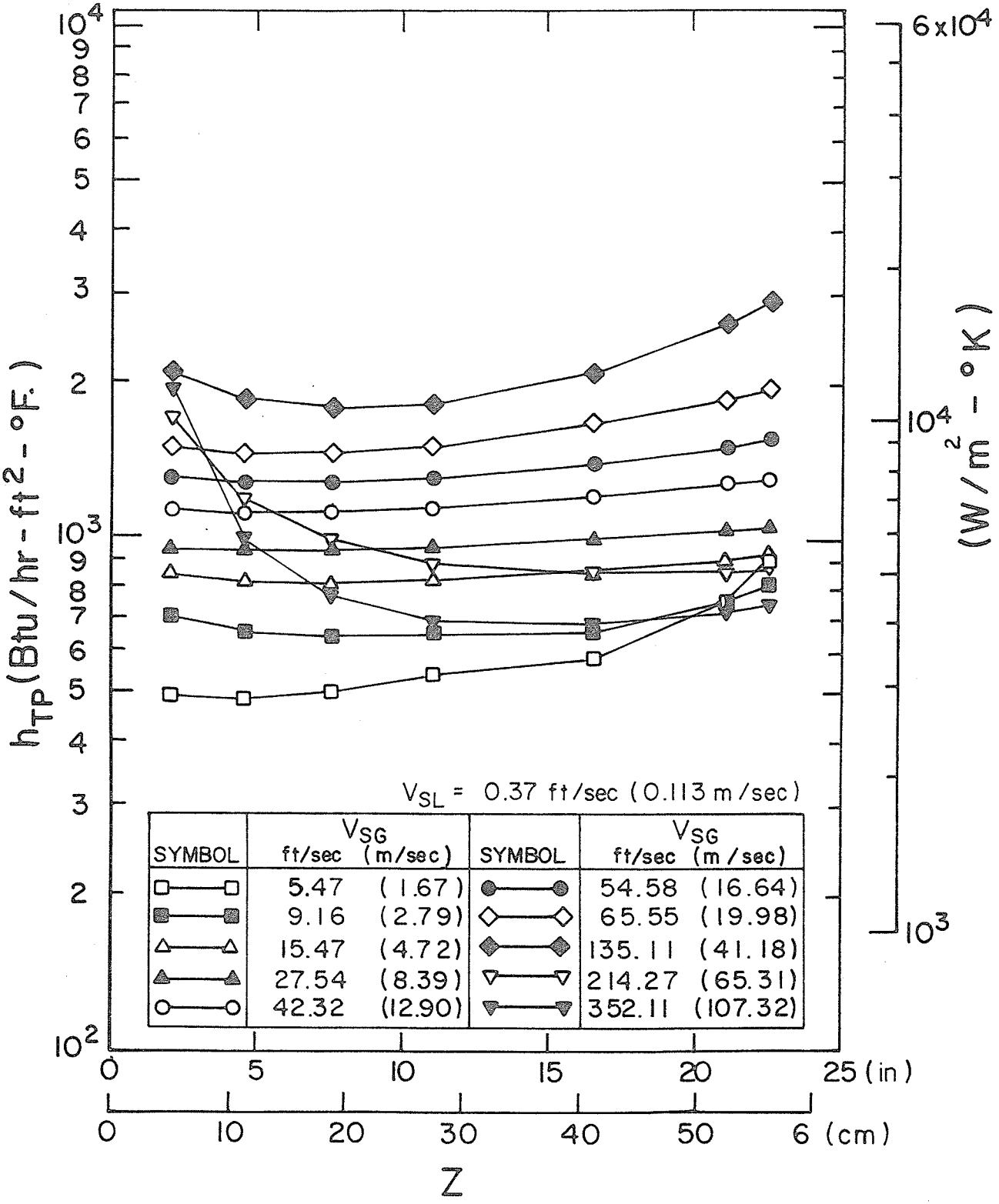


Fig. 6.6B Two-Phase Surfactant Solution-Air Local Heat-Transfer Data

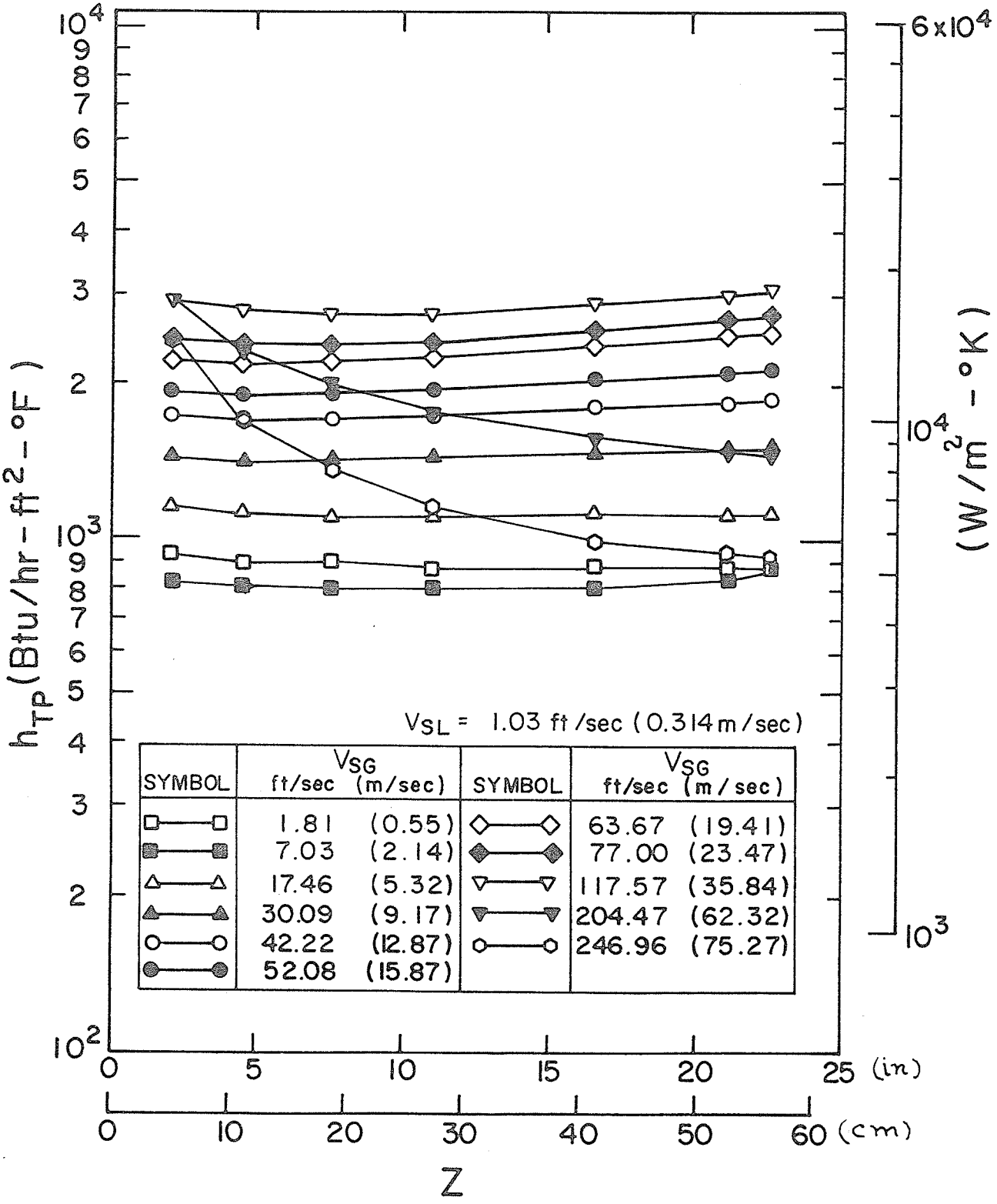


Fig.6.6C Two-Phase Surfactant Solution-Air Local Heat-Transfer Data

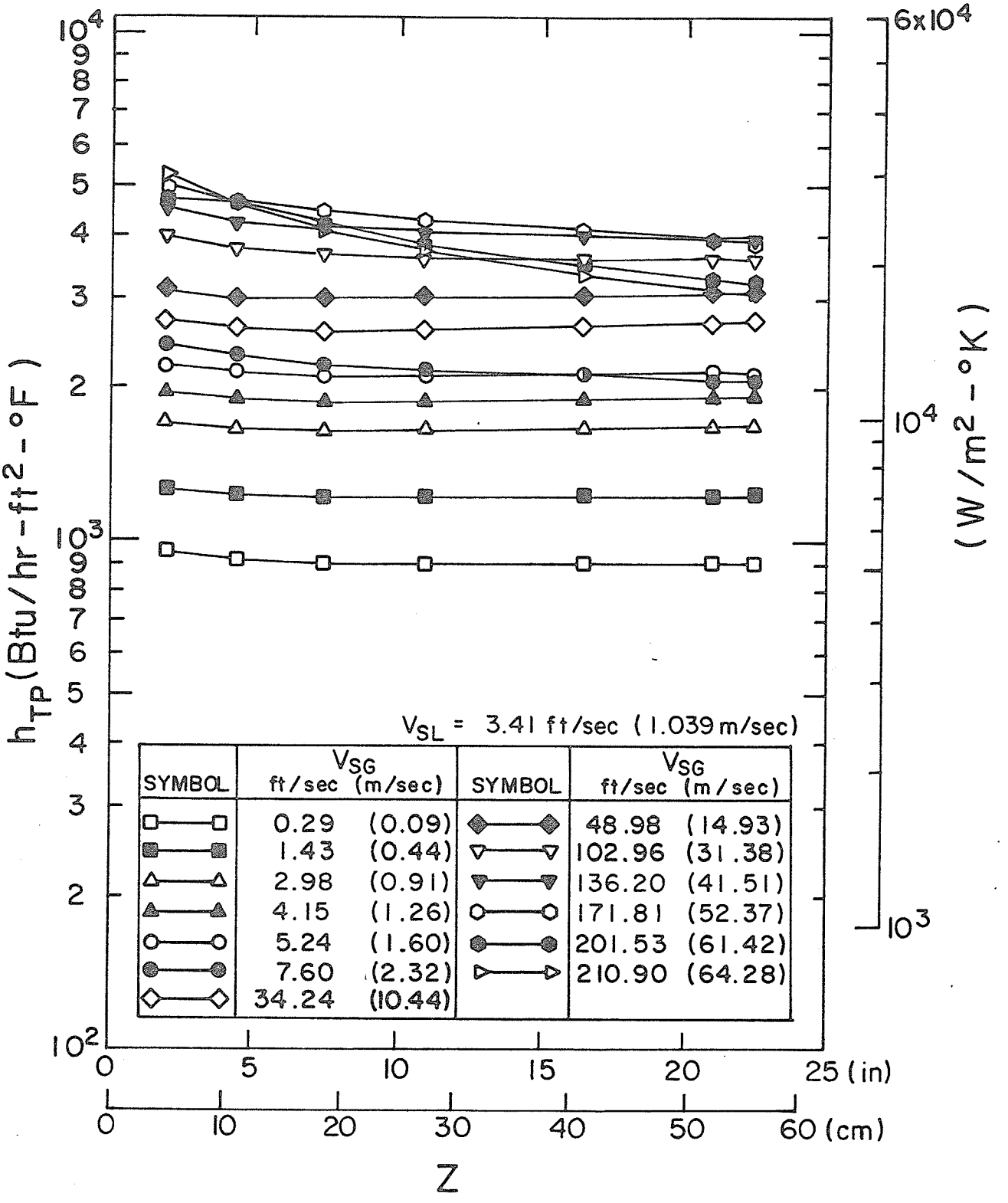


Fig. 6.6D Two-Phase Surfactant Solution-Air Local Heat-Transfer Data

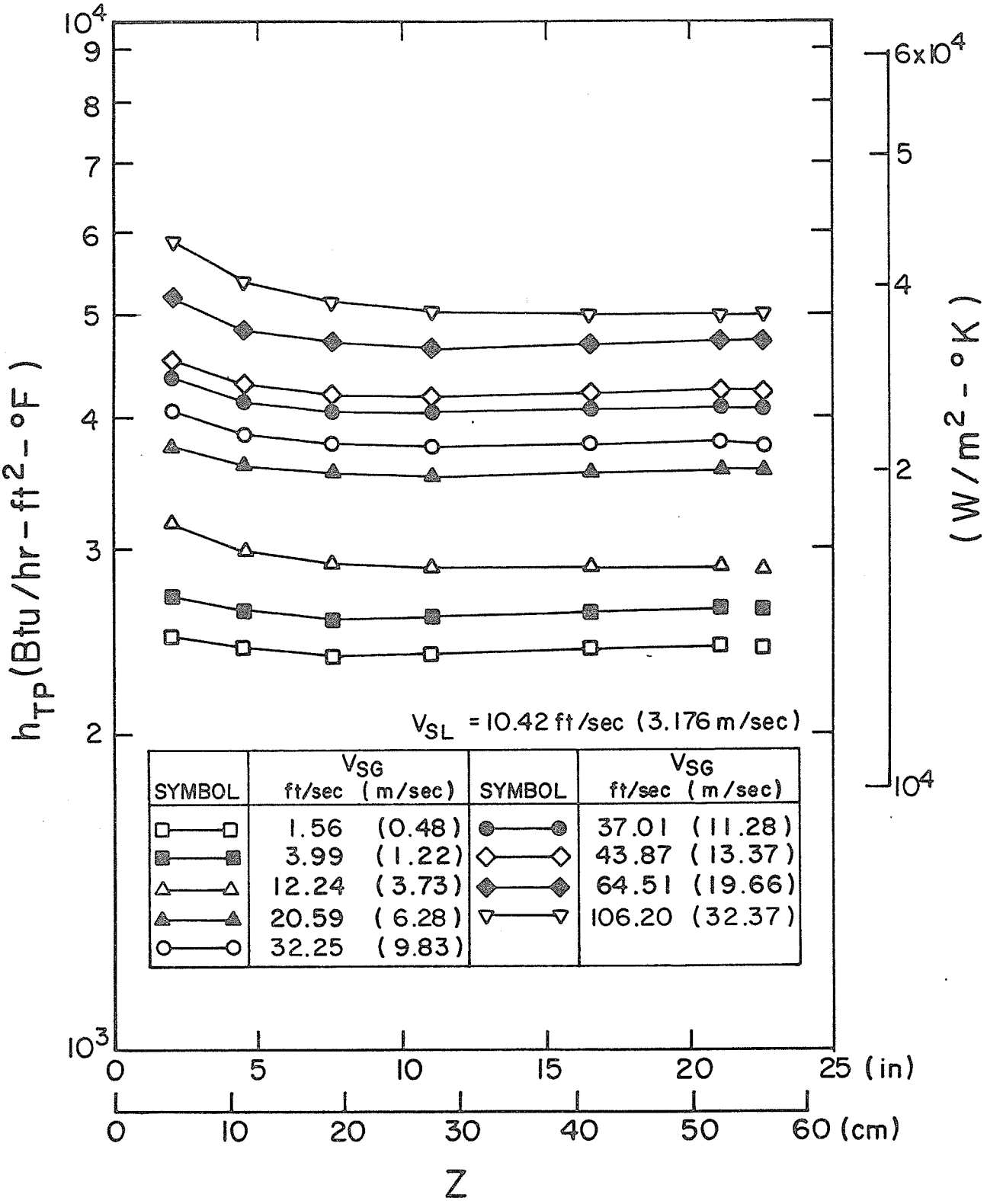


Fig. 6.6E Two-Phase Surfactant Solution-Air Local Heat Transfer Data

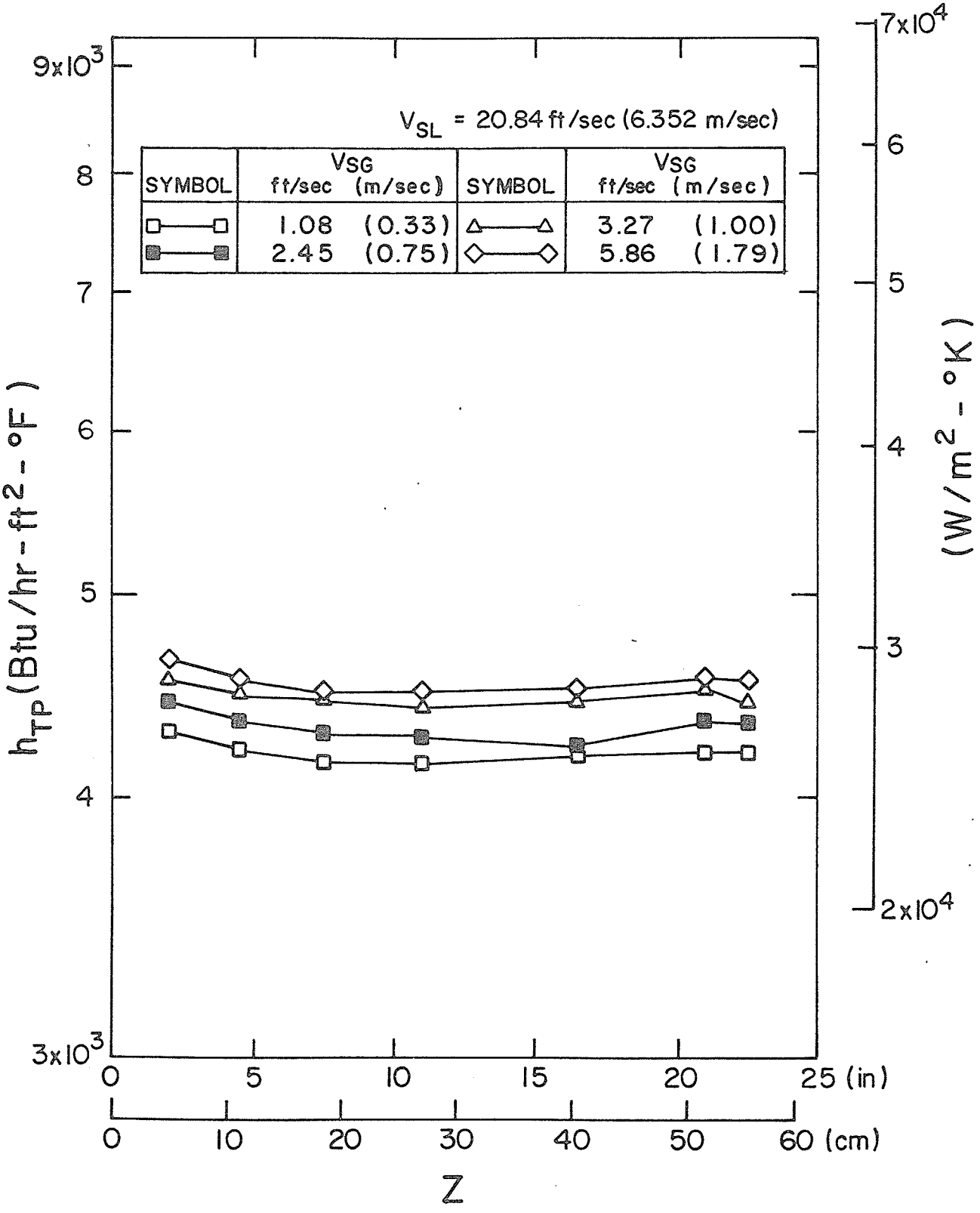


Fig. 6.6F Two-Phase Surfactant Solution-Air Local Heat Transfer Data

Frisk and Davis (15) made studies for gas-liquid stratified flow in a horizontal rectangular channel ($100 < Re_L < 250$) and reported that at some points downstream from the start of the heated wall a minimum Nusselt number was attained followed by a sudden increase in Nu.

In the earlier work (48, 1) conducted on the present experimental facility, the downflow of the liquid film at the tube wall at low V_{SL} and low-to-moderate V_{SG} (in bubble, slug, churn and annular flow) was suggested as one of a number of possible mechanisms for this behaviour of $h_{TP} \sim Z$. A theory was developed which qualitatively explains this behaviour. Downflow of the liquid film was not observed before for bubble flow but a visualization study made by Aggour (1) confirmed this downflow.

In the present work, in slug flow at low V_{SL} and low-to-moderate V_{SG}, one had the impression that the length of the gas bubble was of the same order of length as the test section and much larger than the liquid slug; therefore under these conditions, the flow could be considered as a falling flow at the tube wall with short periods of upward flow which could explain this reversed behaviour of $h_{TP} \sim Z$. However, this trend was not observed in slug flow at higher

V_{SL} e.g. V_{SL} = 3.41 ft/sec (1.039 m/sec); one of the possible mechanisms for this behaviour might be that under these conditions, the length of the bullet-shaped bubble became smaller and approximately equal to the liquid slug, therefore periods of downflow and upflow could be considered as approximately equal.

At low V_{SL} and low-to-moderate V_{SG}; the h_{TP} was also observed to increase in the annular flow, (Fig. 6.5, A-C and Fig. 6.6, A to C). At low liquid flow rates, the existence of downflow has been reported in References (8, 24) which could explain this behaviour of $h_{TP} \sim Z$.

The other possible reasons could be:

(i) variations in the fluid properties along the test section,

(ii) acceleration of bubbles due to pressure gradient along the test section as explained in Reference (48),

(iii) perhaps natural convection effects.

6.3.2 Two-Phase Mean Heat-Transfer Coefficients

The two-phase mean heat-transfer coefficients, $\overline{h_{TP}}$ were evaluated by integrating the local values of heat-

transfer coefficients over the heated length of the test section as explained in Appendix C. These mean heat-transfer coefficients are presented in Fig. 6.7 for water-air and in Fig. 6.8 for surfactant solution-air tests. The $\overline{h_{TP}}$ is plotted as a function of V_{SG} with V_{SL} as a parameter.

Examination of Figs. 6.7 and 6.8 shows that for a given fixed liquid velocity, the heat-transfer coefficients generally increase as the gas mass flux is increased. These results show that the contribution of the gas-phase in increasing the heat-transfer coefficient is more pronounced at low liquid flow rates than at high liquid flows. A plausible explanation in terms of the level of turbulence already present in the flow before injecting the gas phase has been suggested by Kudirka (28). At low liquid flow rates, the turbulence level is initially small. The introduction of the gas-phase will increase the turbulence level and mixing action in the main stream caused by continuous interaction of the two-phases. The addition of the gas phase will also disturb and reduce the thickness of the laminar boundary sublayer. These effects act to increase the heat transfer rate. At high liquid flow rates, the turbulence level is initially higher; therefore, the effect of gas phase on heat-transfer coefficient is less

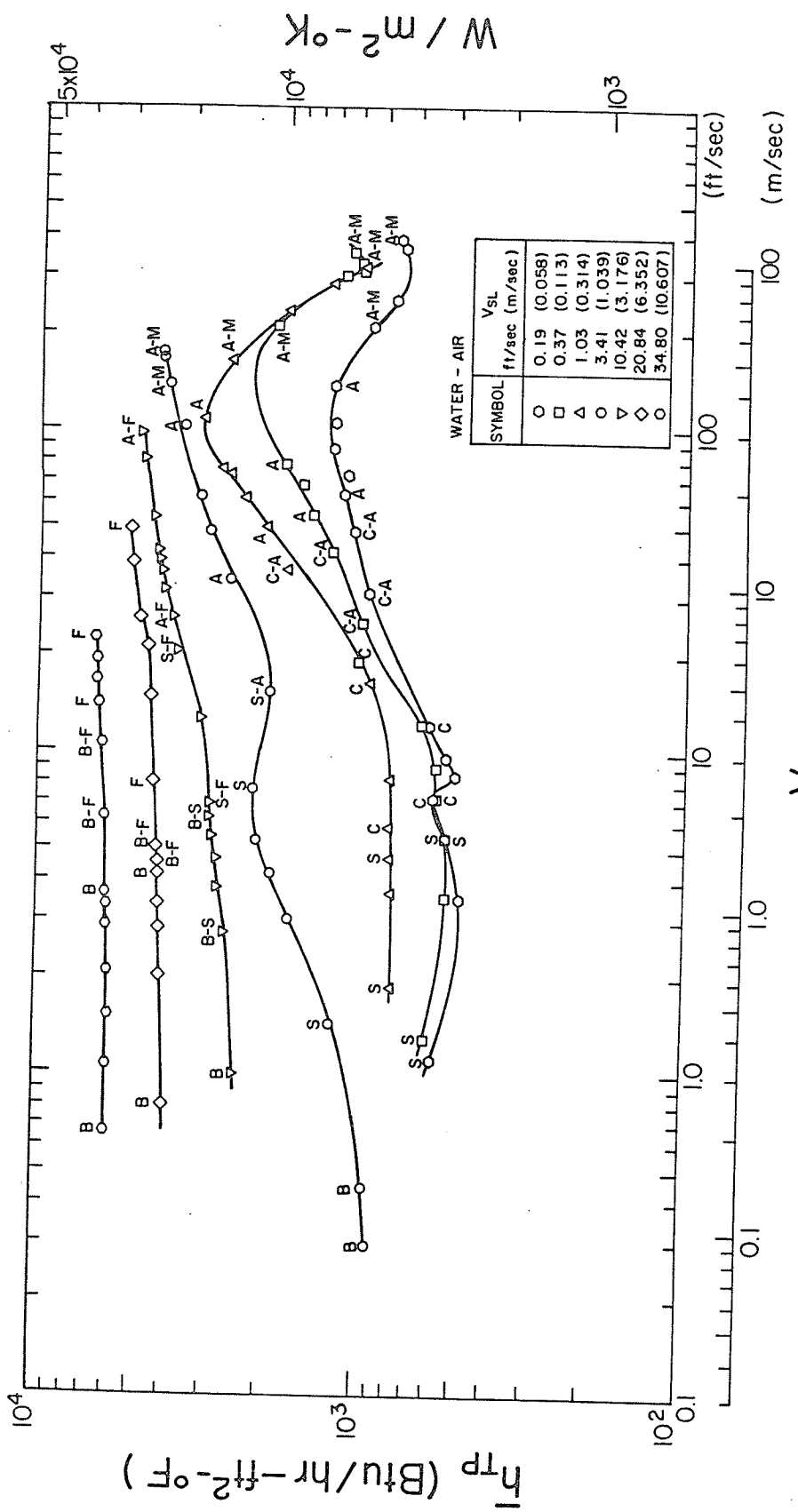


Fig. 6.7 Two-Phase Water-Air Mean Heat Transfer Data

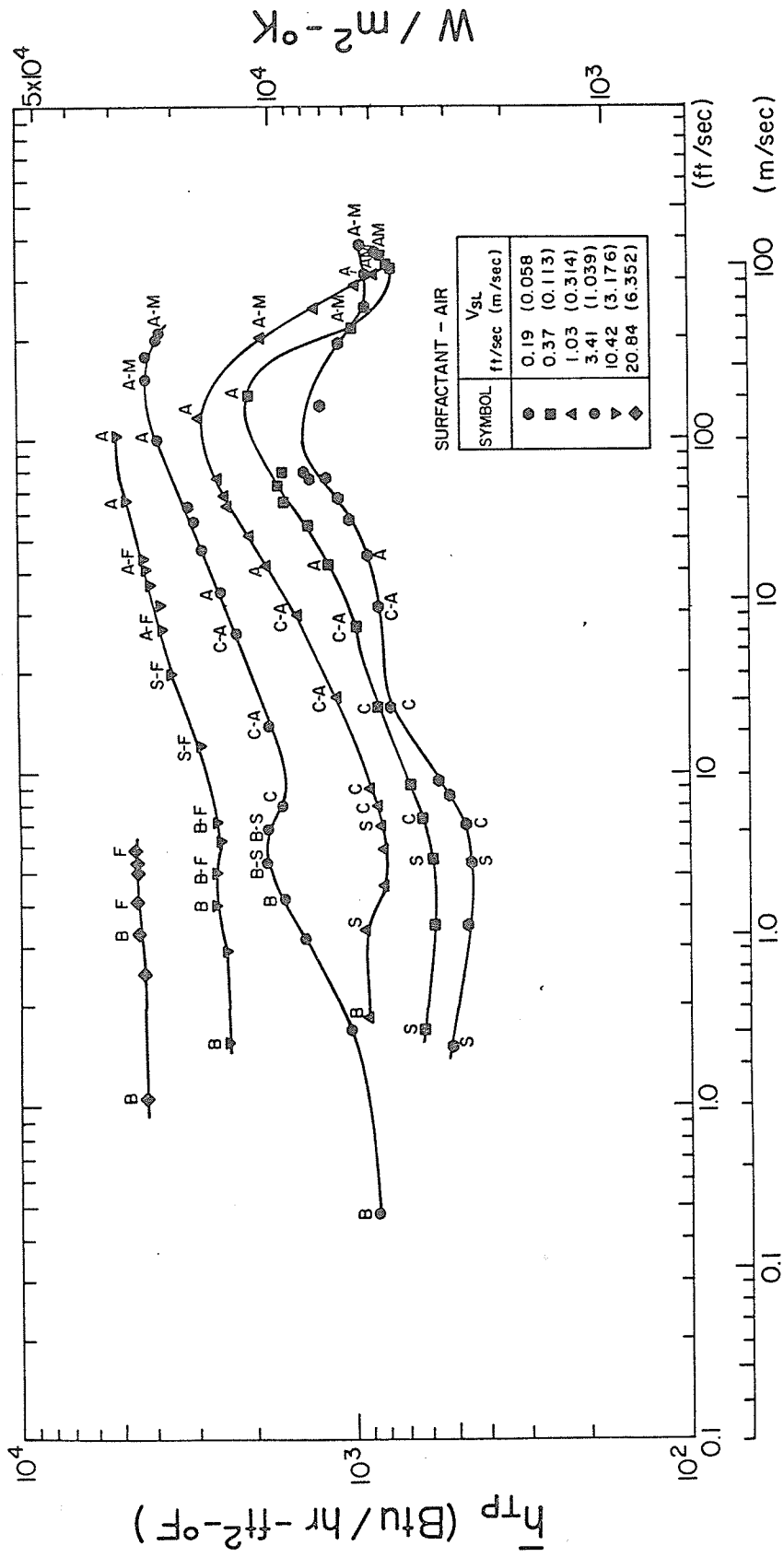


Fig. 6.8 Two-Phase Surfactant Solution-Air Mean Heat Transfer Data.

pronounced.

In general one would expect that the velocity increase of the mixture due to the introduction of the gas phase would serve to increase the turbulence level.

The increase in heat-transfer coefficients has also been associated with the two-phase flow patterns (24, 8, 11). To demonstrate the influence of flow patterns on the mean heat-transfer coefficients, the code letters (Table 5.2) of the observed flow patterns for each test have been marked beside the data points in Figs. 6.7 and 6.8. It can be observed from these figures that the changes in the slope of the curves mainly occur at flow pattern transitions.

For each of the lower V_{SL} a distinct maximum in $\overline{h_{TP}}$ generally appears as the flow pattern changes from annular to annular-mist. The possible mechanism for the existence of these maxima could be explained as follows (22). Just before the maxima in annular flow, the thickness of the liquid film is very small. At this critical point any increase in the gas flow rate would disintegrate the very thin liquid film attached to the wall causing randomly disturbed dry spots to appear on the heated wall and giving rise to the annular-mist flow pattern. Heat transfer beyond this maximum is then no longer controlled by the heat transfer to a turbulently flowing

liquid film but also by transfer from the wall to the air at these dry spots, resulting in a drop in $\overline{h_{TP}}$. The occurrence of similar maxima in the $\overline{h_{TP}}$ has been reported in the literature by Verschoor and Stemerding (47), Groothuis and Hendal (22) and Ravipudi (33, 34) and was also observed in the earlier work (48, 1) conducted on the present experimental facility.

In order to demonstrate the effect of surface tension on the mean heat-transfer coefficients, the water-air and surfactant solution-air data are plotted together and are shown in Fig. 6.9A and B. Examination of these figures indicates that reduced surface tension produced some effects on $\overline{h_{TP}}$ and in general where differences are considered as significant, the tendency is for the $\overline{h_{TP}}$ to be lower for the surfactant solution than for water. In Fig. 6.9A and B lines are drawn where the differences are believed to be significant; these differences mainly occur where changes in the flow patterns were observed.

In Fig. 6.9, for V_{SL} = 0.19 ft/sec (0.058 m/sec) large differences appear at $V_{SG} \approx 7$ ft/sec (2.13 m/sec); it was not apparent whether differences appearing at the low V_{SG} could be attributed to surface tension effects since

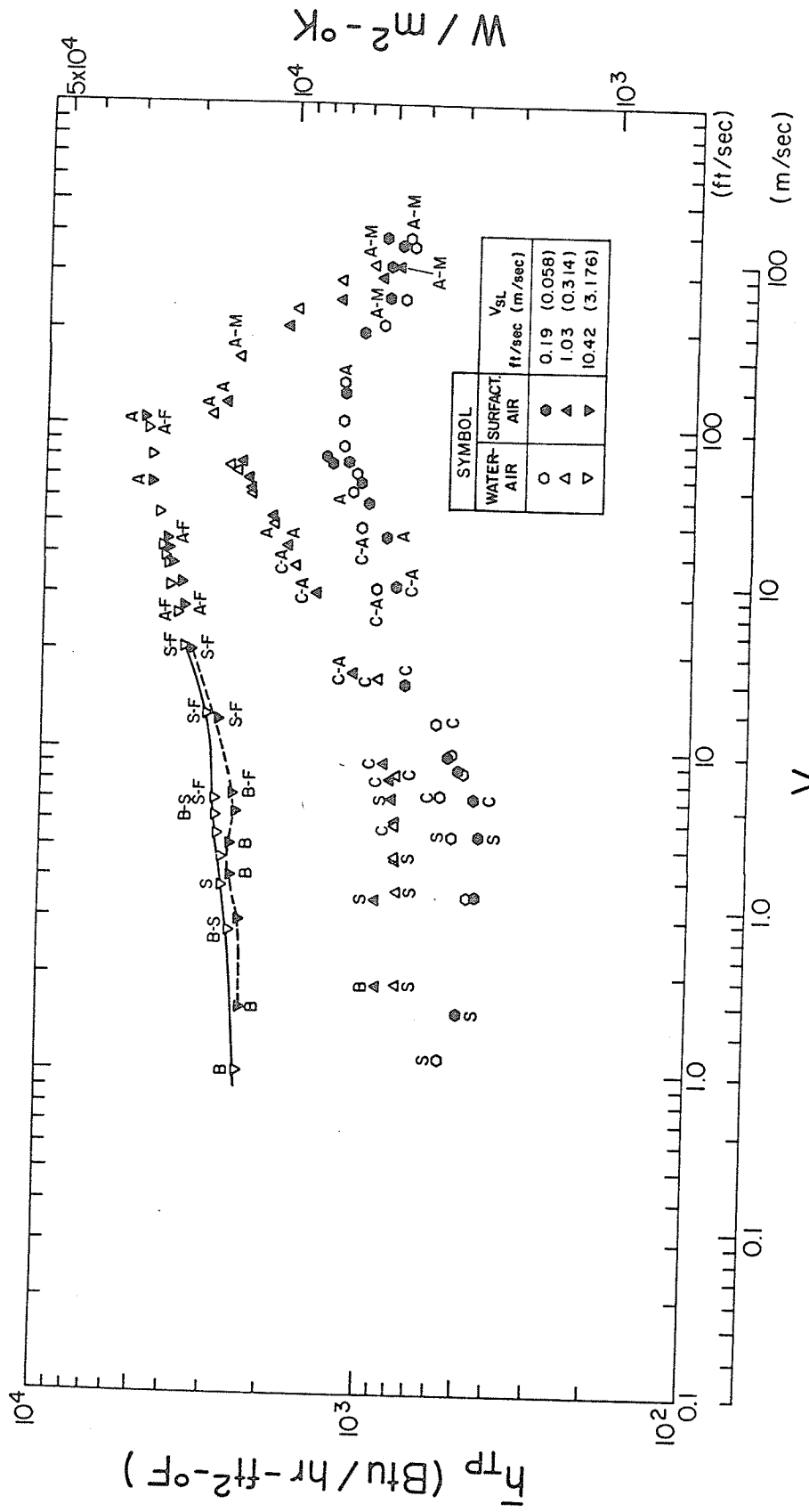


Fig. 6.9A Effect of Surface Tension on Mean Heat Transfer Coefficients.

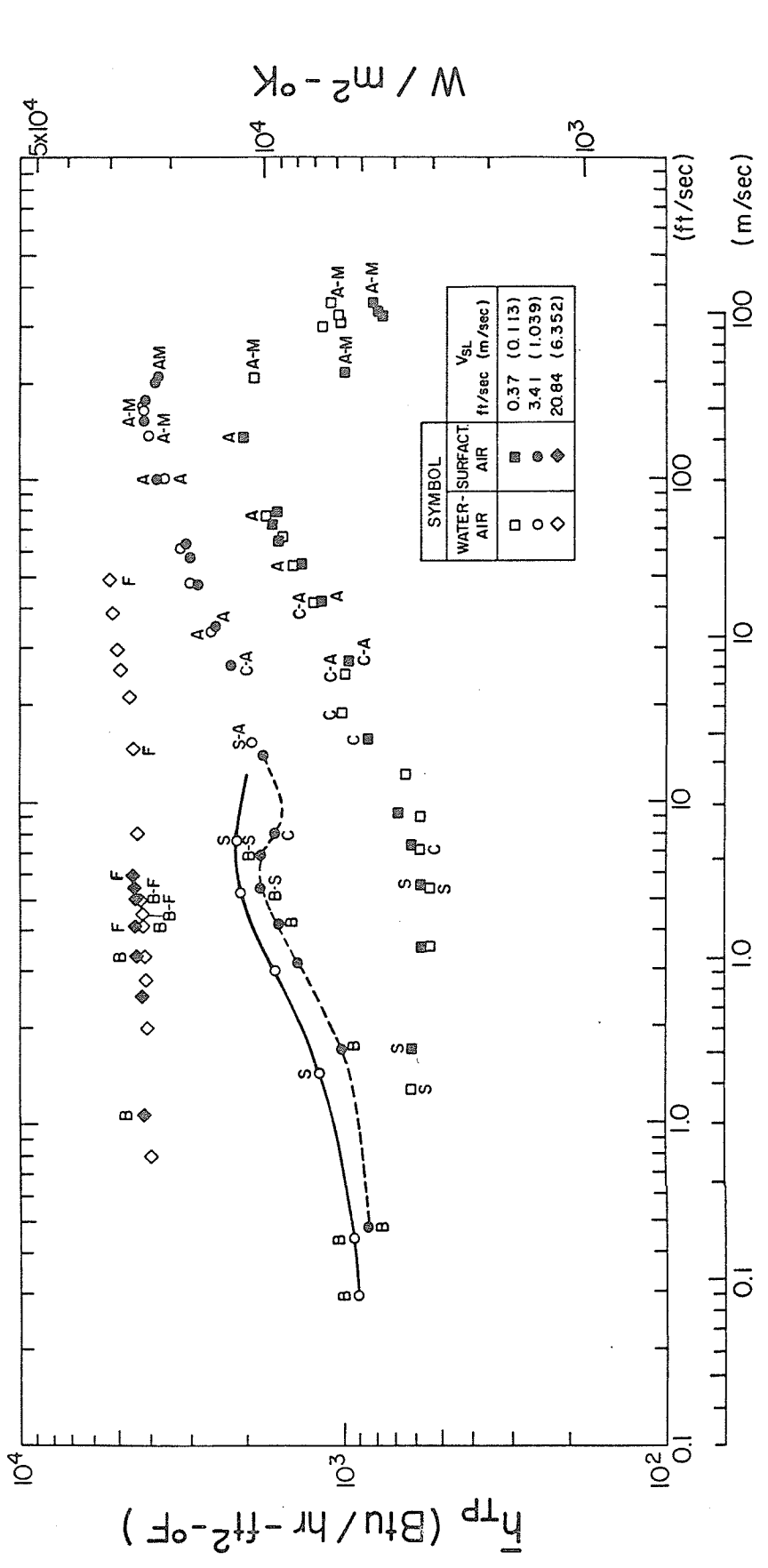


Fig. 6.9B Effect of Surface Tension on Mean Heat Transfer Coefficients.

these data points lie in a region (slug and churn flow) where it was very difficult to obtain accurate data because of the large fluctuations in the wall temperature readings.

At V_{SL} = 0.37 ft/sec (0.113 m/sec) and in the annular-mist region the differences appearing there are not considered significant as the data shown for water-air, as mentioned earlier, are the highest in this region while other water-air data (not shown) exhibited the same magnitude of deviation as the surfactant solution-air data do from the water-air data.

At V_{SL} = 1.03 ft/sec (0.314 m/sec), differences appear at the lower end of V_{SG}. The first two data points for surfactant solution are higher than those for water. These two data points for water-air and one for surfactant solution-air belong to a region (slug flow) where it was difficult to obtain accurate data because of the large fluctuations in the temperature readings; further, only two data points are involved for each liquid.

The author feels that significant differences appearing at the lower end of V_{SL} = 3.41 ft/sec (1.039 m/sec),

indicated by drawing the lines, can be considered as real. In this region changes in the flow patterns were observed, the region previously occupied by slug flow with water-air is now mainly occupied by bubble flow for the surfactant solution-air system. It can be observed that the heat-transfer coefficients for slug flow are higher than for bubble flow for approximately the same fluid flow rates. Where no differences in flow patterns exist there are no significant differences in $\overline{h_{TP}}$.

Similarly at V_{SL} = 10.42 ft/sec (3.176 m/sec), at the lower V_{SG} (where the lines are drawn), significant differences in the $\overline{h_{TP}}$ appear to exist where changes in the flow patterns were observed, again the data points having an element of slug flow being higher than the bubble or bubble froth flow.

It should be noted that it was not possible to operate the rig with the surfactant solution-air system for the entire range of data covered for water-air, due to uncontrollable foam growing in the storage tank.

6.4 Comparison of Local Heat-Transfer Coefficients

This section presents a comparison of local heat transfer data obtained in this work with the modified theory

of Spalding in the manner proposed by Vijay (48). The modification to the existing single-phase theory (41) is based on a homogeneous flow model where the wall shear stress and fluid properties are assumed to be uniform during two-phase flow along the distance Z. The variables S_q and Z^+ for two-phase flow are defined below in their modified form (48)

$$Z^+_{TP} = \int_o^Z \frac{1}{\nu_{mix}} \left(\frac{g_c \tau_w}{\rho_{mix}}\right)^{1/2} dz \tag{6.13}$$

$$= \frac{Z \left(g_c \tau_w \rho_{mix}\right)^{1/2}}{\mu_{mix}} \tag{6.14}$$

$$= \frac{Z}{D^*} \tag{6.15}$$

$$(S_q)_{TP} = \frac{Pr_{mix} h_{TP}}{(C_p)_{mix} \left(g_c \tau_w \rho_{mix}\right)^{1/2}} \tag{6.16}$$

$$= \frac{h_{TP}}{k_{mix}} \cdot \frac{\mu_{mix}}{\left(g_c \tau_w \rho_{mix}\right)^{1/2}} \tag{6.17}$$

$$= \frac{h_{TP}}{k_{mix}} D^* \tag{6.18}$$

$$= Nu^*_{TP}$$

where

Nu^*_{TP} is a modified two-phase Nusselt No.

$$D^* = \frac{\mu_{mix}}{(g_c \tau_w \rho_{mix})^{1/2}} \qquad (6.20)$$

$$\tau_w = \frac{D}{4L} \Delta P_{TPF} \qquad (6.21)$$

τ_w is the two-phase wall shear stress.

Vijay (48) correlated his two-phase local heat transfer data with the modified theory and concluded an excellent agreement as 84% of his experimental data points compared with the theory within $\pm$ 50%. Later the theory was tested by Aggour (1) and its range of applicability was defined which will be discussed later in this section. Aggour (1) compared his local heat transfer data with the theory within its range of applicability and found that 99.75% of his data points were correlated within $\pm$ 50%. In an attempt to generalize the theory, Aggour (1) combined his local heat transfer data with the earlier data obtained by Vijay (48) from the same experimental facility and tested the theory against the complete set of data. It was concluded that the agreement was excellent as 92.7% of the total data points agreed with the theory within $\pm$ 50%. The rms deviation for

the complete set was 30.71%.

It was important to consider the range of applicability of the modified theory of Spalding before the present data were correlated with the theory; this is discussed below.

Examination of the Eqs. (6.13) and (6.16) reveals that a knowledge of mixture properties is required in order to correlate the two-phase local heat transfer results with the theory, Eq. (6.5). The problem of evaluating the mixture properties had been studied in detail by Vijay (48) and Aggour (1) and the use of liquid properties for the mixture properties was recommended for all flow patterns with the exception of annular-mist and mist flow. This reservation seems logical when one considers the structure of mist flow. The void fractions are quite high for annular-mist and mist flow and the main medium of heat transfer would be expected to be the gas phase. Therefore the use of liquid properties for mixture properties in these flow regimes would lead to erroneous results.

At low liquid and gas mass flux, a reversed behavior of $h_{Tp} \sim Z$ exists, as mentioned earlier where h_{TP} increases with an increase in Z along the test section. Since the modified theory proposed by Vijay (48) is essentially a single-phase heat transfer theory of Spalding which does

not accommodate this reversed trend of heat-transfer coefficients, comparison of these data with the theory would indicate large deviations. Exclusion of these data is justified (this represents only a small proportion of the total data).

It can be observed from Eqs. (6.13) and (6.16) that a term of wall shear stress is involved, which in turn requires a knowledge of frictional pressure drop, Eq. (6.21), to predict the local heat-transfer coefficients. Therefore it is desired to use only the accurate and reliable experimental values of frictional pressure drop for the purpose of comparison.

The present local heat-transfer coefficients were correlated with the theory within its range of applicability. Therefore the data falling in any one or more of the following categories were excluded for the purpose of comparison.

1. The data falling in the annular-mist flow, because the use of liquid properties as mixture properties would be inappropriate.
2. The local heat-transfer coefficients which increase with an increase in the distance.

3. The data for which pressure drop measurements were suspected to be in error. The unreliable data in this category includes the data for which the differential in readings on the inverted manometer was less than 0.3 in. of water and also the frictional pressure drop data having negative values. It should be noted that most of the data falling in this category also have a behaviour as described in category 2.

The results of the comparison of the present data with the modified theory of Spalding are shown in Fig. 6.10 for water-air and in Fig. 6.11 for surfactant sol.-air mixtures. Experimental values were used to calculate the ordinate

$$\frac{S_q}{\left(\frac{Pr_L}{Pr_T}\right)^{1/3}},$$

(plotted as data points) while theoretical values were obtained from Eq. (6.5), (indicated by a line on the figure). A value of the turbulent Prandtl number, $Pr_T = 0.887$, was assumed for calculations. The comparison can be considered as excellent, since most of the data is scattered around the theoretical line within $\pm$ 50% deviation.

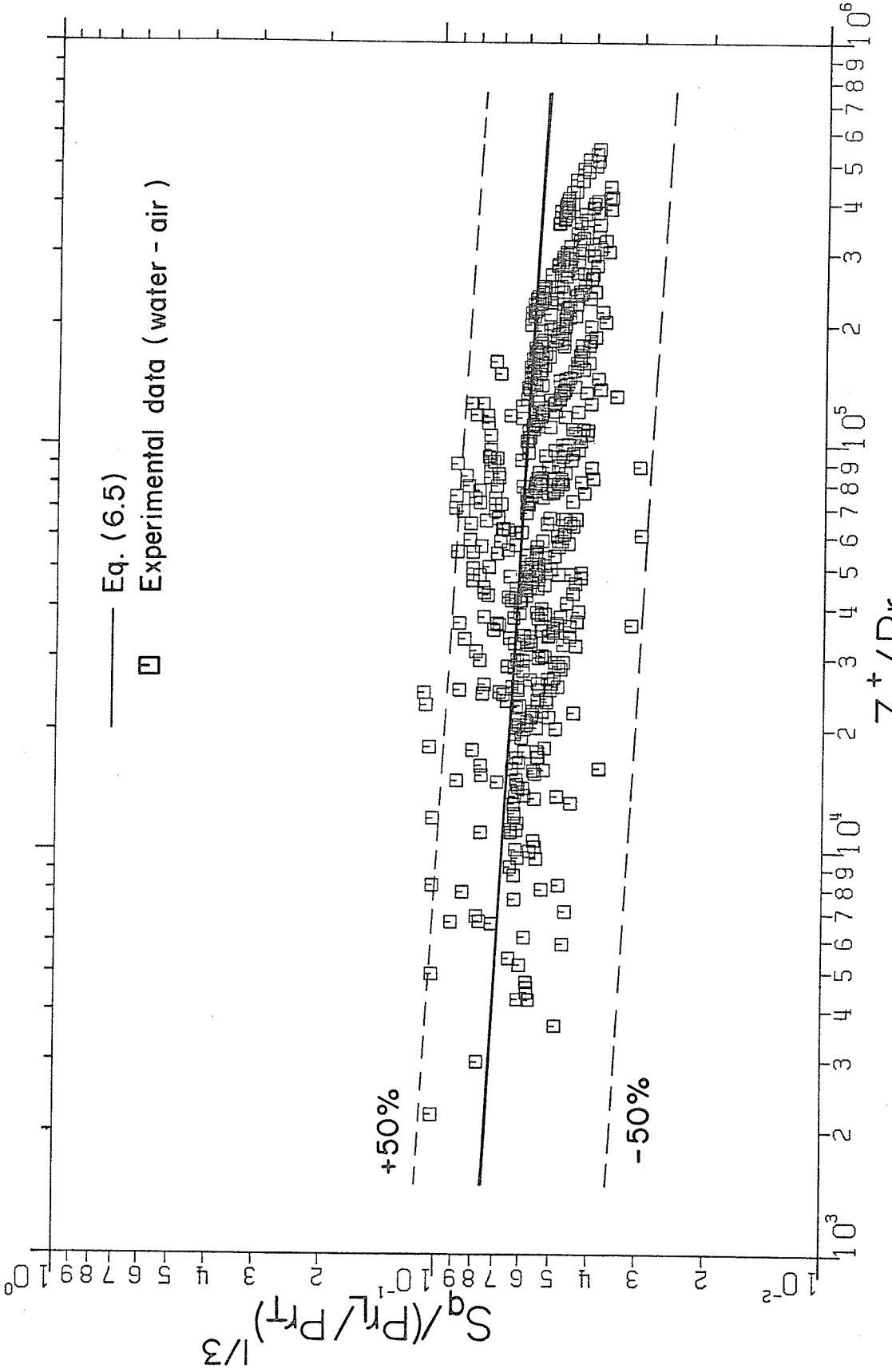


Fig. 6.10 Comparison of Local Water-Air Heat-Transfer Coefficients with the Modified Theory of Spalding

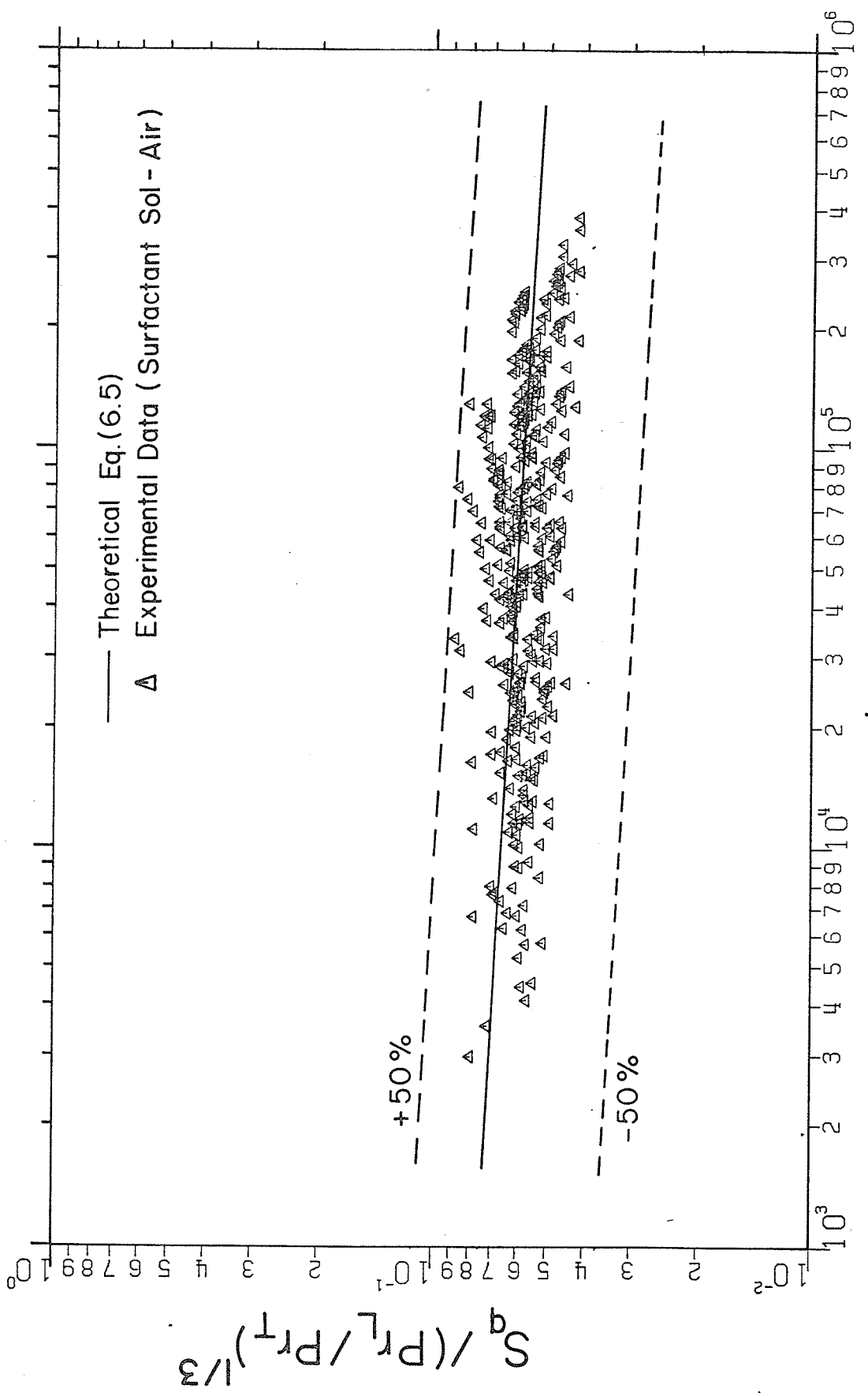


Fig. 6.11 Comparison of Local Surfactant Solution-Air Heat-Transfer Coefficients with the Modified Theory of Spalding

In order to establish the generality of the modified theory, present local heat transfer data were incorporated with the data of Vijay (48) and Aggour (1) which were obtained from the present experimental facility. Then the theory was tested against this combined set of data, which covers the widest range of variables studied so far (see Table 6.4). The summary of this comparison is given in Table 6.4. It should be noted that the water-air data of Vijay (48) and Aggour (1) have been excluded from comparison, since the present water-air data covers almost the entire range studied by them and moreover the present water-air data are similar to their data. It can be observed from Table 6.4 that the majority of the data points (82.6%) agree within $\pm$ 30% and 93.4% of the data compare with the theory within $\pm$ 50%. This illustrates an excellent agreement between the theory and the complete set of data. Therefore, the general nature of the theory is proposed for its use to predict the two-phase local heat transfer coefficients, provided its range of applicability is observed.

6.5 Comparison of Mean Heat Transfer Data Against Some Existing Correlations

This section presents the results of comparison made between some of the existing correlations and the

TABLE 6.4 Summary of comparison between local two-phase heat transfer data and modified Spalding's Eq.(6.5)

Range of Deviation	PERCENT OF TOTAL N LYING IN THE SPECIFIED RANGE OF DEVIATION										
	Present Data			Data of Aggour			Data of Vijay			Present + Aggour + Vijay	Range of Variables
	Water-air	Surfactant sol.-air	Complete Set	Helium-water	Freon-water	Complete Set	Glycerine + water-air	Glycerine air	Complete Set		
$\pm$ 20%	65.79	83.67	73.38	64.88	93.23	77.4	42.67	45.57	43.93	63.20	$1.8 \leq Re_{SL} \leq 1.26 \times 10^5$
$\pm$ 30%	89.29	98.47	93.18	88.39	100	93.52	61.14	70.20	65.09	82.62	$14.0 \leq Re_{SG} \leq 1.5 \times 10^5$
$\pm$ 40%	96.40	99.23	97.6	100.0	100	100.0	73.71	79.56	76.26	90.10	$5.6 \leq Pr_L \leq 6960$
$\pm$ 50%	98.31	100.0	99.03	100.0	100	100.0	81.71	85.86	83.57	93.41	$103 \leq \rho_L/\rho_G \leq 5378$
$\bar{e}$(%)	-7.59	-4.46	-6.26	-12.04	4.45	4.75	30.27	29.11	29.76	10.09	$19.75 \leq \sigma_L \leq 72.0$
$\overline{e^r}$(%)	20.71	14.35	18.28	18.56	11.27	15.76	42.82	38.67	41.06	28.73	
No. of data pts.	532	392	924	336	266	602	525	406	931	2457	

experimental data obtained in this work. The correlations tested are those of Groothius & Hendal (22), Kudirka (28), Ravipudi (33, 34), Vijay (48) and Aggour (1). Some of these correlations (22, 28) have been previously tested by Vijay (48) and Aggour (1) against their data; therefore the same correlations were also selected to compare the present data.

It should be noted that the correlations tested in this section, with the exception of Vijay (48) and Aggour (1) are purely empirical. The pertinent empirical coefficients are, therefore, sensitive to the range of variables under consideration. However, these correlations are tested here for the entire range of present data. In some cases, the results of comparisons within the range of the correlation are also provided.

6.5.1 Correlation of Groothius and Hendal (22)

As discussed in Section 2.2 the authors presented heat transfer measurements for the two-phase flow of water-air and gas-oil-air mixtures in a vertical tube. The heat-transfer coefficients up to the maximum values were correlated by the following expression for the water-air system.

$$\overline{Nu_{TP}} = 0.029\ Re_{TP}^{0.87}\ Pr^{1/3}\ \left\{\frac{\mu_L}{\mu_W}\right\}^{0.14} \qquad (6.22)$$

$$\frac{V_{SG}}{V_{SL}} \geq 1.0 \text{ and } Re_{SL} > 5{,}000$$

where

$$R_{TP} = Re_{SL} + Re_{SG} \quad . \qquad (6.23)$$

The correlation was tested against the present data; only those data points lying within the range specified by the authors were considered for comparison.

The results are summarized in Table 6.5 and would appear as shown in Figs. 7.17 and 6.20 in References (48) and (1) respectively.

The agreement between Eq. (6.22) and present data within the range suggested by the authors can be considered as fair.

6.5.2 Correlation of Kudirka (28)

The author obtained local heat-transfer coefficients at a distance of Z ≈ 14D on the heated section and correlated

TABLE 6.5 Comparison of present data with the correlation of Groothius and Hendal

Liquid-Gas system / Deviation	Water-air	Surfactant-air	Complete set
$\bar{e}(\%)$	-17.99	-20.1	-19.13
$\overline{e'}(\%)$	25.18	23.1	24.08

his air-water and air-ethylene glycol results with the following expression

$$\frac{Nu_{TP}}{(Re_{SL})^{1/4}(Pr)^{1/3}\left(\frac{\mu_G}{\mu_L}\right)^{0.6}\left(\frac{\mu_L}{\mu_w}\right)^{0.14}} = 125\left(\frac{V_{SG}}{V_{SL}}\right)^{0.125} . \quad (6.25)$$

Range of applicability:

$$1 \leq V_{SL} \leq 9 \text{ (ft/sec)}$$

$$0.1 < \frac{V_{SG}}{V_{SL}} < 90 .$$

Eq. (6.25) was compared with all the mean heat transfer data obtained in the present work. The results of comparison are summarized in Table 6.6 and would look like as shown in Figs. 7.19 and 6.22 in References (48) and (1) respectively. Table 6.6 illustrates a poor agreement between the Eq. (6.25) and the present data. However, a better agreement was observed ($\overline{e'}$ = 30.8%) when the correlation was tested within its specified range of applicability and using the present local values of h_{TP} at $Z \approx 16.3D$.

TABLE 6.6 Comparison of $\overline{h_{TP}}$ with the correlation of Kudirka

Range of Deviation	Number of data points (% of total N) lying in the specified range of deviation		
	Water-air (N = 110)	Surfactant-air (N = 98)	Complete set (N = 208)
± 20%	22.73	22.45	22.60
± 30%	32.73	35.71	34.22
± 40%	40.90	42.85	41.88
± 50%	51.0%	53.07	52.04
± 50%	49.0%	46.93	47.97
$\bar{e}$(%)	-8.97	-28.84	18.33
$\overline{e'}$(%)	54.03	48.52	51.49

6.5.3 Correlation of Ravipudi (33, 34)

The author correlated his water-air and Toluene-air data with the following equation within 8% up the maxima in $\overline{h_{TP}}$.

$$Nu_{TP} = 0.56 \left(\frac{V_{SG}}{V_{SL}}\right)^{0.3} \left(\frac{\mu_G}{\mu_L}\right)^{0.2} Re_{SL}^{0.6} Pr_L^{0.33} \left(\frac{\mu_L}{\mu_w}\right)^{0.14} . \quad (6.26)$$

The range of Re_{SL} as covered by the author is from 8,554 to 89,626 and the volumetric gas-liquid flow ratio varies from 1 to 90. Equation (6.26) predicts $\overline{h_{TP}}$ up to a maximum value which would appear at the transition of annular to mist flow.

Eq. (6.26) was tested against present data within the range covered by the author as well as against the complete set of data obtained in this work. The present data along with the correlation, i.e. Eq. (6.26), are plotted in Fig. 6.12 and the results of comparison are summarized in Table 6.7. It can be observed from Fig. 6.12 that the data is scattered around the correlation, especially within the $\frac{V_{SG}}{V_{SL}}$ range specified for Eq. (6.26). The agreement between the complete set of data and Eq. (6.26) is generally good, as 76% of the data points fall within $\pm$ 50%. However, the comparison improves considerably ($\overline{e'}$ = 13.37%) if

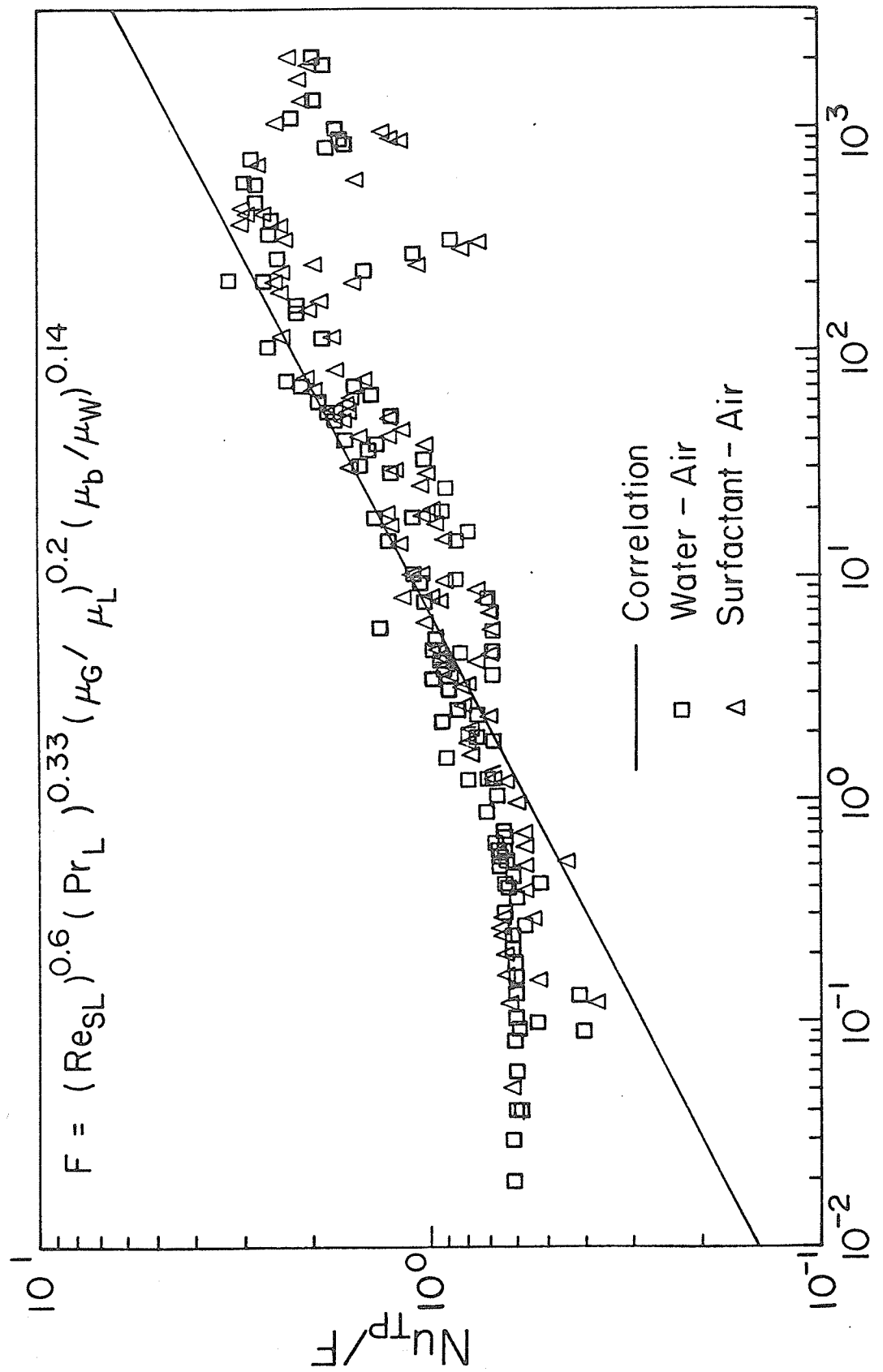


Fig. 6.12 Comparison of Present $\bar{h}_{TP}$ with the Correlation of Ravipudi

Eq. (6.26) is compared with the data bounded by the range as covered by the author. However, it should be noted that the data falling in range of applicability constitute only 25% of the main body of the data obtained in this work.

TABLE 6.7 Comparison of $\overline{h_{TP}}$ with the correlation of Ravipudi (33,34)

Range of Deviation	Percentage of data points lying in the specified range of deviation		
	Water-air (N = 110)	Surfactant-air (N = 98)	Complete Set (N = 208)
± 20%	40.00	50.00	44.70
± 30%	50.91	68.37	59.14
± 40%	66.36	77.55	73.07
± 50%	72.73	80.61	76.44
> 50%	27.27	19.39	23.56
$\bar{e}$ (%)	15.73	-5.61	-5.35
$\overline{e'}$ (%)	59.85	40.08	51.49

6.5.4 Correlation of Vijay (48)

The author proposed the following correlation to predict the mean heat transfer coefficients and compared his data with Eq. 6.27 and found that 87% were correlated within ± 50%.

$$\bar{h}_{TP} = \bar{h}_{AL} + \bar{h}_{AG} \quad . \tag{6.27}$$

As discussed in Chapter 2, the correlation is based on a simple model of separated flow in which it is assumed that both phases flow in separate cylinders; $\bar{h}_{AL}$ and $\bar{h}_{AG}$ appearing in Eq. (6.27) are the single-phase mean heat transfer coefficients based on actual mean velocities and actual flow cross-sectional area of both phases.

The mean heat transfer results obtained in the present work were compared with Eq. (6.27). To calculate the actual mean Re, the void fraction correlation proposed by Chisholm (10) was used. The results of this exercise are shown in Fig. 6.13 where experimental values of $\bar{h}_{TP}$ are plotted against the expected values of $\bar{h}_{TP}$ obtained from Eq. (6.27). Single-phase heat transfer correlations in the form (Eq. 6.11B, 6.12, 2.8 and 2.11) were used to

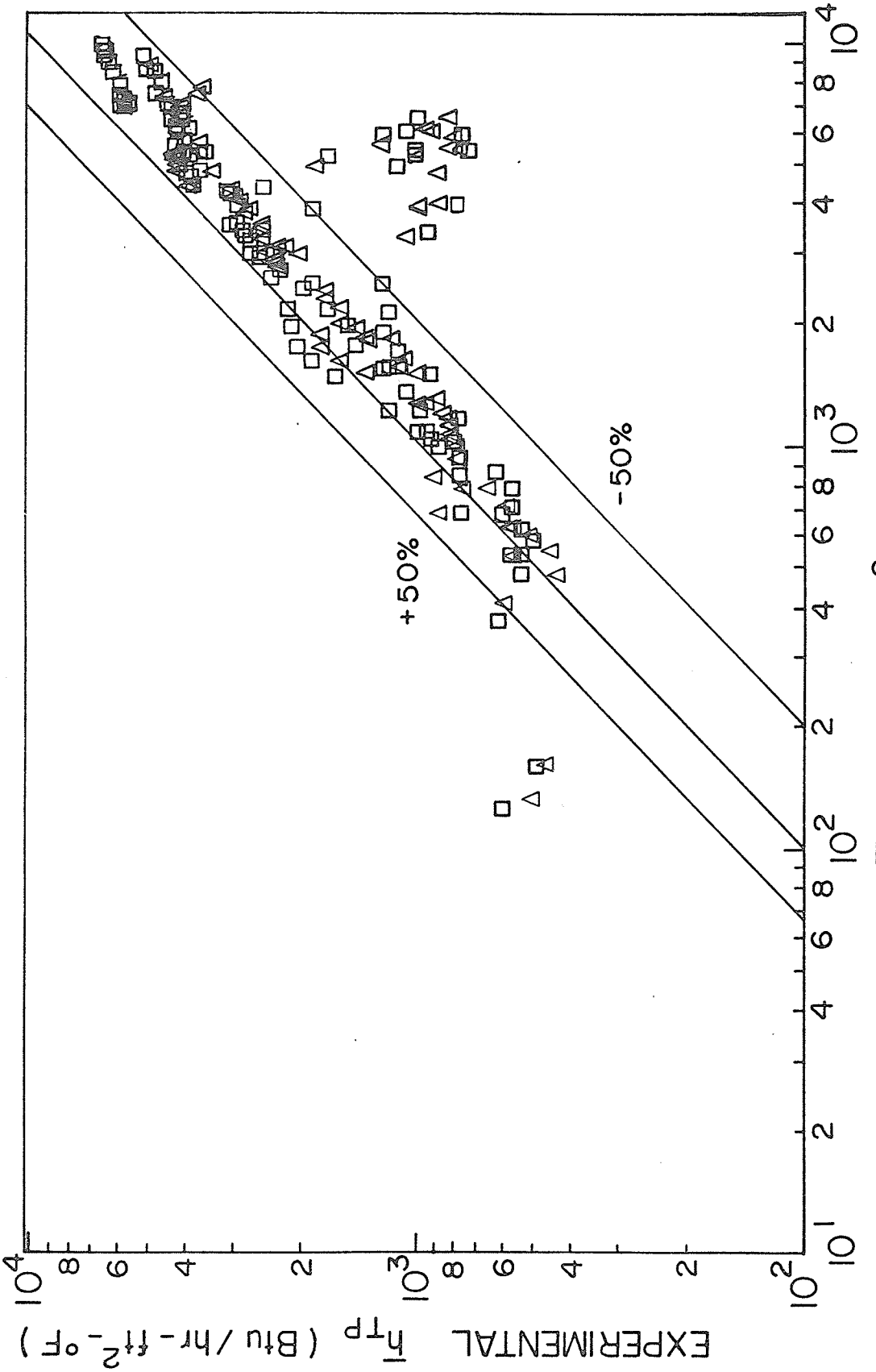


Fig. 6.13 Comparison of $\bar{h}_{TP}$ with the Correlation of Vijay

evaluate $\bar{h}_{AL}$ and $\bar{h}_{AG}$. A summary of the comparison is also given below in Table 6.8.

TABLE 6.8 Comparison of $\bar{h}_{TP}$ with Vijay's correlation

Range of Deviation	Percentage of data points lying in the specified range of deviation		
	Water-air (N = 110)	Surfactant-air (N = 98)	Complete Set (N = 208)
$\pm$ 20%	48.18	34.69	41.82
$\pm$ 30%	70.00	65.31	67.79
$\pm$ 40%	82.73	78.57	80.77
$\pm$ 50%	86.36	84.69	85.57
> $\pm$ 50%	13.64	15.31	14.43
$\bar{e}$(%)	-17.85	-22.43	-20.00
$\overline{\lvert e' \rvert}$	53.06	50.51	51.87
*$\bar{e}$(%)	-23.58	-27.81	-25.57
$\overline{\lvert e' \rvert}$(%)	34.08	37.40	35.68

*Excluding 4 data points for which $\bar{e}$ > 100%

A good agreement between Eq. (6.27) and the present total data is concluded as 85.6% the data points compare within

± 50%. It should be noted that large values of $\overline{e'}$ appearing in Table 6.8 are due to a few data points lying in the slug flow region at the lowest liquid and gas flow rates and in the annular-mist. It was concluded by Vijay (48) that the correlation failed under these conditions and the errors magnified. For example, if the first two data points at the lowest liquid and gas velocity are ignored from water-air as well as surfactant sol.-air results, $\overline{e'}$ for the complete body of the data would improve from 51.87% to 35.68%.

Since the present single-phase laminar heat transfer data were predicted by the Sieder-Tate equation better than by Eq. 6.11.B, therefore Eq. 6.11A was also tried to evaluate $\overline{h}_{AL}$. The change in $\overline{e'}$ was negligible, since most of the data belonged to turbulent flow (based on actual Re, as defined in Reference (48)).

It can be observed from Fig. 6.13 that the correlation has a general tendency to overpredict the $\overline{h}_{TP}$; therefore the correlation Eq. (6.27) was improved by Aggour (1), which will be discussed when the present data is compared with his (1) correlation.

In general, the correlation gives a good prediction of $\bar{h}_{TP}$.

6.5.5 Correlation of Aggour (1)

The author proposed the following correlation to predict the mean heat-transfer coefficients

$$\bar{h}_{TP} = \bar{h}_{SP} (1 - \alpha)^n \qquad (6.28)$$

where

$n = -1/3$ for laminar flow ($Re_{SL} > 1{,}000$)

$n = -0.83$ for turbulent flow ($Re_{SL} > 2{,}000$) .

Equation (6.28) is basically a modification to the correlation earlier proposed by Vijay (48), Eq. (6.27). For the development of the above correlation, the author assumes that the contribution of gas to the heat transferred to the two-phase mixture is very small. The introduction of gas phase acts only to accelerate the liquid phase, this phase acting as the heat transfer medium.

In Eq. (6.28) $\bar{h}_{SP}$ is the single-phase liquid mean heat-transfer coefficient based on the superifical Reynolds number Re_{SL} and evaluated from Eqs. (2.13) and (2.14) as

explained in Section (2.6).

The correlation is tested in Fig. 6.14 where experimental $\bar{h}_{TP}$ is plotted against the expected values calculated from Eq. (6.28). The results of this comparison are also summarized in Table 6.9 and are given below

TABLE 6.9 Comparison of $\bar{h}_{TP}$ with Aggour's correlation

Range of Deviation	Percentage of data points lying in the specified range of deviation		
	Water-air (N = 110)	Surfactant-air (N = 98)	Complete Set (N = 208)
$\pm$ 20%	55.45	53.06	54.32
$\pm$ 30%	78.18	77.55	77.88
$\pm$ 40%	87.27	82.65	85.09
$\pm$ 50%	87.27	83.67	85.57
> $\pm$ 50%	12.73	16.32	14.42
$\bar{e}$(%)	-15.87	-19.24	-17.46
$\overline{e'}$(%)	33.33	33.68	33.50

Table 6.9 illustrates a very good agreement between the present experimental data and Eq. (6.28) as 85% data points were correlated within $\pm$ 40%. It should be noted that the

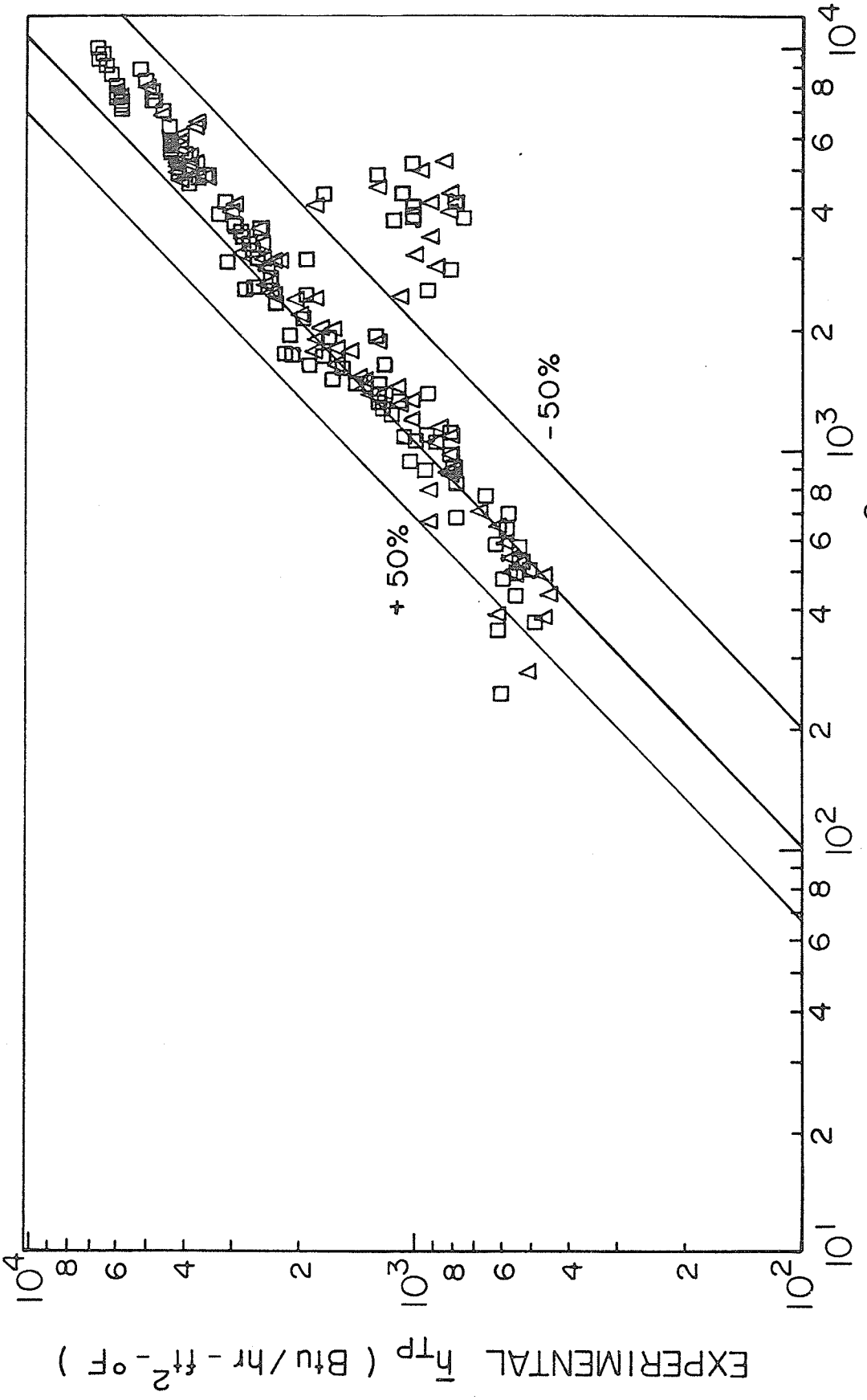


Fig. 6.14 Comparison of $\bar{h}_{TP}$ Against the Correlation of Aggour

TABLE 6.10 Comparison of present and previous (Vijay and Aggour) Data with Aggour's correlation. Eq. (6.28)

Range of Deviation	Percentage of data points lying in the specified range of deviation				Range of Variables
	Present Data (N = 208)	Data of Aggour (N = 96)*	Data of Vijay *(N = 133)$	Complete Set (437)	
± 20%	54.32	59.38	72.18	60.86	Re_{SL} $(1.8 - 1.26 \times 10^5)$
± 30%	77.88	84.37	78.20	79.40	Re_{SG} $(14 - 1.6 \times 10^5)$
± 40%	85.09	93.75	78.20	84.90	
± 50%	85.57	95.83	79.70	86.03	Pr_L (5.6 - 6960)
$\bar{e}$(%)	-17.46	-8.57	18.17	-4.66	ρ_L/ρ_G (103 - 5378)
$\overline{e'}$(%)	33.50	23.48	43.83	35.21	σ_L (20 - 72)

*Water-air data not included

$Taken from Reference (1)

agreement would further improve if the results belonging to the annular-mist flow were excluded from the comparison. In annular-mist flow, gas-phase is the main medium of heat transfer which contravenes the basic assumption made for the development of Eq. (6.28).

In an attempt to generalize Aggour's correlation, present data were combined with the previous data obtained from the same experimental facility (48, 1). Equation (6.28) was tested against this combined body of data, which covered the widest range of variables studied so far, as could be observed from Table 6.10. The results of this excercise are summarized in Table 6.10, which does not include the water-air data of Vijay (48) and Aggour (1) since they were similar to the present water-air results. It can be concluded from Table 6.10 that the comparison between the correlation and the data is excellent as 86% of combined set of data agrees within $\pm$ 50%. The comparison is most certainly excellent, especially when one considers the range of variables covered in the data.

6.5.6 Conclusion of the Comparison of Mean Heat Transfer Results

The comparative study presented in the previous sections allows one to conclude that the simple correlations of Vijay (48) and Aggour (1) are the best among those considered in this study. However, a comparison between Tables 6.8 and 6.9 suggests that Aggour's correlation is superior to that of Vijay (48). The correlation of Aggour when compared against the whole body of data (present + (48) + (1)) obtained from the same experimental apparatus, does excellently (see Table 6.10). This correlation, Eq. (6.28), is therefore recommended to predict the two-phase mean heat transfer coefficients with good accuracy in all the flow patterns occurring in vertical upflow except in annular-mist and mist flows.

CHAPTER 7

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary and Conclusions

1. Data for flow patterns, frictional pressure drop and mean heat-transfer coefficients were reported for water-air and surfactant solution-air systems for a wide range of liquid and gas flow rates.

2. The effect of reducing the surface tension of water by the addition of surfactant was determined on the above-mentioned measured variables.

3. Flow pattern photographs were presented and flow regime maps determined for both liquid-air systems. The surface tension produced essentially no effect on the slug-churn, churn-annular, annular-mist and bubble-froth transitions for all liquid and air flow rates. Bubble-slug is the only boundary significantly affected by surface tension; for this boundary the surfactant produced effects in such a way that the region previously occupied by slug flow for water-air is now mainly occupied by bubble flow. Figure 5.7 shows the region (cross-hatched) where these effects are apparent.

4. Some of the existing flow pattern maps were studied and the present data were compared with the Govier and Aziz map (20) and the map proposed by Taitel et al. (43); it was concluded that maps based on experimental data are restricted to lower liquid flow rates while maps based on analytical correlations are not yet adequate to predict all the transition boundaries accurately.

5. It was concluded that surface tension produced little effect on the frictional pressure drop, with ΔP_{TPF} being generally slightly lower for the surfactant solution-air system than for the water-air system where differences existed.

6. Surface tension produced no effects on the shape of the profiles of local heat-transfer coefficients as a function of distance Z along the test section. Surface tension produced some effects on mean heat-transfer coefficients, with a general tendency for the $\bar{h}_{TP}$ was to be lower for surfactant solution-air than for water-air where differences existed. Significant differences were observed at V_{SL} = 3.41 ft/sec (1.039 m/sec) and 10.42 ft/sec (3.176 m/sec) for low V_{SG}; these differences

appeared where a difference in the flow pattern was observed $\bar{h}_{TP}$ being lower for bubble flow than slug flow for approximately the same liquid and air velocities.

7. The local heat-transfer coefficients were correlated with the modified theory of Spalding (41) in the manner proposed in Reference (48) which with certain justifiable exclusions, gave agreement with an rms deviation of approximately 18%. The correlation was tested for generality with a wide range of data [present and previous (48, 1)]; 93% of 2457 data points agreed with the theory within $\pm$ 50%, for all the data, the mean and rms deviations were 10.09% and 28.73% respectively.

8. Present mean heat transfer data were tested against some of the well-known existing correlations; the results were generally good; however, the best agreement was obtained with the correlation of Aggour (1).

7.2 Recommendations for Future Work

(i) In the present work, a surfactant was added to the water in order to achieve low surface tension values; in future work, the next step in investigating the effect of surface tension would be to use pure liquids.

(ii) In measuring the total pressure drop, pressure transducers should be used rather than manometers in order to avoid the errors encountered due to readings of small deflection on the manometers and large fluctuations in the readings at low flow rates of the liquid and gas.

(iii) It is recommended that in future work, void fraction should be measured. Predicting the void fraction for different liquid-gas systems from the same correlations, especially when differences in the flow patterns occur, may not be as good as using actual measurements.

(iv) Better techniques should be used to photograph the flow patterns at high liquid flow rates (in froth flow) where the flow is opaque.

(v) To obtain more accurate temperature readings under highly unsteady condition (slug and churn flow), it is recommended to use a programmable data logger having a high scan rate.

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APPENDIX A

DETAILED INFORMATION ON EXPERIMENTAL EQUIPMENT

This appendix gives details of the apparatus and measuring equipment including the fluid property measuring devices.

It should be noted that most of material presented in this Appendix is taken from Reference (48).

Table A.1 lists the manufacturer, model number, etc. of the equipment used. The numbers appearing in the table (the item number) correspond with the circled numbers in Figs. 3.2 to 3.9 of Chapter 3.

Some of the important measuring instruments such as electrical power measuring meters, fluid flow meters, temperature-measuring instruments, etc. were calibrated occasionally during the period of the present work. Other components like thermocouples and the heat transfer test section were calibrated only once (48) before installing in the facility. The detailed information on the calibration of such components is given in Reference (48).

TABLE A.1

Information on the Components of the Experimental Facility

Part No. in Figs. 3.2 to 3.9	Name of the Component	Remarks
MIXING CHAMBER		
1	Stainless steel strainer	3.0 in. dia., 1/32 in. performated stainless steel type 304 Sarco strainer. Sarco Canada Limited, Agincourt, Ontario, Canada.
2	Porosint bronze tube	0.460 in. I.D. x 0.740 in. O.D. x 8.0 in. grade E; Sintered Products Limited, Sutton-in-Ashfield, Notts, England, U.K.
HEATED TEST SECTION		
3	Heated test tube	Stainless steel type 304; 0.460 in. I.D. x 0.020 in. thick; Atlas Alloys, L = 2 ft.; Atlas Steels Limited, Welland, Ontario, Canada.
4	Bus bars	Brass, 6.75 x 3.0 x 0.94 in.
5	Supporting bar	1.0 x 1.0 in. Permali insulating material; Permali (Canada) Limited, Toronto, Ontario, Canada.
6	Guard heater tube	1.5 in. I.D. x 0.0625 in. thick split copper tube retained by Permali rings.
7	Heating elements	Two Briskeat silicone rubber embedded heating tapes (0.5 in. wide x 8 ft. & 0.5 in. x 10 ft.); Briscoe Manufacturing Co., Columbus, Ohio, U.S.A.
OBSERVATION SECTION		
8	Visual section	3.0 x 3.0 in. x 1 ft. cast acrylic rectangular prism with 0.460 in. precision-bored hole.

Part No. in Figs. 3.2 to 3.9	Name of the Component	Remarks
9	Digital voltmeter	Keithley 191 Digital multimeter, model 191, 5-1/2 digit, 0.0005% resolution, accuracy 0.007% vdg + 3 digits; Keithley Instruments, Inc., Cleveland, Ohio, U.S.A. Calibrated in the laboratory regularly.
10	Strip recorder	Honeywell Two-Pen Electronik 104 Multi-Range Lab/Test Wide Chart Recorder, Model No. 104112-002-002); specified accuracy: span: ± 0.25% of span or 1 microvolt whichever is greater; zero position: ± (0.25 + 0.1 x suppression ratio)% of span or 1 microvolt whichever is greater; Honeywell Controls Ltd., Scarborough, Ontario, Canada. Calibrated in the laboratory regularly.
11	Data logger	Fluke Data Logger Model 2240A, 60 channel capacity (could be extended up to 1000 channels), scanning speed up to 15 channel/sec., accuracy ± 0.1°C, programmable, equipped with a digital display and printer, displays and prints date, time (hour, min., sec.), channel no., reading (mV or °C) and units. John Fluke Mfg. Co., Inc., Mountlake Terrace, Washington, 98043.
12	Voltage standard	Fluke DC Voltage Standard-Differential Voltmeter-null Detector, (Model 335A), accuracy: (0.002% of setting + 10 μv); John Fluke Mfg. Co., Inc., Seattle, Washington, U.S.A.

Part No. in Figs. 3.2 to 3.9	Name of the Component	Remarks
13	Ice bath	Thermo-Electric ICELL T.M. Ice Point Reference Unit; a completely automatized Ice Bath (Model 80020-6); Thermo Electric (Canada) Limited, Brampton, Ontario, Canada Accuracy: 0.00°C to ± 0.05°C; Stability: ± 0.01° for any constant ambient.
14	Selector switch	Thermo-Electric Selector Switch; 96 points, 48 switches, custom key palladium contact switches, Model No. 33212. Double pole, double throw, centre OFF type.
15	Constant temperature bath	Gebruder Haake Model FS/FT Constant Temperature Bath; specified accuracy: ± 0.02°C; Gebruder Haake, Karlsruhe W. Germany. Used for calibrating the thermo-couples in the laboratory (Reference (48)).
LIQUID FLOW LOOP		
16	Pump	Waukesha Positive Displacement Pump, Model No. 25 DO-1 1/2. All Nickel-Bronze construction (Waukesha Metal). Complete assembly supplied with a 5 hp (220 volt, DP) motor and a V-belt drive. Max. flow = 24 USGPM (water); Max. Pressure = 150 psi and Max. Temp. = 225°F. Buna-N seals; Waukesha Foundry Company, Waukesha, Wisconsin, U.S.A.
17	Flowmeters A	Fischer & Porter Indicating Type Flowrator (Rotameter), Model No. 10A3537A, 316 stainless steel float (1/2 - GUSVT-40), Tube: FP = 1/2-21-G-10/83, percent scale. Flowrate: Max. = 0.328 USGPM Liquid sp. gr. = 1.0.

Part No. in Figs. 3.2 to 3.9	Name of the Component	Remarks
17 - continued	B	Model No. 10A3537A, 216 stainless steel float (3/4 27-G-10/83, % scale, Flowrate: Max. = 3.55 USGPM liquid sp. gr. - 1.0.
	C	Model No. 10A3537A, 316 Stainless Steel float (2-GSVGT-98). Tube: FP-2-27-G-10/83, %, scale, Flowrate: Max. = 30 USGPM liquid sp. gr. 1.0.
	D	Model No. 10A3537P, 316 stainless steel float (NSVT-622), Tube: PP-1-60-P 8/83, % scale, Flow-rate: Max. = 20 USGPM liquid sp. gr. = 1.0. (Used for controlling the cooling water rate in the heat exchanger). All flow ratos were calibrated in laboratory for water for the present investigation. Fischer and Porter (Canada) Ltd., Downsview, Ontario.
18	Manometer (to measure ΔP)	1/4 in. I.D. inverted glass manometer. Designed and manufactured in the Mechanical Engineering Laboratory.
19	Manometer (to measure ΔP)	Meriam Model 20AA25TM, Range 100 in. U-type, mercury manometer. Equipped with standard scale and 303 stainless steel wetted parts. The Meriam Instrument Company, Cleveland, Ohio, U.S.A.
20	Gas-liquid separator tank	1 1/2 x 1.0 ft. stainless steel tank with 3 in. outlet in the cover plate and 1 1/2 in. drain; Greensteel Industries Limited, Winnipeg, Manitoba, Canada

Part No. in Figs. 3.2 to 3.9	Name of the Component	Remarks
21	Liquid storage tank	1 1/2 x 3 ft. stainless steel tank with 3 holes in the cover plate (3 in. dia.) 1 1/2 in. drain and a side mounted 1/2 in. I.D. glass level indicator; Greensteel Industries Limited.
22	Heat exchanger	Liquid-to-liquid shell and tube type exchanger. All copper 0.625 in. I.D. tubes by 4 ft. long shell dia. 2 ft. Automedic Instruments Limited, Winnipeg, Manitoba, Canada.
POWER SUPPLY CIRCUIT		
23	Variac	Powerstat variable Auto-transformer, Model No. P1156-4PS. Single-phase, 240 volt-100 amps-24 kvA. American Superior Electric Company, U.S.A.
24	Transformer	Single-phase Dry Type Distribution Transformer. Open-ventilated, class-F. Primary: 240 volt-100 amps, secondary: 1200 amps. Pioneer Electric Manitoba Limited, Winnipeg, Manitoba, Canada.
25	Current transformer	Weston Model 327, Type 2. Primary: 100 amps, secondary: 5 amps. Weston Electrical Instrument Corporation, Newark, N.J., U.S.A. Calibrated in the laboratory (Reference (48)).
26	Ammeter	Weston A.C. Ammeter, Model 433 (25-500 cycles). Range: 5/2.5/1. amp. Calibrated in the laboratory (Reference (48)).
27	Voltmeter	Weston A.C. R.M.S. Voltmeters. Range: 0 to 10 volts and 0 to 30 volts. Calibrated in the Laboratory (Reference (48)).

Part No. in Figs. 3.2 to 3.9	Name of the Component	Remarks
28	Potential transformer	Weston Potential Transformer, Model 311, Type 1. 2300/1150: 115V, 15 VA, 25-133 CPS. Calibrated in the laboratory (Reference (48)).
29	Wattmeter	Weston Portable Wattmeter, Model 432. 5 amp capacity. Voltage range: 75/150/300 v. Calibrated in the laboratory.
30	Temperature controller	Honewell Servotronik Temperature Controller, Model No. 5500101-2-05-02. Type T-couple. Range: 0 - 200°C.
PHOTOGRAPHIC SECTION		
31	Camera	Pentax Spotmatic Single Lens Reflex Camera equipped with Super-Takumar 50 mm f/4 Macro (close up) lens.
32	Camera	Nikon protomatic FTN equipped with Nikkor-S lens, 50 mm f/1.4 lens.
33	Strobotac	General Radio Type 1538-A Strobotac Electronic Stroboscope. Flashing-rate range: 110 to 150,000 flashes per minute. Flash Duration: 0.5 to 3 μs. General Radio Company, West Concord, Massachusetts, U.S.A.
34	Flash unit	EG&G 549 Microflash System consisting of the Model 549-11 Flash Unit and the Model 549-21 Driver Unit. Flash Duration 0.5 μs; Peak light: 50 x 10^6 beam candle power. Edgerton, Germeshausen & Grier, Inc., Boston, Mass. U.S.A.
AIR FLOW LOOP		
35	Compressor	7 x 7 in. double acting, single cylinder, type ES-1 and serial no. 14415; 1.375 in. diameter of piston rod; dual control; water cooled, single pass, conter-flow;

Part No. in Figs. 3.2 to 3.9	Name of the Component	Remarks
AIR FLOW LOOP - Continued		
35	Compressor	electrical drive, 15 hp, 220-440 V, 3-phase, 1750 rpm motor; 92CFM capacity at 300 rpm at 100 psi; Canadian Ingersoll Rand Co. Ltd., Canada.
36	Orifice plates	Three sharp-edged plates of 0.418, 0.141 and 0.046 in. dia., designed and manufactured in the laboratory according to ASME Power Test Code. All orifice plates were calibrated in the laboratory (Reference (48)).
37	Rotameter	Tube No. 3-15-4; Glass Float; Brooks Instrument Co., Inc., Hatfield, Pennsylvania, U.S.A.
38	Manometer	Meriam Model 30EB25TM, Range 100", well-type manometer. Equipped with standard scale and 303 stainless steel wetted parts.
FLUID-PROPERTY MEASURING EQUIPMENT		
39	Surface tension analyzer	Fisher Model 215 Autotensiomat surface tension analyzer (operates on the principles of the du Nouy ring and Wilhelmy plate methods); analog panel meter readout (or potentiometric recorder); 0 to 100 dynes/cm range; 0.02 dynes/cm sensitivity $\pm$ 2% relative accuracy; 0.02 dynes/cm resolution (on 0-5 dynes/cm range, using the recorder). Calibrated in laboratory several times during each run, supplied by Fisher Scientific Canada, Ltd.

Part No. in Figs. 3.2 to 3.9	Name of the Component	Remarks
40	Potentiometer recorder (accessory for surface-tension meter)	Fisher Recordall series 500, single-pen wide chart recorder, 1 MV to 10V range; 12 chart speeds; maximum error 0.1% of 1 MV full scale; repeatability ± 0.01% of full scale. Houston Instrument, Austin, Texas. Calibrated regularly in laboratory.
41	Viscometer	Haake Falling-Ball Viscometer Model B, used with a constant temperature circulator; measuring range of 0.01 to 5×10^5 CP; accuracy of -0.1 to 0.5%; temperature range of -60 to +150°C. Supplied by Fisher Scientific Co., Ltd. Edm., Alta., Canada.
42	Constant temperature circulator	Haake Constant Temperature Circulator Model FS; temperature range up to 250°C; maximum accuracy of ± 0.004°C. Supplied by Fisher Scientific Co., Ltd.

APPENDIX B

PHYSICAL PROPERTIES OF FLUIDS

The physical properties used for the reduction of present heat transfer data are summarized in Table B.1. These equations are taken from Reference (1) where in Reference (1) these equations were taken from the References (B1) and (B2). In the present work the property equations for water, other than for surface tension, were also used for surfactant solution since surfactant produces large variation is surface tension values at relatively low concentration while keeping the other properties essentially unaltered. In Reference (1) it was assumed, in obtaining these equations, that the pressure has no effect on viscosity, thermal conductivity and specific heat.

Table B.1

Physical Properties of Fluids (From Reference (1))

Water

Value or Equation for the Physical Property (T in °F)	Units	Range of Validity and Deviation
$\rho_L = [0.01602 - 1.303 \times 10^{-6}\ T + 2.101 \times 10^{-8}\ T^2]^{-1}$	lbm/ft^3	$32 \leq T \leq 212$ 0.1%
$C_{PL} = 1.018 - 3.374 \times 10^{-4}\ T + 1.337 \times 10^{-6}\ T^2$	Btu/lbm-°F	$32 < T < 212$ 0.3%
$\sigma_L = 5.346 \times 10^{-3} - 4.75886 \times 10^{-6}\ T - 8.05936 \times 10^{-9}\ T^2 + 5.52288 \times 10^{-12}\ T$	lbf/ft	$68 < T < 150$
$K_L = 0.3149 + 4.722 \times 10^{-4}\ T$	Btu/hr-ft-°F	$32 < T < 176$ 0.2%
$\mu_L = [0.09461 + 3.863 \times 10^{-3}\ T + 1.207 \times 10^{-5}\ T^2]^{-1}$	lbm/ft-hr	$32 < T < 212$ 1.0%

Table B.1

Physical Properties of Fluids

Air

Value or Equation for the Physical Property (T in °F)	Units	Range of Validity and Deviation
$\rho_G = P/RT$ $P(lbf/ft^2)$, T(°R), R - 53.34 lbf-ft/lbm°R	lbm/ft^3	Accurate in the range of pressure investigated
$C_{PG} = 0.2401 + 7.540 \times 10^{-6}T$	Btu/lbm°F	-10<T<242 0.2%
$k_G = 0.01313 + 2.591 \times 10^{-5}T - 2.67 \times 10^{-9}T^2$	Btu/hr-ft°F	-10<T<242 0.1%
$\mu_G = 0.03936 + 6.819 \times 10^{-5} - 2.673 \times 10^{-8}T^2$	lbm/ft-hr	same as above

References for Appendix B

B.1 Greenland, R., Ph.D. Thesis, Mechanical Engineering Department, Imperial College of Science & Technology, University of London, London, England, U.K., (1963)

B.2 Gambil, W.R., Estimating Engineering Properties Parts I to VI, Chemical Engineering (1957, 1958, 1959 and 1960)

APPENDIX C

CALCULATION PROCEDURE

This appendix gives the definitions and procedure for obtaining the heat-transfer coefficients and the hydrodynamic quantities of interest in the present work. It should be noted that most of the material presented in this appendix has been taken from (48, page 323; 1, page 299).

The calculations were performed on IBM 370 computer at The University of Manitoba.

C.1 Definition of the Heat-Transfer Coefficients

The local and mean heat-transfer coefficients were calculated as follows:

a) Local Heat Transfer Coefficients

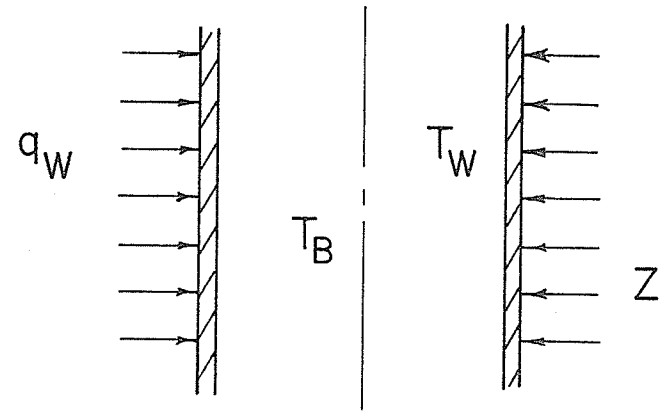


Fig. C.1

$$h(Z) = \frac{q_w}{T_w - T_B} \qquad (C.1)$$

where

q_w is heat flux at the wall at the location Z,

T_w is inner wall temperature at the location Z,

T_B is bulk fluid temperature at the location Z,

h(Z) is local heat-transfer coefficient.

b) Mean Heat Transfer Coefficient

The mean heat-transfer coefficients were calculated from the local values by the following expression

$$\bar{h} = \frac{1}{\Delta L} \int_{L_1}^{L_2} h(Z)\, dZ \quad . \qquad (C.2)$$

Local values of h as a function of Z are illustrated qualitatively in Fig. C.2.

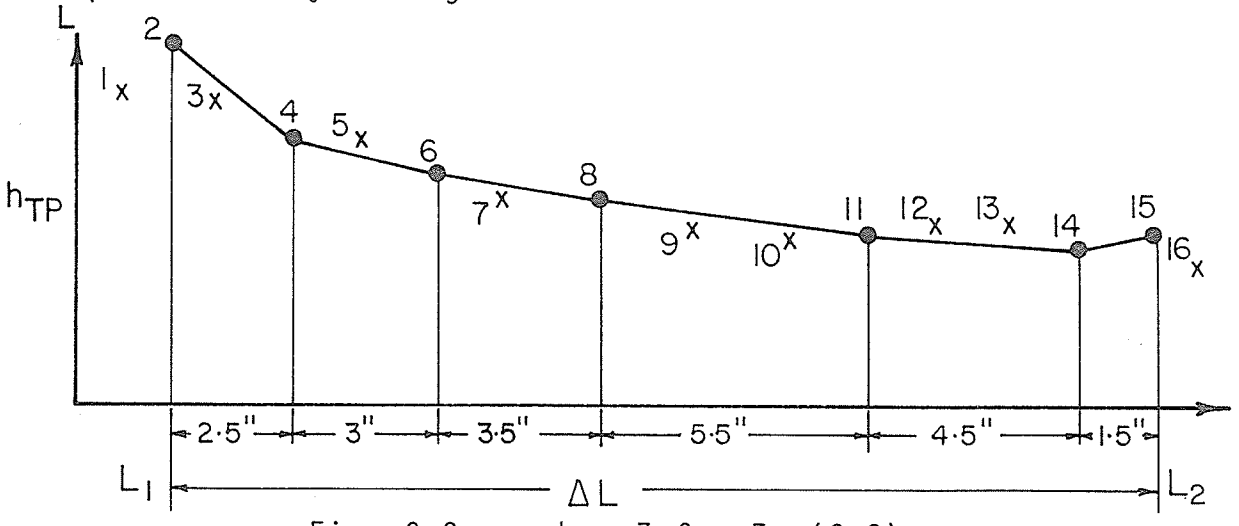


Fig. C.2 h ~ Z for Eq.(C.2).

The local values of heat-transfer coefficients were calculated from Eq. (C.1) at 16 horizontal planes along the test section as shown in Fig. C.2. However, the values at seven planes denoted by circles were used to calculate $\bar{h}$ for the reasons explained in References (48, page 326) and (1, page 301) in detail.

Eq. (C.2) was solved numerically by using trapezoidal rule for integration.

C.2 Calculation of The Local Heat-Flux (q_w)

The local heat flux at the wall at the location Z (Fig. C.3) was calculated from the knowledge of the local resistivity and the current flowing through the tube as follows:

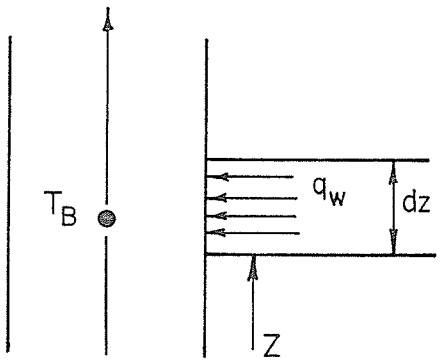


Fig. C.3

Consider the elemental length dZ of the tube at location Z. The heat generated in this elemental length is given by

$$dq_w = GI^2 dR_t \qquad (C.3)$$

where

dR_t is the resistance of the elemental length dZ of the tube and is given by

$$dR_t = \overline{\rho'} \frac{dZ}{A_c}$$

$\overline{\rho'}$ is the average resistivity of the tube at location Z,

A_c is the cross-sectional area of tube wall,

I is the electric current flowing through the tube,

G is the conversion factor - 3.413 Btu/watt-hr.

Therefore

$$q_w = \frac{dq_w}{dA_s} = \frac{GI^2\overline{\rho'}\, dZ}{A_c(\pi D)dZ} \qquad (C.4)$$

where

$dA_s = \pi D dZ$, is the elemental surface area of the tube.

Hence

$$q_w = \frac{GI^2\overline{\rho'}}{\pi D\, A_c} \qquad \left(\frac{Btu}{hr\text{-}ft^2}\right) . \qquad (C.5)$$

The thermal losses from the outside of the heated section are negligible due to the presence of guard heaters and insulation. Therefore eq. (C.5) represents the net heat flux transferred to the fluid.

C.3 Calculation of the Inner Wall Temperature from the Measured Outer Wall Temperature

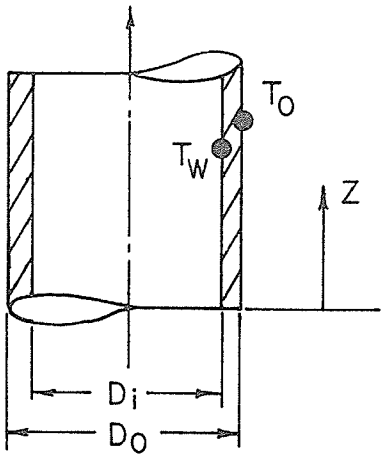


Fig. C.4 Temperature Drop Through the Wall of the Tube.

In order to calculate the local heat-transfer coefficient from Eq. (C.1), the local temperature T_w (Fig. C.4) at the fluid-wall interface (inner wall temperature) is required. This T_w was obtained by measuring the outer wall temperature T_o and then calculating the temperature drop across the wall, that is

$$T_w = T_o - \Delta T_w \qquad (C.6)$$

where

ΔT_w is the temperature drop across the wall.

In Reference (48) ΔT_w was calculated by using the method developed by Kreith and Summerfield (C.3) for the

temperature distribution in an electrically heated resistor of tubular shape with the total energy dissipated to the fluid flowing inside. The expression for ΔT_w as given by the authors (C.3) is as follows:

$$\Delta T_w = B_0 t^2 + B_1 t^3 + (B_2 + B_3) t^4 \qquad (C.7)$$

where

t is the wall thickness, given by $t = R_o - R_i$,

$B_0 = m/(1+\beta' T_o)\ (1+\alpha' T_o)$,

$B_1 = 2m/3D_o\ (1+\beta' T_o)\ (1+\alpha' T_o)$,

$B_2 = m^2(3\alpha'+4\alpha'\beta' T_o + \beta')/6(1+\beta' T_o)^3(1+\alpha' T_o)^3$,

$B_3 = m/D_o^2(1+\beta' T_o)\ (1+\alpha' T_o)$,

D_o is the outer diameter of the tube,

R_o is the outer radius of the tube,

R_i is the inner radius of the tube,

$m = G(de/dZ)^2/2\rho_o' k_o' \qquad (C.8)$

β' is the temperature coefficient of resistivity of the tube material, given by

$$\rho' = \rho_o'(1+\beta' T)$$

ρ' is the electrical resistivity of the tube material,

α' is the temperature coefficient of thermal conductivity of the tube material defined by

$$k_t = k_o'\ (1+\alpha' T)$$

k_t is the thermal conductivity of the tube material,

(de/dZ) is the voltage gradient in the tube.

Eq. (C.8) for m can be expressed in terms of the measured current (I) flowing through the tube as follows.

For the elemental length dZ, the voltage gradient can be obtained from

$$\frac{\partial e}{\partial Z} = - \rho' i = - \rho' \frac{I}{A_c} \quad .$$

Hence

$$m = \frac{G}{2\rho'_o k'_o} \cdot \rho'^2 \cdot \left(\frac{I}{A_c}\right)^2 \qquad (C.9)$$

where

$$A_c = \frac{\pi}{4} \left(D_o^2 - D_i^2\right) .$$

In calculating m from Eq. (C.9), ρ' was assumed to be constant within the wall at a particular location of interest and was evaluated at the mean temperature T_{avg} of the wall at that particular location. Then ρ' was designated by $\overline{\rho'}$ and is given by

$$\rho' = \overline{\rho'} = \rho'_o \left(1+\beta' T_{avg}\right) \qquad (C.10)$$

where

$$T_{avg} = \frac{T_o + T_w}{2} \quad . \qquad (C.11)$$

Therefore

$$m = \frac{G}{2\rho'_o k'_o} \cdot \overline{\rho'}^2 \cdot \left(\frac{I}{A_c}\right)^2 \qquad (C.12)$$

The electrical resistivity of the tube was measured by Vijay (48) in the laboratory and the following equation was used to calculate ρ':

$$\rho' = 0.216581 \times 10^{-5} (1 + 0.650408 \times 10^{-3} T) \text{ ohm-ft} . \quad (C.13)$$

The thermal conductivity of the tube material (type-304 stainless steel) was calculated from the equation reported by Bergles and Rohsenow (C.2) which agreed within $\pm$ 2% with the data obtained from the manufacturer (48, page 302) in the temperature range of 75-150°F. The expression for k_t is given by

$$k_t = 8.46 (1 + 0.000526T) \frac{\text{Btu}}{\text{hr-ft-°F}} . \quad (C.14)$$

As Eq. (C.7) now contains two unknowns, ΔT_w and implicitly T_w, the iteration method given below was used for ΔT_w.

(i) To start with, T_w was assumed to be equal to T_o,

(ii) $\overline{\rho'}$ and m were calculated from Eqs. (C.10) and (C.12) respectively,

(iii) ΔT_w was calculated from Eq. (C.7) and then T_w from Eq. (C.6),

(iv) This new value of T_w was then used to obtain a new value for T_{avg} and the above steps were repeated until two successive values of ΔT_w agreed within $\pm$ 0.0005°F.

C.4 Determination of The Local Bulk Temperature

In deriving the equations for T_B, it is assumed that the gas-liquid mixture enters the test section fully saturated, that is, the saturation process takes place in the calming length. Detailed calculations done by Sims (C.4) show that this assumption is valid.

Consider the elemental volume of the heated tube, having a surface area of dA_s (Fig. C.3). Let the temperature rise of the mixture in this length be dT_B. The amount of heat transferred to the fluid in this section is given by

$$dq_f = q_w \, dA_s$$

where

$$dA_s = \pi D \, dZ = p \, dZ \quad .$$

Applying the principal of conservation of energy on this elemental volume and assuming the steady state conditions, the following expression is obtained.

$$q_w \ (p \ dZ) = \dot{m}_L \ C_{pL} \ dT_B + \dot{m}_G \ C_{pG} \ dT_B \quad .$$

Hence

$$dT_B = \frac{q_w \ p dZ}{\dot{m}_L \ C_{pL} + \dot{m}_G \ C_{pG}} \quad . \qquad (C.15)$$

Equation (C.15) was integrated step-by-step and it was assumed that the specific heats and the wall heat flux remained constant in the interval between two successive locations. Integrating Eq. (C.15) between Z_i and Z_{i+1} gives

$$\int_{Z_i}^{Z_{i+1}} dT_B = \frac{p q_w}{\dot{m}_L \ C_{pL} + \dot{m}_G \ C_{pG}} \int_{Z_i}^{Z_{i+1}} dZ \quad .$$

Therefore

$$(T_B)_{i+1} - (T_B)_i = \frac{p q_w}{\dot{m}_L \ C_{pL} + \dot{m}_G \ C_{pG}} \cdot (Z_{i+1} - Z_i) \ . \qquad (C.16)$$

To obtain the T_B at successive locations along the test section by Eq. (C.16), an initial value of T_B is required. For this purpose, T_{IN}, the mixture inlet temperature, was used to calculate T_B at plane 1 which in turn was

used to calculate T_B at plane 2 and so on.

In reference (48, 1), detailed derivations are given to obtain the inlet mixture temperature, T_{IN}, and the following equation is obtained by performing a conservation of mass and energy on the control volume indicated by dashed line in Fig. C.5.

$$T_{IN} = \frac{\left(\frac{\dot{m}_{L1}}{\dot{m}_{DG2}}\right) C_{pL} T_L + C_{pG} T_{G2} + (\omega_3 - \omega_2) h_{L3} + \omega_2 h_{v2} - \omega_3 h_{v3}}{C_{pG} + \left(\frac{\dot{m}_{L1}}{\dot{m}_{DG2}}\right) C_{pL}} \qquad (C.17)$$

where

$\dot{m}_{DG2}$ is the mass flow rate of dry gas = $\dot{m}_{DG3}$,
In Fig. C.5, $\dot{m}_G = \dot{m}_{DG2} + \dot{m}_{v2}$

ω is the mass of liquid vapour per unit mass of dry gas, given by

$$\omega = \dot{m}_v / \dot{m}_{DG}$$

h is the enthalpy per unit mass of the fluid.

Eq. (C.17) is the general equation for the inlet temperature of a gas-liquid mixture.

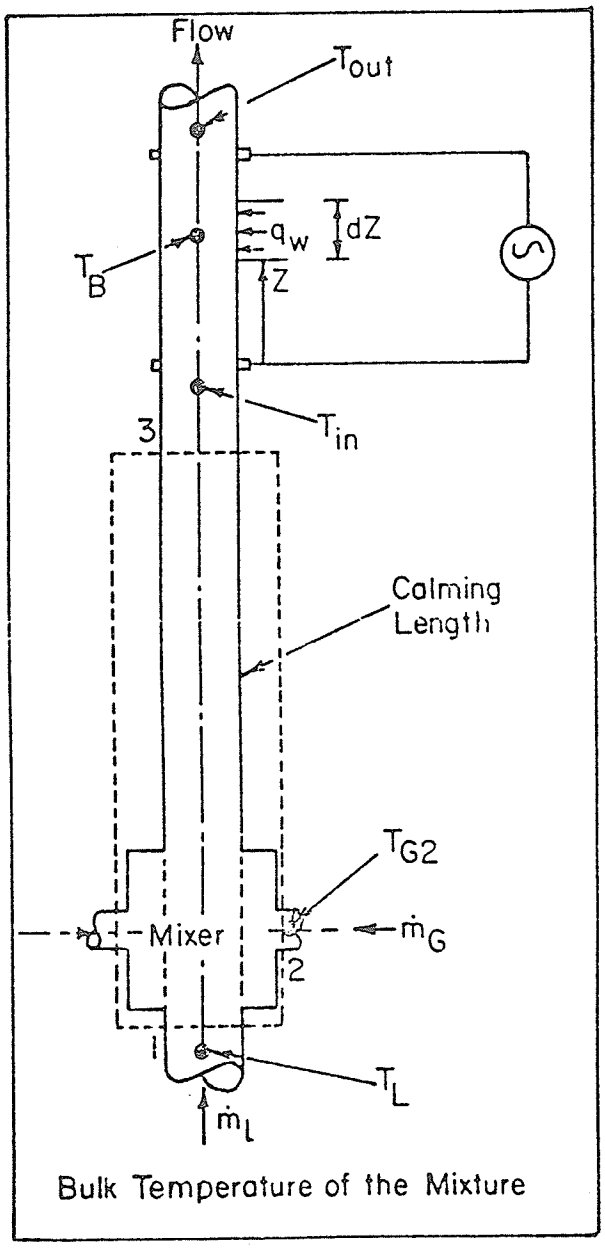


Fig. C.5 Control Volume for the Calculation of Mixture Inlet Temperature. [From Reference (1)]

In Eq. (C.17), the quantities T_L, T_{G2}, $\dot{m}_{L1}$ and $\dot{m}_{DG2}$ are known from measurements; C_{pL}, C_{pG} and h can be found from property equations or thermodynamic tables. By definition (C.5)

$$\omega_2 = R_M \ \phi_2 \ P_{v2}/P_{Dg2} \qquad (C.18)$$

$$\omega_3 = R_M \ \phi_3 \ P_{v3}/P_{Dg3} \qquad (C.19)$$

where

R_M is the ratio of the molecular weight of the liquid to that of dry gas,

ϕ is the relative humidity,

P_{v2} is the saturation pressure of liquid vapour in the gas at the temperature T_{G2}, obtained from thermodynamic tables (C.5),

P_{Dg2} is the partial pressure of dry gas in the gas-liquid vapour mixture = $P_{G2} - P_{v2}$,

P_{G2} is the total pressure of gas-liquid vapour mixture,

P_{v3} is the saturation pressure of the liquid vapour at T_{IN},

P_{Dg3} is the partial pressure of dry gas = $P_{IN} - P_{v3}$

P_{IN} is the total pressure measured at the test section inlet.

It can be seen that among all the quantities described above, only P_{v3} is a function of T_{IN}, therefore, Eq. (C.17) has two unknowns i.e. T_{IN} and ω_3 (T_{IN}). Eq. (C.17) was solved by an iterative procedure on the computer.

In the present experiments, air was always the gas phase and the liquid phase consisted of water and water-surfactant solution. Since it was assumed, as mentioned earlier, that the physical (except surface tension) and thermodynamic properties of water remain unaltered by the addition of surface active agent, therefore the same equation, reduced from Eq. C.17, given below Eq. (C.22) was used to calculate T_{IN} for both mixtures.

In the present work, Eq. (C.18) was not used directly for ω_2; however, the following procedure was adopted to evaluate ω_2:

(i) The air coming from the storage tank at the outlet of the compressor was always saturated because of the presence of water at the bottom of storage tank, therefore, relative humidity (ϕ) at the storage tank is equal to 1.0,

(ii) Since the conditions at the storage tank are essentially the same as at the inlet to the rig (supply line), the relative humidity at supply line conditions will

also be equal to 1.0; therefore

$$\omega_{line} = 0.622 \frac{P_{v_{line}}}{P_{DG_{line}}} \qquad (C.20)$$

Because of mass continuity, the humidity ratio at the storage tank at the outlet of the compressor would be equal to the humidity ratio at the inlet to the rig and at the inlet to the mixer, i.e.

$$\omega_{storage\ tank} = \omega_{line} = \omega_2$$

The humidity ratio was calculated at the inlet to the orifice (at the inlet to the rig) using Eq. (C.20) as it was convenient to take measurements at that point. In Eq. (C.20) $P_{v_{line}}$, the saturation pressure of liquid vapour in the air, was calculated from the knowledge of temperature at the inlet to the orifice. Since $P_{v_{line}}$ is very small as compared with the total line pressure, the $P_{DG_{line}}$ will be approximately equal to the total line pressure; therefore, this measured total line pressure was used in Eq. (C.20).

(iii) As mentioned above,

$$\omega_{line} = \omega_2$$

and the value calculated for ω_{line} above was therefore used for ω_2 in the computer program.

The air at the test section inlet was assumed to be saturated (ϕ_3 also equal to 1.0); therefore Eq. C.19 reduces to

$$(\omega_3)_a = 0.622\ (P_{v3}/P_{a3}) \qquad (C.21)$$

where subscript 'a' stands for dry air.

$$P_{a3} = P_{IN} - P_{v3}$$

and

$$T_{IN} = \frac{(\frac{\dot{m}_{L1}}{\dot{m}_{a2}})\ C_{pL}\ T_L + C_{pa}\ T_{G2} - (\omega_3)_a\ h_{fg3} + (\omega_2)_a\ (h_{v2} - h_{L3})}{C_{pa} + (\frac{\dot{m}_{L1}}{\dot{m}_{a2}})\ C_{pL}} \qquad (C.22)$$

where

$$h_{fg3} = h_{v3} - h_{L3}$$

C.5 Calculation of the Frictional Pressure Drop

In the present work, frictional pressure drop was calculated from the measured total pressure drop across the test section. The total pressure drop was measured by means of two manometers, one inverted manometer using the test liquid and the other upright mercury manometer. These are shown in Figs. C.6a and C.6b. The measured total

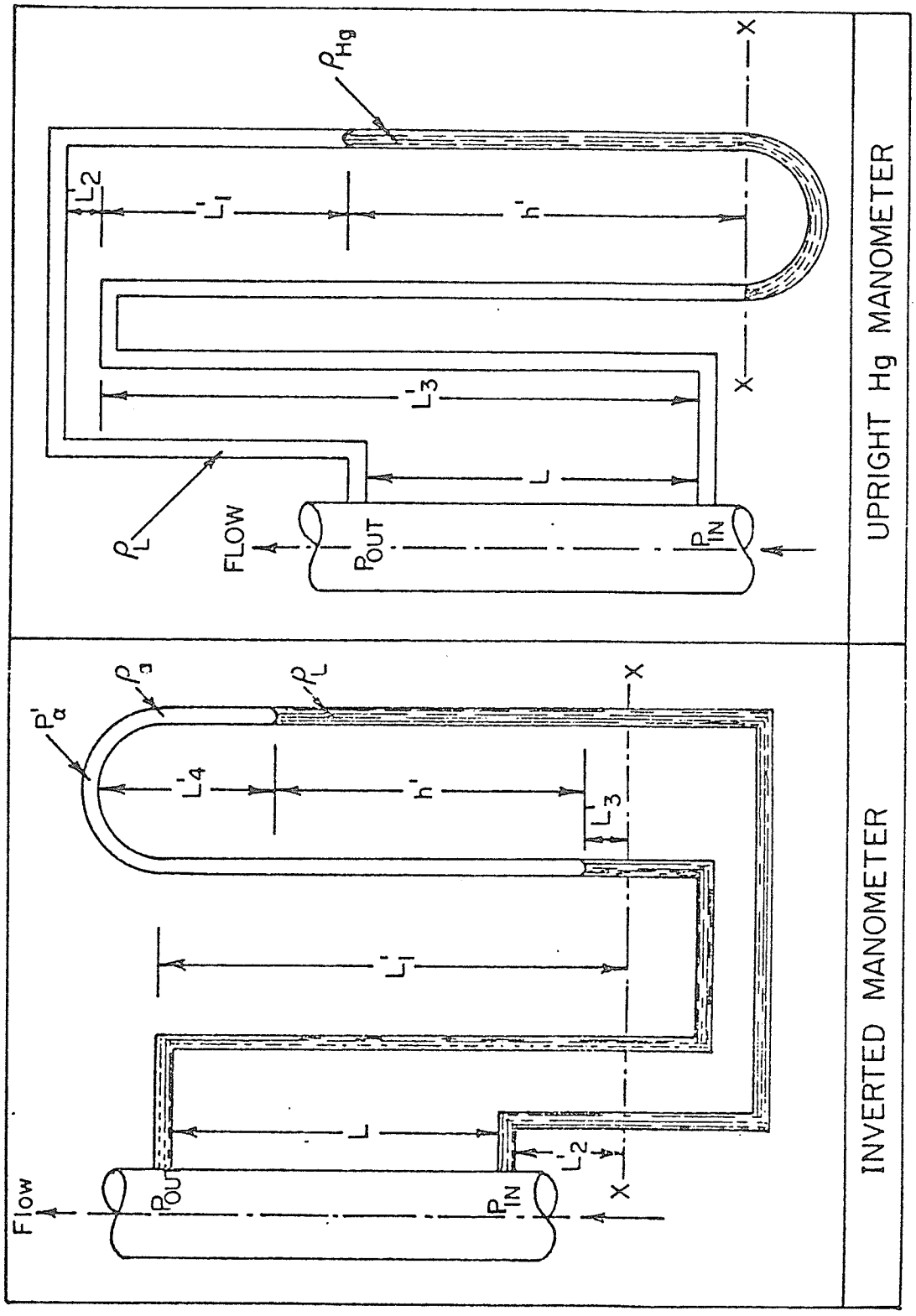


Fig. C.6(a)

Fig. C.6(b) [From Reference (1)]

pressure drop was used to calculate the frictional pressure drop in the manner described below.

C.5.1 Inverted Manometer

Consideration of the balance of forces acting on the planes xx (Fig. C.6a) results in the following equation.

$$P_{IN} - P_{OUT} = \frac{g}{g_c} \rho_L L + \frac{g}{g_c} (\rho_L - \rho_a) h' \qquad (C.23)$$

where

ρ_a is the density of air in the manometer and is extremely small as compared with the density of the liquid ρ_L. Therefore ρ_a can be neglected and Eq. (C.23) reduces to

$$P_{IN} - P_{OUT} = \frac{g}{g_c} \rho_L L + \frac{g}{g_c} \rho_L h' \; . \qquad (C.24)$$

It is assumed in deriving these equations that ρ_L in the manometer is equal to the density of the liquid in the test section.

(i) Single-Phase Flow

The total pressure drop consists of three components, for single phase flow it is given by

$$\Delta P = P_{IN} - P_{OUT} = \Delta P_{SPG} + \Delta P_{SPA} + \Delta P_{SPF} \qquad (C.25)$$

where

ΔP_{SPG} is the single-phase gravitational component,

ΔP_{SPA} is the single-phase accelerational pressure drop $\doteq$ 0 for all the tests,

ΔP_{SPF} is the single-phase frictional pressure drop.

The gravitational (hydraulic) pressure gradient is simply the head of liquid in the test section and is given by

$$\Delta P_{SPG} = \frac{g}{g_c} \rho_L L \qquad (C.26)$$

Therefore

$$\Delta P_{SPF} = \Delta P - \Delta P_{SPG}$$

$$= \frac{g}{g_c} \rho_L h' \qquad (C.27)$$

where

h' is the differential reading on the manometer (Fig. C.6a).

ii) Two-Phase Flow

Neglecting the accelerational pressure drop, Eq. (C.25) for two-phase flow becomes:

$$\Delta P = \Delta P_{TPG} + \Delta P_{TPF} \qquad (C.28)$$

where

ΔP_{TPG} is the two-phase hydraulic pressure drop,

ΔP_{TPF} is the two-phase frictional pressure drop.

The hydraulic pressure drop in two-phase flow is given by

$$\Delta P_{TPG} = \frac{g}{g_c} L \rho_{mix} \tag{C.29}$$

where

ρ_{mix} is the mixture density and is given by

$$\rho_{mix} = (1 - \alpha) \rho_L + \alpha \rho_G$$

Substitution of these quantities in Eq. (C.28) yields

$$\Delta P_{TPF} = \frac{g}{g_c} \rho_L L + \frac{g}{g_c} \rho_L h' - \frac{g}{g_c} L \{(1-\alpha) \rho_L + \alpha \rho_G\}$$

$$= \frac{g}{g_c} \rho_L h' + \frac{g}{g_c} L \alpha (\rho_L - \rho_G) \tag{C.30}$$

Since $\rho_G << \rho_L$, Eq. (C.30) reduces to

$$\Delta P_{TPF} = \frac{g}{g_c} \rho_L (h' + \alpha L) \tag{C.31}$$

C.5.2 Upright Manometer

A force balance on the plane xx in Fig. C.6b results in the following equation

$$P_{IN} - P_{OUT} = \frac{g}{g_c} (\rho_{HG} - \rho_L) h' + \frac{g}{g_c} \rho_L L \qquad (C.32)$$

where

ρ_{HG} is the density of mercury in the manometer,

h' is the differential reading in the manometer.

Following the same procedure adopted for the inverted manometer, the frictional pressure drop is calculated from the following equations.

i. Single-Phase Flow

$$\Delta P_{SPF} = \frac{g}{g_c} (\rho_{Hg} - \rho_L) h' \qquad (C.33)$$

ii. Two-Phase Flow

$$\Delta P_{TPF} = \frac{g}{g_c} (\rho_{Hg} - \rho_L) h' + \frac{g}{g_c} \alpha (\rho_L - \rho_G) L \qquad (C.34)$$

Assuming

$$\rho_G << \rho_L$$

then yields

$$\Delta P_{TPF} = \frac{g}{g_c} \rho_{Hg} h' + \frac{g}{g_c} \rho_L (\alpha L - h') \qquad (C.35)$$

C.6 Calculation of the Mean Pressure and Temperature in the Test Section

The mean mixture pressure in the test section was calculated as follows:

$$P_{MIX} = P_{IN} - (\frac{\Delta P}{2}) \qquad (C.36)$$

The average mixture temperature was evaluated by the following Eq. (C.37).

$$\bar{T}_{MIX} = \frac{T_{IN} + T_{OUT}}{2} \qquad (C.37)$$

Where T_{IN} and T_{OUT} are the bulk temperatures at the inlet and outlet of the test section respectively.

C.7 Calculation of the Void Fraction

A knowledge of void fraction was required to calculate the frictional pressure drop as shown in Section C.5 and to correlate the mean heat transfer data as discussed in Chapter 6. The void fraction correlation proposed by Chisholm (C3) was used to predict the actual void fraction. This was used because it is well accepted (1, 48) and simple to use. The void fraction, wherever appearing in the thesis, was calculated by the following procedure.

The ratio of the mean velocities of the two-phases, usually termed as slip ratio, is given by

$$S = \frac{V_G}{V_L} \tag{C.38}$$

In the paper (C3), the author also showed that S can be approximated by

$$S \approx \left(\frac{\rho_L}{\rho_{MIX}}\right)^{\frac{1}{2}} \tag{C.39}$$

where

$$\frac{1}{\rho_{MIX}} = \frac{1 - x}{\rho_L} + \frac{x}{\rho_G} \tag{C.40}$$

and

x, the flow quality is given by

$$x = \frac{\dot{m}_G}{\dot{m}_G + \dot{m}_L}$$

From the definition of flow quality and void fraction, it can be shown that

$$R_L = 1 - \alpha = \frac{S(1 - x)/\rho_L}{(x/\rho_G) + S(1 - x)/\rho_L} \tag{C.41}$$

where

R_L is the liquid volume fraction.

Since x, ρ_G and ρ_L were known, ρ_{MIX} and S were calculated from the Eqs. (C.40) and (C.39) respectively, and the void fraction was then determined from Eq. (C.41).

C.8 Calculation of the Liquid and Gas Flow Rates and Superficial Velocities

C.8.1 Liquid Flow Rate and Superficial Velocity

i. Flow Rate ($\dot{m}_L$)

The liquid flow rates were measured by means of three rotameters which were calibrated in situ in the laboratory (48). The flow rate of liquid was determined by the appropriate equation below

- For meter number 1 (high flow range)

$$\dot{m}_L = 0.274286 + 179.914\ Rm \qquad (C.42)$$

- For meter number 2 (medium flow range)

$$\dot{m}_L = 4.14875 + 17.560\ Rm \qquad (C.43)$$

- For meter number 3 (low flow range)

$$\dot{m}_L = 1.05622 + 1.565\ Rm \qquad (C.44)$$

where

Rm is the % meter reading.

ii. Superficial Velocity (V_{SL})

According to the definition, the superficial liquid velocity was calculated from the following equation:

$$V_{SL} = \dot{m}_L / \rho_L A_T \qquad (C.45)$$

where A_T is the cross-sectional area of the tube and is given by

$$A_T = \frac{\pi}{4} D^2$$

C.8.2 Gas Flow Rates and Superficial Velocity

i. Flow Rate ($\dot{m}_G$)

The air flow rate was measured by means of three orifice plates and a rotameter. The following equations were used to determine the air flow rate (48).

The mass flow rate from the rotameter, which was used for the lowest flow rates, was calculated from the following equation

$$\dot{m}_G = 0.27364 \, (\rho_{G1})^{\frac{1}{2}} \, Q_o \qquad (C.46)$$

where

ρ_{G1} is the gas density at the rotameter inlet,

Q_o is the volumetric flow rate (ft^3/hr) at standard conditions and was obtained from the calibration

curve (48) and is given by

$$Q_o = - 0.1825 + 0.0813\ R_G \qquad (C.47)$$

where

R_G is the meter reading.

The mass flow rate through the orifice plates was calculated from the following equation (C.1, Ref. C.1 in 48)

$$\dot{m}_G = 359.052\ d^2\ FYC\ F_a\ (\rho_{G1} h_w)^{\frac{1}{2}} \qquad (C.48)$$

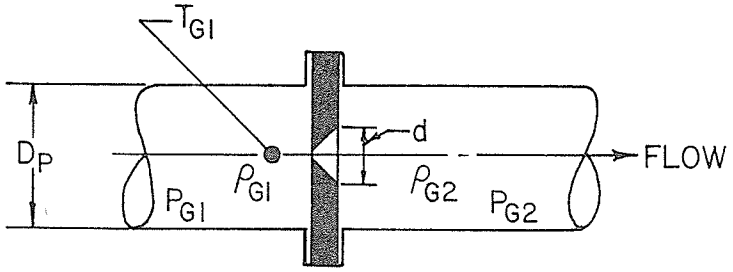


Fig. C.7 Flow through an orifice plate

where

d is the orifice throat diameter,

$F = (1 - \beta^4)^{-\frac{1}{2}}$ is the velocity of approach factor,

where $\beta = d/D_P = \frac{\text{Throat dia.}}{\text{Pipe dia.}}$,

Y is the expansion factor, given by,

$$Y = 1 - (0.41 + 0.35\ \beta^4)\ \frac{\Delta P_{OR}}{k P_{G1}}\ , \qquad (C.49)$$

F_a is the thermal expansion factor ≈ 1.0 in the temperature range involved in the experiments,

h_w is the pressure drop across the orifice plate (inches of H_2O),

k is the ratio of specific heats and is equal to 1.4 for air,

ΔP_{OR} is the pressure drop across the orifice plate, $= P_{G1} - P_{G2}$,

C is the coefficient of discharge which was determined (48) from calibration charts. In these charts C is plotted as a function of Re_d, Reynolds number based on the throat diameter, i.e.

$$Re_d = \frac{4\ \dot{m}_G}{\pi d\ \mu_G}\ . \qquad (C.50)$$

The following equations for C, were obtained from the calibration charts (48).

Orifice Plate No.	Throat diameter (inches)	C
1	0.418	$0.687\ \exp(-3.83\times10^{-7}\ Re_d)$
2	0.141	$0.689\ \exp(-9.45\times10^{-7}\ Re_d)$
3	0.048	$0.732\ \exp(-3.06\times10^{-6}\ Re_d)$

The following procedure was employed to calculate $\dot{m}_G$.

(i) Assuming an ideal gas, ρ_{G1} was calculated from the measured values of P_{G1} and T_{G1}

$$\rho_{G1} = P_{G1}/RT_{G1}$$

R is the characteristic gas constant,

(ii) Y was calculated from Eq. (C.49) where ΔP_{OR} was calculated with the knowledge of h_w from this relation

$$\Delta P_{OR} = \frac{g}{g_c} \frac{\rho_w}{1728} h_w \quad (psi) \qquad (C.51)$$

(iii) An arbitrary value for C was chosen (0.6 to start with) and $\dot{m}_G$ was determined from Eq. (C.48), then Re_d was evaluated and a new value for C was obtained

(iv) Based on this new value of C, a new $\dot{m}_G$ was determined.

(v) The procedure was repeated until two successive values of $\dot{m}_G$ agreed within $\pm$ 0.1%.

ii. Superficial Velocity (V_{SG})

The superficial velocity of gas was determined by the following equation.

$$V_{SG} = \dot{m}_G / \rho_G \, A_T \qquad (C.52)$$

The gas phase density changes along the length of the heated test section due to changes in the temperature and pressure. Therefore, local values of V_{SG} were calculated by assuming a linear drop in the total pressure along the test tube and, using the local values of T_B, the mean value of V_{SG} was calculated from the following relation

$$\overline{V_{SG}} = \frac{1}{L} \int_0^L V_{SG}(Z) \, dz \qquad (C.53)$$

C.9 Determination of Surface Tension

The measurements of static surface tension made by the surface tension analyzer indicate the apparent surface tension. These readings were corrected for absolute surface tension by the following relationship.

$$\sigma_{abs} = F \times \sigma_{app} \qquad (C.54)$$

where

σ_{abs} is the absolute surface tension

σ_{app} is the apparent surface tension

F is the correction factor as mentioned in (C.6) and given by

$$F = 0.725 + \left(\frac{0.01452 \quad \sigma_{app}}{C^2 \ (\rho_{LP} - \rho_{UP})} + 0.04534 - 1.679 \ \frac{r}{R}\right)^{\frac{1}{2}} \quad (C.55)$$

where

R is the radius of the ring (cm)

r is the radius of the wire of the ring (cm)

ρ_{LP} is the density of the lower phase in the measuring vessel (gm/cm^3)

ρ_{UP} is the density of the upper phase in the measuring vessel (gm/cm^3)

C is the circumference of the ring (cm).

For the ring used in the present work,

$$C = 6.0 \text{ cm}$$

$$\frac{R}{r} = 53.7489 \quad .$$

The values of absolute surface tension are reported in the thesis.

C.10 Repeatability of Results

In order to establish the repeatability of the water-air results, V_{SL} = 20.84 ft/sec (6.352 m/sec) was selected. Six data points covering the whole range of V_{SG} for the base data were repeated part-way through the program and also at the end of the investigation. The results are shown in Fig. C.8 which illustrate an excellent repeatability.

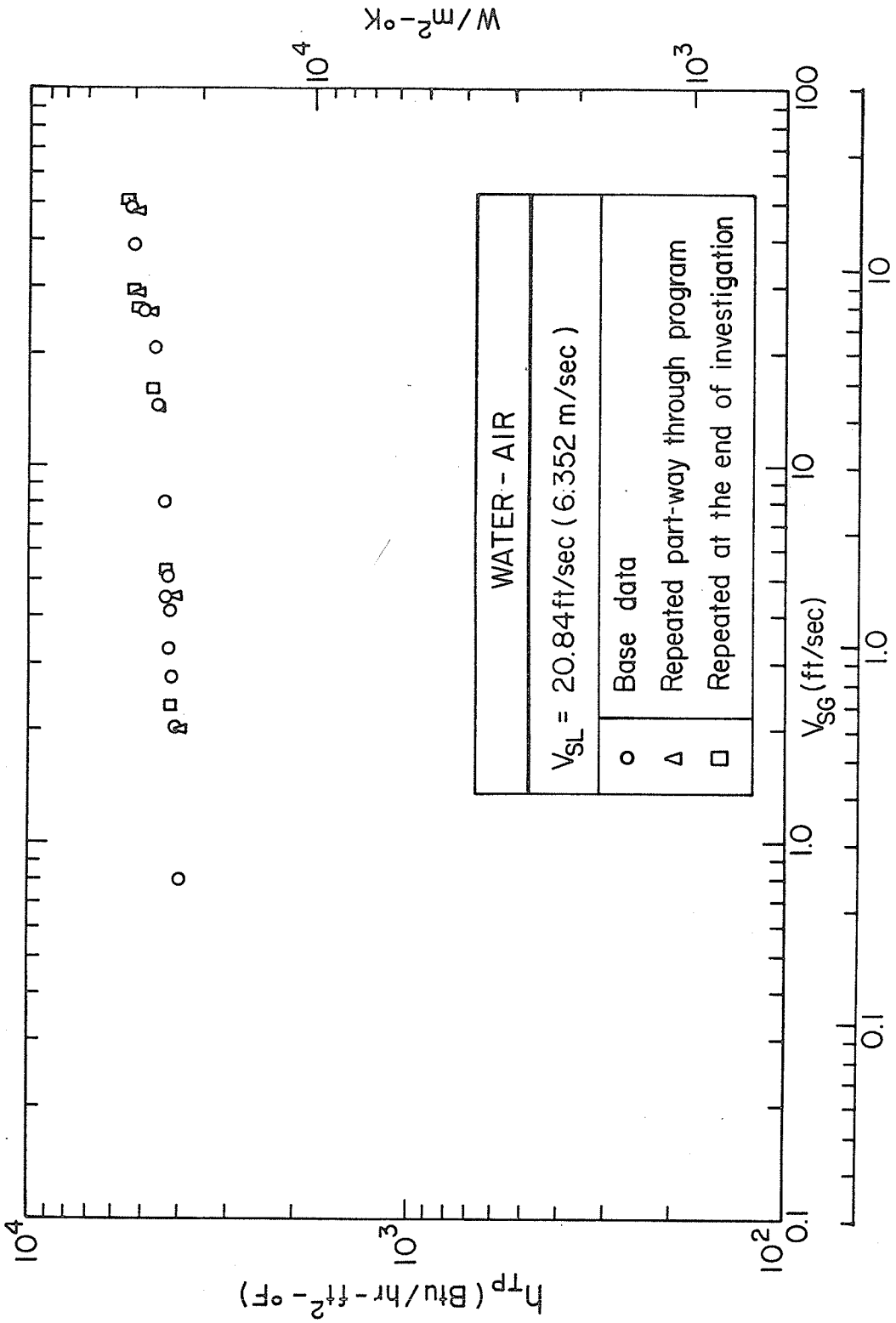


Fig. C.8 Repeatability of Water-Air Results

References for Appendix C

C.1 ASME Power Test Codes, Instruments and Apparatus. Chapter 4, "Flow Measurement, Part 5, Measurement of Quality of Materials", February (1959).

C.2 Bergles, A.E. and Rohsenow, W.M. "Forced Convection Surface-Boiling Heat Transfer and Burnout in Tubes of Small Diameters", Technical Report No. 8767-21, MIT, May (1962).

C.3 Kreith, F. and Summerfield, M. "Investigation of Heat Transfer at High Heat-flux Densities: Experimental Study with Water of Friction Drop and Forced Convection With and Without Surface Boiling in Tubes", Progress Report No. 4-68, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, April (1948).

C.4 Sims, G.E. "Forced Convection Heat Transfer to Water With Air Injection Through One Porous Heated Wall of a Rectangular Duct, Ph.D. Thesis, Imperial College of Science and Technology, University of London, London, U.K. (1969), p. 239.

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C.6 Zuidema, H.H. and Walters, G.W. "Ring Method for the Determination of Interfacial Tension". Industrial and Engineering Chemistry, Vol. 13, No. 3, May 15 (1941), pages 312-313. (Reference No. 19 in the Instructional Manual for Fisher (MOdel 215) Auto-tensiomat Surface Tension Analyzer).

APPENDIX D

TABULATED DATA

This appendix presents the two-phase experimental data. The water-air data are given in Table D.1, the surfactant solution-air data in Table D.2. The data for each liquid-air mixtures are given in the order of increasing air flow rate for each liquid mass flow rate. For each test the data are tabulated in the following order:

- The first two lines give the average values of the following quantities:

ML=	water mass flow rate	lb/hr
MG=	gas mass flow rate	lb/hr
QFLUX=	average heat flux	$Btu/hr\text{-}ft^2$
NUTP=	average Nusselt number	
HTP=	average two-phase heat-transfer coefficient	$Btu/hr\text{-}ft^2\text{-}F$
PDT=	total pressure drop	lb_f/in^2.
PDF=	frictional pressure drop	lb_f/in^2.
ALFA=	void fraction	
XTT=	Martinelli parameter	
WE=	Weber number	
FR=	Froude number	
STN=	Surface Tension (absolute)	dyne/cm

(The surface tension value is just included for the surfactant solution-air results)

- The next three lines give respectively the inlet, outlet and mean values of the following quantities:

TMIX=	mixture temperature	F
RESL=	superficial liquid Reynolds number	
RESG=	superficial gas Reynolds number	
P=	pressure	$lb_f/in.^2$
PRL=	liquid Prandtl number	
PRG=	gas Prandtl number	
VSL=	superficial liquid velocity	ft/sec
VSG=	superficial gas velocity	ft/sec

- Then, the local values of the quantities listed below are given at seven locations (Z in.) along the test section.

RESL=	superficial liquid Reynolds number	
VSG=	superficial gas velocity	ft/sec
TBULK=	bulk temperature of the mixture	F
(T_W-T_B)=	temperature difference between wall and bulk	F
NUTP=	two-phase Nusselt number	
HTP=	two-phase heat-transfer coefficient	Btu/hr ft^2F

TABLE D.1 WATER-AIR DATA

TEST NO.: W1. 1 FLOW PATTERN:SLUG

ML= 48 MG= 0.35 QFLUX= 6657 NUTP= 64.2 HTP= 597 PDT= 0.252

PDF=-0.009 ALFA=0.693 XTT= 4.23 WE= 0.5 FR= 0.03

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	70.13	677	267.2	15.6	6.63	0.710	0.19	1.07
OUTLET	103.49	994	254.9	15.3	4.44	0.706	0.19	1.16
MEAN	86.81	836	261.1	15.4	5.45	0.708	0.19	1.12

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	702	1.08	72.89	13.50	53.7	489.0
4.5	733	1.09	76.35	13.63	53.1	486.0
7.5	771	1.10	80.51	12.80	56.3	518.0
11.0	817	1.11	85.37	12.46	57.7	534.0
16.5	890	1.13	93.04	11.00	64.9	607.0
21.0	953	1.15	99.33	8.54	83.1	784.0
22.5	974	1.16	101.43	6.19	114.4	1082.0

TEST NO.: W1. 2 FLOW PATTERN:SLUG

ML= 48 MG= 1.06 QFLUX= 6387 NUTP= 52.9 HTP= 493 PDT= 0.121

PDF=-0.043 ALFA=0.808 XTT= 1.55 WE= 0.5 FR= 0.03

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	69.98	676	799.5	14.9	6.65	0.710	0.19	3.36
OUTLET	101.87	978	764.3	14.8	4.53	0.706	0.19	3.59
MEAN	85.93	827	781.9	14.8	5.51	0.708	0.19	3.48

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	700	3.38	72.62	22.42	31.2	283.0
4.5	729	3.41	75.94	20.77	33.5	306.0
7.5	766	3.44	79.93	19.93	34.8	320.0
11.0	809	3.47	84.58	17.17	40.2	372.0
16.5	880	3.52	91.91	12.85	53.3	498.0
21.0	938	3.57	97.91	7.62	89.3	841.0
22.5	958	3.58	99.91	4.08	166.0	1568.0

TEST NO.: W1. 3 FLOW PATTERN:SLUG

ML= 48 MG= 1.63 QFIUX= 5927 NUTP= 59.2 HTP= 550 PDT= 0.115

PDF=-0.019 ALFA=0.843 XTT= 1.05 WE= 0.5 FR= 0.03

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	69.70	674	1228.0	14.6	6.69	0.710	0.19	5.25
OUTLET	99.21	951	1178.0	14.5	4.67	0.706	0.19	5.58
MEAN	84.46	812	1203.1	14.6	5.61	0.708	0.19	5.42

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	695	5.28	72.15	22.05	29.5	268.0
4.5	723	5.31	75.22	21.18	30.6	279.0
7.5	757	5.36	78.91	18.51	34.9	320.0
11.0	797	5.41	83.22	15.42	41.6	384.0
16.5	861	5.48	90.00	10.98	58.0	541.0
21.0	915	5.55	95.55	5.62	112.5	1056.0
22.5	933	5.57	97.40	2.89	218.6	2057.0

TEST NO.: W1. 4 FLOW PATTERN:CHURN

ML= 48 MG= 2.15 QFLUX= 5962 NUTP= 64.1 HTP= 596 PDT= 0.125

PDF= 0.007 ALFA=0.861 XTT= 0.82 WF= 0.5 FR= 0.03

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	68.69	665	1626.0	14.6	6.78	0.710	0.19	6.93
OUTLET	98.30	942	1559.6	14.5	4.72	0.706	0.19	7.37
MEAN	83.50	803	1593.1	14.6	5.68	0.708	0.19	7.16

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	686	6.97	71.15	21.41	30.6	277.0
4.5	714	7.02	74.23	20.82	31.3	286.0
7.5	748	7.07	77.93	19.29	33.7	309.0
11.0	788	7.14	82.26	16.82	38.5	354.0
16.5	852	7.24	89.06	10.27	62.5	581.0
21.0	906	7.33	94.62	4.50	141.4	1326.0
22.5	924	7.36	96.48	2.79	227.9	2143.0

TEST NO.: W1. 5 FLOW PATTERN:CHURN

ML= 48 MG= 2.58 QFLUX= 5556 NUTP= 55.4 HTP= 514 PDT= 0.143

PDF= 0.034 ALFA=0.873 XTT= 0.69 WF= 0.5 FR= 0.03

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	69.41	671	1948.0	14.6	6.72	0.710	0.19	8.33
OUTLET	96.94	929	1874.1	14.5	4.79	0.707	0.19	8.83
MEAN	83.18	800	1911.5	14.6	5.69	0.708	0.19	8.59

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	691	8.37	71.69	16.67	36.5	332.0
4.5	717	8.42	74.55	17.09	35.6	324.0
7.5	748	8.49	77.99	15.91	38.1	349.0
11.0	785	8.56	82.01	14.10	42.8	394.0
16.5	845	8.68	88.34	10.49	57.1	530.0
21.0	895	8.78	93.52	7.00	85.0	796.0
22.5	912	8.81	95.25	3.26	182.2	1710.0

TEST NO.: W1. 6 FLOW PATTERN:CHURN

ML= 48 MG= 2.91 QFLUX= 6132 NUTP= 59.4 HTP= 551 PDT= 0.147

PDF= 0.044 ALFA=0.880 XTT= 0.62 WF= 0.5 FR= 0.03

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	69.00	667	2199.0	14.6	6.75	0.710	0.19	9.39
OUTLET	99.34	953	2107.1	14.5	4.66	0.706	0.19	10.00
MEAN	84.17	810	2153.4	14.6	5.63	0.708	0.19	9.70

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	690	9.44	71.51	15.05	44.6	405.0
4.5	718	9.50	74.66	15.31	43.7	399.0
7.5	752	9.58	78.45	15.00	44.5	408.0
11.0	793	9.68	82.88	13.89	47.8	441.0
16.5	860	9.82	89.85	12.10	54.6	508.0
21.0	915	9.94	95.57	6.85	95.8	899.0
22.5	934	9.98	97.47	4.03	162.4	1529.0

TEST NO.: W1. 7 FLOW PATTERN:CHURN

ML= 48 MG= 3.68 QFIUX= 6563 NUTP= 67.5 HTP= 626 PDT= 0.167

PDF= 0.075 ALFA=0.892 XTT= 0.51 WE= 0.5 FR= 0.03

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	69.41	671	2775.0	14.9	6.70	0.710	0.19	11.66
OUTLET	101.76	977	2651.9	14.7	4.53	0.706	0.19	12.49
MEAN	85.58	824	2713.9	14.8	5.54	0.708	0.19	12.09

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	695	11.73	72.08	11.69	61.3	557.0
4.5	725	11.82	75.44	11.58	61.7	564.0
7.5	762	11.92	79.47	11.55	61.7	567.0
11.0	806	12.05	84.20	11.73	60.6	560.0
16.5	877	12.24	91.64	10.64	66.4	620.0
21.0	937	12.41	97.75	8.05	87.2	821.0
22.5	957	12.46	99.78	7.50	93.4	882.0

TEST NO.: W1. 8 FLOW PATTERN:CHURN-ANNULAR

ML= 48 MG= 9.22 QFIUX= 8534 NUTP=104.8 HTP= 977 PDT= 0.131

PDF= 0.074 ALFA=0.933 XTT= 0.22 WE= 0.5 FR= 0.03

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	68.01	659	6973.0	14.6	6.81	0.710	0.19	29.65
OUTLET	108.96	1050	6583.5	14.5	4.19	0.705	0.19	32.16
MEAN	88.48	855	6778.4	14.6	5.37	0.708	0.19	30.95

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	688	29.86	71.39	10.23	90.8	826.0
4.5	727	30.13	75.62	10.25	90.4	826.0
7.5	773	30.45	80.72	9.79	94.3	868.0
11.0	829	30.83	86.68	9.41	97.6	906.0
16.5	920	31.42	96.10	8.32	109.6	1030.0
21.0	998	31.91	103.83	6.99	129.6	1230.0
22.5	1024	32.08	106.42	6.60	137.2	1306.0

TEST NO.: W1. 9 FLOW PATTERN:CHURN-ANNULAR

ML= 48 MG= 14.49 QFIUX= 8935 NUTP=116.6 HTP=1086 PDT= 0.149

PDF= 0.104 ALFA=0.948 XTT= 0.15 WE= 0.5 FR= 0.03

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	66.91	649	10986.0	14.6	6.91	0.710	0.19	46.54
OUTLET	108.74	1048	10358.1	14.5	4.20	0.705	0.19	50.63
MEAN	87.83	849	10672.1	14.6	5.42	0.708	0.19	48.65

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	679	46.89	70.36	9.67	100.8	915.0
4.5	718	47.32	74.69	9.88	98.3	898.0
7.5	766	47.84	79.89	9.61	100.6	925.0
11.0	823	48.45	85.98	9.06	106.3	985.0
16.5	916	49.42	95.60	7.82	122.2	1147.0
21.0	995	50.22	103.50	6.27	151.4	1436.0
22.5	1021	50.49	106.14	5.78	163.9	1560.0

TEST NO.: W1.10 FLOW PATTERN:ANNULAR

ML= 48 MG= 18.52 QFLUX= 9395 NUTP=124.7 HTP=1162 PDT= 0.184

PDF= 0.145 ALFA=0.955 XTT= 0.12 WE= 0.5 FR= 0.03

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	65.98	641	14058.0	14.6	7.00	0.710	0.19	59.37
OUTLET	109.14	1052	13229.7	14.4	4.18	0.705	0.19	64.89
MEAN	87.56	847	13644.3	14.5	5.45	0.708	0.19	62.21

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	672	59.84	69.53	9.32	110.0	997.0
4.5	712	60.42	73.99	9.66	105.8	965.0
7.5	761	61.12	79.36	9.57	106.4	977.0
11.0	820	61.95	85.65	9.17	110.5	1024.0
16.5	915	63.26	95.58	7.79	129.1	1212.0
21.0	997	64.34	103.74	6.00	166.3	1578.0
22.5	1025	64.70	106.46	5.30	187.8	1789.0

TEST NO.: W1.11 FLOW PATTERN:ANNULAR

ML= 48 MG= 22.00 QFLUX= 9969 NUTP=122.3 HTP=1142 PDT= 0.213

PDF= 0.177 ALFA=0.959 XTT= 0.10 WE= 0.5 FR= 0.03

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	65.59	637	16705.0	15.3	7.04	0.710	0.19	67.57
OUTLET	110.67	1068	15679.3	15.0	4.11	0.705	0.19	74.19
MEAN	88.13	853	16192.5	15.1	5.42	0.708	0.19	70.98

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	670	68.13	69.30	10.43	104.3	945.0
4.5	712	68.83	73.96	11.05	98.2	895.0
7.5	763	69.67	79.57	10.92	98.9	909.0
11.0	824	70.66	86.14	9.93	108.1	1002.0
16.5	925	72.24	96.51	8.44	126.3	1187.0
21.0	1010	73.54	105.03	6.11	173.1	1645.0
22.5	1039	73.97	107.87	5.32	198.5	1894.0

TEST NO.: W1.12 FLOW PATTERN:ANNULAR

ML= 48 MG= 26.90 QFLUX= 10499 NUTP=135.3 HTP=1264 PDT= 0.270

PDF= 0.239 ALFA=0.964 XTT= 0.09 WE= 0.5 FR= 0.03

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	64.91	632	20446.0	15.4	7.10	0.710	0.19	81.84
OUTLET	111.36	1075	19153.4	15.1	4.08	0.705	0.19	90.40
MEAN	88.13	854	19800.0	15.2	5.43	0.708	0.19	86.24

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	665	82.56	68.73	10.02	114.4	1036.0
4.5	708	83.46	73.53	10.94	104.4	952.0
7.5	760	84.55	79.31	10.74	105.9	973.0
11.0	824	85.83	86.08	10.00	113.2	1049.0
16.5	927	87.87	96.77	7.73	145.1	1365.0
21.0	1015	89.55	105.55	5.66	196.6	1870.0
22.5	1046	90.12	108.48	4.75	233.8	2232.0

TEST NO.: W1.13 FLOW PATTERN:ANNULAR

ML= 48 MG= 32.35 QFLUX= 10867 NUTP=133.3 HTP=1243 PDT= 0.311

PDF= 0.283 ALFA=0.968 XTT= 0.07 WE= 0.5 FR= 0.03

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	64.38	627	24613.0	15.5	7.16	0.710	0.19	97.71
OUTLET	111.33	1075	23039.8	15.2	4.08	0.705	0.19	108.30
MEAN	87.86	851	23826.8	15.3	5.45	0.708	0.19	103.15

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	661	98.59	68.25	9.92	119.6	1083.0
4.5	704	99.71	73.10	10.95	108.0	984.0
7.5	757	101.06	78.94	10.97	107.4	986.0
11.0	821	102.64	85.78	10.33	113.4	1051.0
16.5	925	105.16	96.58	8.37	138.7	1304.0
21.0	1014	107.25	105.46	5.97	193.0	1836.0
22.5	1045	107.95	108.43	5.63	204.4	1952.0

TEST NO.: W1.14 FLOW PATTERN:ANNULAR

ML= 48 MG= 44.13 QFLUX= 11271 NUTP=135.0 HTP=1256 PDT= 0.564

PDF= 0.541 ALFA=0.974 XTT= 0.06 WE= 0.5 FR= 0.03

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	61.61	603	33712.0	16.1	7.47	0.711	0.19	127.71
OUTLET	107.96	1040	31569.3	15.5	4.24	0.705	0.19	143.60
MEAN	84.79	822	32640.9	15.8	5.67	0.708	0.19	135.84

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	636	129.02	65.43	10.48	117.9	1063.0
4.5	678	130.68	70.22	12.31	100.2	909.0
7.5	730	132.69	75.99	11.97	102.5	937.0
11.0	792	135.06	82.75	11.15	109.5	1010.0
16.5	894	138.85	93.41	9.04	133.8	1253.0
21.0	981	142.01	102.17	5.58	214.9	2035.0
22.5	1011	143.07	105.10	4.37	273.6	2601.0

TEST NO.: W1.15 FLOW PATTERN:ANNULAR-MIST

ML= 48 MG= 72.63 QFLUX= 10803 NUTP=104.2 HTP= 959 PDT= 0.961

PDF= 0.944 ALFA=0.981 XTT= 0.04 WE= 0.5 FR= 0.03

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	60.13	591	55609.0	17.4	7.67	0.711	0.19	193.62
OUTLET	99.91	958	52529.5	16.4	4.65	0.706	0.19	219.75
MEAN	80.02	774	54069.3	16.9	6.01	0.709	0.19	206.92

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	619	195.75	63.41	8.81	134.7	1211.0
4.5	654	198.43	67.52	11.83	100.2	906.0
7.5	698	201.70	72.48	13.04	90.6	825.0
11.0	751	205.59	78.28	13.12	89.8	823.0
16.5	836	211.84	87.43	11.69	100.0	929.0
21.0	909	217.08	94.95	9.04	128.3	1204.0
22.5	934	218.86	97.46	8.05	143.9	1354.0

TEST NO.: W1.16 FLOW PATTERN:ANNULAR-MIST

ML= 48 MG= 91.06 QFLUX= 10166 NUTP= 89.8 HTP= 824 PDT= 1.641

PDF= 1.626 ALFA=0.984 XTT= 0.03 WE= 0.5 FR= 0.03

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	60.86	597	69647.0	18.4	7.61	0.711	0.19	230.06
OUTLET	95.92	919	66223.9	16.7	4.87	0.707	0.19	268.30
MEAN	78.39	758	67935.4	17.6	6.12	0.709	0.19	249.33

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	622	233.07	63.75	7.50	148.8	1339.0
4.5	653	236.91	67.37	11.57	96.5	872.0
7.5	692	241.62	71.74	13.76	80.9	736.0
11.0	738	247.25	76.86	14.75	75.3	689.0
16.5	813	256.44	84.93	13.46	82.0	759.0
21.0	876	264.27	91.55	11.10	98.8	922.0
22.5	898	266.95	93.76	10.11	108.2	1014.0

TEST NO.: W1.17 FLOW PATTERN:ANNULAR-MIST

ML= 48 MG=160.28 QFLUX= 9879 NUTP= 84.7 HTP= 772 PDT= 1.681

PDF= 1.671 ALFA=0.989 XTT= 0.02 WE= 0.5 FR= 0.03

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	60.16	591	122713.0	22.0	7.73	0.711	0.19	337.75
OUTLET	87.68	839	117905.7	20.3	5.38	0.708	0.19	383.48
MEAN	73.92	715	120309.5	21.2	6.47	0.709	0.19	360.89

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	610	341.40	62.43	7.11	153.1	1375.0
4.5	635	346.03	65.28	12.07	90.3	814.0
7.5	665	351.70	68.71	14.56	74.8	677.0
11.0	700	358.47	72.73	15.37	70.6	643.0
16.5	758	369.44	79.06	13.97	77.3	710.0
21.0	806	378.73	84.26	11.92	90.2	834.0
22.5	823	381.89	85.99	10.23	104.8	972.0

TEST NO.: W1.18 FLOW PATTERN:ANNULAR-MIST

ML= 48 MG=190.92 QFLUX= 9896 NUTP= 88.3 HTP= 805 PDT= 2.180

PDF= 2.170 ALFA=0.990 XTT= 0.02 WE= 0.5 FR= 0.03

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	60.75	596	146044.0	24.6	7.67	0.711	0.19	359.84
OUTLET	86.16	824	140748.8	22.4	5.48	0.708	0.19	412.23
MEAN	73.46	710	143396.6	23.5	6.51	0.710	0.19	386.26

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	614	363.98	62.85	6.66	163.6	1470.0
4.5	637	369.24	65.48	11.56	94.4	852.0
7.5	664	375.70	68.65	14.08	77.5	701.0
11.0	697	383.43	72.36	14.84	73.4	667.0
16.5	750	396.01	78.21	13.47	80.4	737.0
21.0	795	406.73	83.00	11.32	95.2	879.0
22.5	810	410.39	84.60	10.53	102.1	945.0

TEST NO.: W2. 1 FLOW PATTERN:SLUG

ML= 94 MG= 0.41 QFLUX= 7162 NUTP= 67.8 HTP= 623 PDT= 0.306

PDF=-0.017 AIFA=0.620 XTT= 6.92 WE= 2.0 FR= 0.11

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	70.44	1346	311.2	15.6	6.66	0.710	0.37	1.25
OUTLET	88.60	1677	303.2	15.3	5.30	0.708	0.37	1.31
MEAN	79.52	1511	307.2	15.5	5.95	0.709	0.37	1.28

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1372	1.25	71.94	12.46	62.9	572.0
4.5	1406	1.26	73.83	12.45	62.9	573.0
7.5	1446	1.27	76.10	12.00	65.1	595.0
11.0	1494	1.28	78.74	11.59	67.3	618.0
16.5	1571	1.30	82.91	11.07	70.2	648.0
21.0	1634	1.31	86.33	10.76	72.0	667.0
22.5	1656	1.31	87.47	10.22	75.8	703.0

TEST NO.: W2. 2 FLOW PATTERN:SLUG

ML= 94 MG= 1.11 QFLUX= 7169 NUTP= 59.1 HTP= 544 PDT= 0.155

PDF=-0.062 AIFA=0.746 XTT= 2.81 WE= 2.0 FR= 0.11

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	70.34	1344	834.0	15.1	6.67	0.710	0.37	3.45
OUTLET	88.49	1675	812.6	15.0	5.31	0.708	0.37	3.60
MEAN	79.41	1509	823.3	15.1	5.96	0.709	0.37	3.53

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1370	3.47	71.85	16.76	46.9	426.0
4.5	1404	3.48	73.74	16.03	49.0	446.0
7.5	1444	3.50	76.00	15.42	50.8	464.0
11.0	1492	3.52	78.65	14.68	53.2	488.0
16.5	1569	3.56	82.82	12.80	60.8	561.0
21.0	1632	3.59	86.23	9.81	78.9	732.0
22.5	1654	3.60	87.36	7.95	97.3	904.0

TEST NO.: W2. 3 FLOW PATTERN:SLUG

ML= 94 MG= 1.65 QFLUX= 7169 NUTP= 59.2 HTP= 545 PDT= 0.166

PDF=-0.016 ALFA=0.787 XTT= 1.95 WE= 2.0 FR= 0.11

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	70.40	1345	1242.0	14.9	6.66	0.710	0.37	5.23
OUTLET	88.51	1675	1210.7	14.7	5.30	0.708	0.37	5.47
MEAN	79.46	1510	1226.6	14.8	5.96	0.709	0.37	5.35

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1371	5.25	71.90	17.00	46.2	420.0
4.5	1405	5.28	73.79	16.62	47.2	430.0
7.5	1445	5.31	76.05	16.35	47.9	438.0
11.0	1493	5.34	78.70	15.31	51.0	468.0
16.5	1569	5.40	82.86	12.94	60.1	555.0
21.0	1633	5.44	86.26	9.14	84.7	785.0
22.5	1654	5.46	87.40	6.77	114.2	1060.0

TEST NO.: W2. 4 FLOW PATTERN:CHURN

ML= 94 MG= 2.27 OFIUX= 7209 NUTP= 63.9 HTP= 588 PDT= 0.167

PDF= 0.007 ALFA=0.812 XTT= 1.49 WE= 2.0 FR= 0.11

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	70.37	1344	1709.0	15.4	6.67	0.710	0.37	6.96
OUTLET	88.56	1676	1665.1	15.2	5.30	0.708	0.37	7.27
MEAN	79.47	1510	1687.1	15.3	5.95	0.709	0.37	7.12

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1371	6.99	71.88	17.21	46.0	418.0
4.5	1405	7.02	73.78	16.86	46.8	427.0
7.5	1445	7.06	76.05	15.88	49.6	453.0
11.0	1493	7.11	78.71	14.79	53.1	488.0
16.5	1570	7.18	82.88	11.40	68.6	633.0
21.0	1634	7.24	86.30	8.12	95.8	888.0
22.5	1655	7.26	87.44	6.23	124.7	1158.0

TEST NO.: W2. 5 FLOW PATTERN:CHURN

ML= 94 MG= 2.78 OFIUX= 7205 NUTP= 63.3 HTP= 582 PDT= 0.204

PDF= 0.059 ALFA=0.830 XTT= 1.21 WE= 2.0 FR= 0.11

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	70.17	1341	2100.0	14.9	6.69	0.710	0.37	8.84
OUTLET	88.32	1672	2046.1	14.7	5.32	0.708	0.37	9.25
MEAN	79.25	1506	2073.1	14.8	5.97	0.709	0.37	9.05

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1367	8.87	71.67	13.96	56.6	514.0
4.5	1401	8.92	73.56	14.04	56.1	512.0
7.5	1441	8.97	75.83	14.12	55.7	509.0
11.0	1489	9.03	78.48	14.25	55.1	506.0
16.5	1566	9.13	82.65	12.24	63.9	589.0
21.0	1629	9.21	86.06	9.32	83.6	775.0
22.5	1651	9.24	87.20	7.94	97.9	909.0

TEST NO.: W2. 6 FLOW PATTERN:CHURN

ML= 94 MG= 3.87 OFIUX= 7627 NUTP= 71.4 HTP= 656 PDT= 0.220

PDF= 0.093 ALFA=0.852 XTT= 0.92 WE= 2.0 FR= 0.11

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	70.12	1340	2920.0	15.4	6.69	0.710	0.37	11.89
OUTLET	89.29	1690	2841.3	15.2	5.25	0.708	0.37	12.48
MEAN	79.70	1515	2880.8	15.3	5.94	0.709	0.37	12.19

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1368	11.94	71.71	11.66	71.6	651.0
4.5	1403	12.00	73.70	11.98	69.6	634.0
7.5	1446	12.08	76.09	11.92	69.8	638.0
11.0	1497	12.16	78.89	11.96	69.4	637.0
16.5	1577	12.31	83.29	11.40	72.6	670.0
21.0	1645	12.42	86.89	11.32	72.9	676.0
22.5	1668	12.46	88.10	10.01	82.3	765.0

TEST NO.: W2. 7 FLOW PATTERN:CHURN

ML= 94 MG= 5.91 QFLUX= 11842 NUTP=112.9 HTP=1046 PDT= 0.227

PDF= 0.124 ALFA=0.879 XTT= 0.61 WE= 2.1 FR= 0.11

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	69.67	1332	4465.0	15.2	6.69	0.710	0.37	18.42
OUTLET	99.28	1884	4281.6	14.9	4.66	0.706	0.37	19.71
MEAN	84.47	1608	4373.4	15.0	5.61	0.708	0.37	19.08

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1375	18.53	72.12	12.46	103.7	943.0
4.5	1430	18.67	75.19	12.81	100.6	919.0
7.5	1496	18.83	78.88	12.17	105.6	970.0
11.0	1576	19.02	83.19	11.26	113.7	1050.0
16.5	1703	19.33	89.99	11.13	114.5	1067.0
21.0	1811	19.58	95.57	9.88	128.4	1205.0
22.5	1847	19.66	97.44	9.94	127.4	1199.0

TEST NO.: W2. 8 FLOW PATTERN:CHURN-ANNULAR

ML= 94 MG= 7.88 QFLUX= 11844 NUTP=109.3 HTP=1012 PDT= 0.205

PDF= 0.115 ALFA=0.895 XTT= 0.47 WE= 2.1 FR= 0.11

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	69.71	1333	5949.0	15.1	6.69	0.710	0.37	24.59
OUTLET	99.18	1882	5706.1	14.9	4.67	0.706	0.37	26.26
MEAN	84.44	1607	5827.8	15.0	5.61	0.708	0.37	25.45

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1376	24.73	72.14	12.25	105.5	960.0
4.5	1430	24.90	75.20	12.41	103.9	949.0
7.5	1496	25.12	78.87	12.15	105.8	972.0
11.0	1575	25.37	83.16	11.95	107.2	990.0
16.5	1702	25.76	89.93	11.36	112.2	1045.0
21.0	1809	26.09	95.49	10.93	116.1	1090.0
22.5	1846	26.20	97.35	10.77	117.7	1108.0

TEST NO.: W2. 9 FLOW PATTERN:CHURN-ANNULAR

ML= 94 MG= 13.05 QFLUX= 13402 NUTP=135.1 HTP=1254 PDT= 0.238

PDF= 0.167 ALFA=0.918 XTT= 0.30 WE= 2.1 FR= 0.11

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	69.14	1323	9862.0	15.4	6.73	0.710	0.37	40.02
OUTLET	102.07	1939	9413.6	15.1	4.52	0.706	0.37	43.08
MEAN	85.61	1631	9637.9	15.3	5.54	0.708	0.37	41.59

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1371	40.27	71.86	11.46	127.5	1160.0
4.5	1431	40.60	75.27	11.48	127.0	1160.0
7.5	1506	40.99	79.37	11.42	127.2	1169.0
11.0	1594	41.45	84.17	11.12	130.2	1204.0
16.5	1737	42.17	91.74	10.23	140.7	1314.0
21.0	1857	42.77	97.95	9.62	148.8	1402.0
22.5	1898	42.98	100.02	9.53	150.0	1417.0

TEST NO.: W2.10 FLOW PATTERN:ANNULAR

ML= 94 MG= 17.17 QFLUX= 14323 NUTP=156.4 HTP=1452 PDT= 0.288

PDF= 0.227 ALFA=0.929 XTT= 0.24 WE= 2.1 FR= 0.11

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	68.77	1316	12976.0	15.5	6.76	0.710	0.37	52.08
OUTLET	103.61	1970	12353.9	15.2	4.44	0.706	0.37	56.42
MEAN	86.19	1643	12665.4	15.4	5.50	0.708	0.37	54.31

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1367	52.45	71.65	10.71	145.8	1325.0
4.5	1431	52.90	75.26	10.85	143.5	1311.0
7.5	1510	53.46	79.59	10.71	144.9	1332.0
11.0	1603	54.11	84.67	10.30	150.1	1389.0
16.5	1755	55.14	92.67	9.39	163.7	1531.0
21.0	1883	55.99	99.25	8.69	175.9	1660.0
22.5	1927	56.28	101.44	8.38	182.0	1722.0

TEST NO.: W2.11 FLOW PATTERN:ANNULAR

ML= 94 MG= 21.23 QFLUX= 15280 NUTP=169.4 HTP=1574 PDT= 0.357

PDF= 0.302 ALFA=0.937 XTT= 0.20 WE= 2.1 FR= 0.11

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	68.13	1305	16060.0	15.6	6.81	0.710	0.37	63.91
OUTLET	104.93	1996	15247.2	15.3	4.38	0.706	0.37	69.76
MEAN	86.53	1651	15653.6	15.4	5.49	0.708	0.37	66.91

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1358	64.40	71.17	12.61	132.2	1201.0
4.5	1426	65.01	74.98	10.51	158.0	1443.0
7.5	1509	65.76	79.56	10.47	158.2	1454.0
11.0	1608	66.63	84.92	10.10	163.2	1511.0
16.5	1768	68.03	93.38	9.31	175.9	1647.0
21.0	1904	69.18	100.32	8.26	197.3	1864.0
22.5	1951	69.57	102.64	8.00	203.2	1926.0

TEST NO.: W2.12 FLOW PATTERN:ANNULAR

ML= 94 MG= 24.40 QFLUX= 16618 NUTP=235.2 HTP=2195 PDT= 0.443

PDF= 0.392 ALFA=0.941 XTT= 0.17 WE= 2.1 FR= 0.11

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	68.53	1312	18452.0	15.8	6.76	0.710	0.37	72.72
OUTLET	108.25	2064	17450.4	15.4	4.22	0.705	0.37	80.20
MEAN	88.39	1688	17951.4	15.6	5.37	0.708	0.37	76.56

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1370	73.35	71.81	9.69	186.7	1698.0
4.5	1443	74.13	75.92	9.70	186.0	1702.0
7.5	1533	75.08	80.86	9.22	194.9	1795.0
11.0	1640	76.20	86.65	8.56	209.0	1939.0
16.5	1815	77.98	95.78	7.06	251.5	2362.0
21.0	1963	79.46	103.27	5.39	327.4	3105.0
22.5	2014	79.95	105.78	5.03	350.5	3336.0

TEST NO.: W2.13 FLOW PATTERN:ANNULAR

ML= 94 MG= 24.72 QFLUX= 16446 NUTP=191.2 HTP=1780 PDT= 0.433

PDF= 0.383 ALFA=0.941 XTT= 0.17 WE= 2.1 FR= 0.11

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	67.71	1298	18717.0	15.9	6.84	0.710	0.37	73.21
OUTLET	106.99	2038	17710.2	15.4	4.28	0.705	0.37	80.62
MEAN	87.35	1668	18214.0	15.7	5.44	0.708	0.37	77.01

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1355	73.82	70.95	10.31	173.9	1580.0
4.5	1427	74.60	75.01	10.63	168.2	1536.0
7.5	1515	75.54	79.90	10.47	170.2	1565.0
11.0	1621	76.65	85.62	10.01	177.1	1641.0
16.5	1793	78.41	94.65	8.77	200.8	1883.0
21.0	1939	79.88	102.07	7.47	234.4	2219.0
22.5	1989	80.37	104.55	7.14	244.8	2325.0

TEST NO.: W2.14 FLOW PATTERN:ANNULAR-MIST

ML= 94 MG= 79.63 QFLUX= 16547 NUTP=207.2 HTP=1919 PDT= 1.664

PDF= 1.637 ALFA=0.970 XTT= 0.07 WE= 2.1 FR= 0.11

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	66.87	1283	60362.0	19.5	6.95	0.710	0.37	192.19
OUTLET	101.83	1934	57443.5	17.8	4.53	0.706	0.37	223.04
MEAN	84.35	1609	58903.1	18.6	5.64	0.708	0.37	207.76

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1334	194.63	69.76	7.23	249.9	2267.0
4.5	1397	197.74	73.37	8.89	202.9	1849.0
7.5	1476	201.54	77.73	9.59	187.5	1719.0
11.0	1569	206.09	82.82	9.77	183.4	1693.0
16.5	1720	213.50	90.86	8.80	202.3	1888.0
21.0	1848	219.80	97.46	7.28	243.3	2290.0
22.5	1891	221.96	99.66	6.57	268.8	2538.0

TEST NO.: W2.15 FLOW PATTERN:ANNULAR-MIST

ML= 94 MG=126.28 QFLUX= 14882 NUTP=127.4 HTP=1171 PDT= 2.610

PDF= 2.590 ALFA=0.977 XTT= 0.05 WE= 2.0 FR= 0.11

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	66.28	1273	95805.0	21.9	7.04	0.710	0.37	270.99
OUTLET	94.90	1798	91962.5	19.2	4.92	0.707	0.37	322.63
MEAN	80.59	1536	93883.9	20.6	5.90	0.709	0.37	296.78

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1314	274.95	68.64	7.64	212.8	1928.0
4.5	1366	280.01	71.60	11.29	144.0	1310.0
7.5	1429	286.26	75.17	13.35	121.7	1112.0
11.0	1505	293.81	79.34	14.33	113.0	1039.0
16.5	1627	306.27	85.92	14.11	114.3	1059.0
21.0	1729	317.04	91.33	12.82	125.1	1168.0
22.5	1764	320.75	93.13	12.24	130.9	1225.0

TEST NO.: W2.16 FLOW PATTERN:ANNULAR-MIST

ML= 94 MG=152.68 QFLUX= 12643 NUTP=114.3 HTP=1047 PDT= 3.222

PDF= 3.203 ALFA=0.979 XTT= 0.04 WE= 2.0 FR= 0.11

	TMIX	RESI	RESG	P	PRL	PRG	VSL	VSG
INLET	66.35	1274	115823.0	25.2	7.05	0.710	0.37	283.86
OUTLET	89.50	1694	112029.9	22.0	5.25	0.708	0.37	337.77
MEAN	77.92	1484	113926.7	23.6	6.10	0.709	0.37	310.71

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1308	287.96	68.26	6.62	209.1	1893.0
4.5	1349	293.21	70.66	10.53	131.5	1194.0
7.5	1401	299.71	73.54	12.74	108.6	990.0
11.0	1461	307.57	76.92	13.84	99.8	913.0
16.5	1558	320.59	82.24	13.65	100.7	929.0
21.0	1639	331.89	86.61	12.51	109.5	1016.0
22.5	1667	335.79	88.06	11.99	114.1	1060.0

TEST NO.: W2.17 FLOW PATTERN:ANNULAR-MIST

ML= 94 MG=168.73 QFLUX= 12731 NUTP=115.1 HTP=1054 PDT= 3.608

PDF= 3.589 ALFA=0.980 XTT= 0.04 WE= 2.0 FR= 0.11

	TMIX	RESI	RESG	P	PRL	PRG	VSL	VSG
INLET	66.23	1272	128022.0	26.9	7.07	0.710	0.37	294.66
OUTLET	88.88	1682	123915.6	23.3	5.29	0.708	0.37	352.89
MEAN	77.56	1477	125969.1	25.1	6.13	0.709	0.37	323.60

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1305	299.06	68.10	6.63	210.1	1901.0
4.5	1346	304.70	70.45	10.68	130.6	1186.0
7.5	1396	311.69	73.27	12.84	108.5	989.0
11.0	1455	320.17	76.58	13.89	100.1	917.0
16.5	1550	334.25	81.78	13.58	102.0	940.0
21.0	1629	346.50	86.05	12.33	112.0	1038.0
22.5	1656	350.74	87.48	11.78	117.0	1087.0

TEST NO.: W2.18 FLOW PATTERN:ANNULAR-MIST

ML= 94 MG=198.36 QFLUX= 12549 NUTP=121.1 HTP=1110 PDT= 4.070

PDF= 4.053 ALFA=0.982 XTT= 0.04 WE= 2.0 FR= 0.11

	TMIX	RESI	RESG	P	PRL	PRG	VSL	VSG
INLET	67.64	1297	150188.0	29.4	6.93	0.710	0.37	317.74
OUTLET	88.85	1682	145678.5	25.3	5.29	0.708	0.37	381.36
MEAN	78.24	1489	147933.5	27.3	6.07	0.709	0.37	349.32

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1327	322.52	69.39	5.65	242.9	2202.0
4.5	1366	328.67	71.59	10.00	137.3	1249.0
7.5	1413	336.29	74.24	12.31	111.5	1017.0
11.0	1468	345.54	77.33	13.30	103.0	944.0
16.5	1557	360.93	82.21	12.86	106.1	979.0
21.0	1632	374.35	86.20	11.59	117.3	1088.0
22.5	1657	379.00	87.54	11.02	123.3	1145.0

TEST NO.: W3. 1 FLOW PATTERN:SLUG

ML= 267 MG= 0.61 QFIUX= 10928 NUTP= 86.2 HTP= 790 PDT= 0.422

PDF= 0.010 ALFA=0.516 XTT= 12.48 WE= 16.1 FP= 0.86

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.63	3901	459.4	15.9	6.49	0.710	1.03	1.83
OUTLET	82.47	4403	453.0	15.5	5.72	0.708	1.03	1.91
MEAN	77.55	4152	456.2	15.7	6.10	0.709	1.03	1.87

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	3942	1.83	73.45	13.43	89.0	811.0
4.5	3994	1.84	74.47	13.64	87.6	799.0
7.5	4056	1.85	75.70	13.87	86.1	787.0
11.0	4128	1.86	77.14	13.91	85.7	785.0
16.5	4244	1.88	79.40	13.86	85.9	789.0
21.0	4339	1.90	81.24	13.89	85.6	789.0
22.5	4371	1.90	81.86	13.94	85.3	786.0

TEST NO.: W3. 2 FLOW PATTERN:SLUG

ML= 267 MG= 1.17 QFLUX= 11103 NUTP= 87.5 HTP= 802 PDT= 0.324

PDF= 0.002 ALFA=0.621 XTT= 6.88 WE= 16.1 FP= 0.87

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.69	3904	882.7	15.6	6.48	0.710	1.03	3.57
OUTLET	82.68	4414	870.1	15.3	5.70	0.708	1.03	3.70
MEAN	77.69	4159	876.4	15.5	6.08	0.709	1.03	3.64

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	3946	3.58	73.52	13.78	88.1	803.0
4.5	3998	3.59	74.56	13.94	87.0	794.0
7.5	4061	3.61	75.81	14.01	86.6	792.0
11.0	4135	3.63	77.27	13.81	87.7	803.0
16.5	4252	3.66	79.56	13.80	87.6	805.0
21.0	4349	3.69	81.44	13.77	87.7	808.0
22.5	4382	3.70	82.06	13.61	88.6	817.0

TEST NO.: W3. 3 FLOW PATTERN:SLUG

ML= 267 MG= 1.49 QFLUX= 11202 NUTP= 88.3 HTP= 809 PDT= 0.329

PDF= 0.035 ALFA=0.656 XTT= 5.53 WE= 16.1 FP= 0.87

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.68	3903	1120.0	15.5	6.48	0.710	1.03	4.56
OUTLET	82.75	4418	1104.7	15.2	5.70	0.708	1.03	4.74
MEAN	77.71	4161	1112.8	15.4	6.08	0.709	1.03	4.65

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	3945	4.57	73.51	13.75	89.1	812.0
4.5	3998	4.59	74.56	13.81	88.7	810.0
7.5	4062	4.61	75.82	13.90	88.0	805.0
11.0	4136	4.64	77.29	14.00	87.3	799.0
16.5	4255	4.68	79.60	13.86	88.0	809.0
21.0	4352	4.72	81.50	13.63	89.4	823.0
22.5	4385	4.73	82.13	13.53	90.0	830.0

TEST NO.: W3. 4 FLOW PATTERN:CHURN

ML= 267 MG= 1.89 QFLUX= 11480 NUTP= 89.4 HTP= 820 PDT= 0.332

PDF= 0.064 ALFA=0.686 XTT= 4.48 WE= 16.1 FR= 0.87

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.75	3907	1420.0	15.6	6.47	0.710	1.03	5.74
OUTLET	83.07	4434	1399.7	15.3	5.68	0.708	1.03	5.97
MEAN	77.91	4170	1410.1	15.5	6.07	0.709	1.03	5.86

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	3950	5.76	73.60	13.64	92.0	839.0
4.5	4004	5.78	74.68	13.90	90.2	824.0
7.5	4069	5.81	75.97	14.06	89.1	815.0
11.0	4145	5.85	77.47	14.07	89.0	816.0
16.5	4267	5.90	79.84	14.30	87.4	803.0
21.0	4367	5.95	81.78	13.86	90.0	830.0
22.5	4401	5.96	82.43	12.96	96.2	888.0

TEST NO.: W3. 5 FLOW PATTERN:CHURN

ML= 267 MG= 2.69 QFLUX= 11302 NUTP= 89.0 HTP= 816 PDT= 0.364

PDF= 0.131 ALFA=0.727 XTT= 3.27 WE= 16.1 FR= 0.87

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.84	3912	2021.0	15.7	6.47	0.710	1.03	8.12
OUTLET	82.99	4430	1992.4	15.4	5.68	0.708	1.03	8.46
MEAN	77.92	4171	2007.1	15.6	6.07	0.709	1.03	8.29

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	3954	8.15	73.68	12.80	96.6	880.0
4.5	4007	8.18	74.74	13.40	92.2	842.0
7.5	4071	8.23	76.01	14.04	87.9	804.0
11.0	4146	8.28	77.49	14.31	86.2	790.0
16.5	4266	8.36	79.82	14.01	87.8	807.0
21.0	4364	8.43	81.73	13.77	89.2	822.0
22.5	4397	8.45	82.36	13.14	93.5	862.0

TEST NO.: W3. 6 FLOW PATTERN:CHURN

ML= 267 MG= 5.32 QFLUX= 12192 NUTP=102.4 HTP= 939 PDT= 0.420

PDF= 0.245 ALFA=0.795 XTT= 1.77 WE= 16.1 FR= 0.87

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	73.10	3925	3992.0	15.7	6.44	0.710	1.03	16.05
OUTLET	84.03	4484	3930.7	15.3	5.61	0.708	1.03	16.80
MEAN	78.57	4205	3961.8	15.5	6.01	0.709	1.03	16.44

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	3970	16.11	74.01	12.30	108.3	988.0
4.5	4027	16.19	75.15	12.86	103.5	946.0
7.5	4097	16.29	76.51	13.07	101.8	932.0
11.0	4178	16.40	78.10	13.34	99.6	914.0
16.5	4307	16.58	80.61	13.07	101.4	934.0
21.0	4413	16.73	82.67	12.71	104.2	961.0
22.5	4449	16.78	83.35	12.57	105.3	973.0

TEST NO.: W3. 7 FLOW PATTERN:CHURN-ANNULAR

ML= 267 MG= 11.83 QFLUX= 21952 NUTP=188.1 HTP=1740 PDT= 0.485

PDF= 0.362 ALFA=0.856 XTT= 0.86 WE= 16.3 FR= 0.87

	TMIX	RESI	RESG	P	PRL	PRG	VSL	VSG
INLET	74.12	3976	8872.0	15.9	6.31	0.709	1.03	35.33
OUTLET	93.69	5000	8629.6	15.4	4.97	0.707	1.03	37.70
MEAN	83.90	4488	8751.1	15.7	5.62	0.708	1.03	36.55

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	4058	35.53	75.74	12.77	187.1	1711.0
4.5	4161	35.78	77.77	13.02	183.3	1680.0
7.5	4286	36.08	80.21	12.86	185.1	1703.0
11.0	4434	36.43	83.07	12.80	185.6	1714.0
16.5	4670	37.00	87.56	12.43	190.5	1770.0
21.0	4868	37.46	91.24	12.12	194.8	1818.0
22.5	4934	37.62	92.47	12.30	191.8	1794.0

TEST NO.: W3. 8 FLOW PATTERN:ANNULAR

ML= 267 MG= 16.02 QFLUX= 22978 NUTP=217.8 HTP=2016 PDT= 0.580

PDF= 0.472 ALFA=0.874 XTT= 0.66 WE= 16.3 FR= 0.87

	TMIX	RESI	RESG	P	PRL	PRG	VSL	VSG
INLET	74.09	3974	12018.0	16.2	6.31	0.709	1.03	46.97
OUTLET	94.49	5044	11675.8	15.7	4.93	0.707	1.03	50.46
MEAN	84.29	4509	11847.1	15.9	5.59	0.708	1.03	48.76

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	4059	47.26	75.78	11.60	215.5	1971.0
4.5	4167	47.63	77.89	11.72	213.0	1953.0
7.5	4298	48.07	80.44	11.74	212.2	1953.0
11.0	4452	48.59	83.41	11.58	214.7	1984.0
16.5	4699	49.42	88.10	11.22	220.7	2052.0
21.0	4905	50.11	91.94	10.93	226.0	2112.0
22.5	4975	50.34	93.22	10.73	229.9	2152.0

TEST NO.: W3. 9 FLOW PATTERN:ANNULAR

ML= 267 MG= 20.28 QFLUX= 26040 NUTP=253.9 HTP=2354 PDT= 0.716

PDF= 0.619 ALFA=0.887 XTT= 0.53 WE= 16.3 FR= 0.87

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	74.07	3973	15214.0	16.5	6.31	0.709	1.03	58.38
OUTLET	97.10	5187	14727.0	15.8	4.78	0.707	1.04	63.48
MEAN	85.58	4580	14970.8	16.2	5.50	0.708	1.03	60.99

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	4069	58.80	75.97	11.45	247.2	2261.0
4.5	4191	59.33	78.36	11.52	245.1	2250.0
7.5	4339	59.97	81.23	11.43	246.6	2272.0
11.0	4514	60.74	84.59	11.20	251.0	2323.0
16.5	4795	61.95	89.88	10.85	258.1	2405.0
21.0	5029	62.97	94.22	10.49	266.2	2496.0
22.5	5109	63.31	95.67	10.42	267.6	2513.0

TEST NO.: W3.10 FLOW PATTERN:ANNULAR

ML= 267 MG= 24.53 QFLUX= 27174 NUTP=284.7 HTP=2642 PDT= 0.856

PDF= 0.767 ALFA=0.896 XTT= 0.45 WE= 16.3 FR= 0.87

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	74.02	3971	18402.0	17.0	6.31	0.709	1.03	68.73
OUTLET	97.96	5235	17790.1	16.1	4.73	0.706	1.04	75.40
MEAN	85.99	4603	18096.2	16.6	5.48	0.708	1.03	72.13

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	4071	69.27	76.00	10.72	275.4	2520.0
4.5	4197	69.96	78.48	10.82	272.4	2501.0
7.5	4351	70.80	81.47	10.76	273.3	2519.0
11.0	4533	71.80	84.96	10.47	280.3	2595.0
16.5	4826	73.39	90.46	10.03	291.1	2715.0
21.0	5070	74.72	94.97	9.62	302.5	2838.0
22.5	5153	75.17	96.48	9.43	308.4	2900.0

TEST NO.: W3.11 FLOW PATTERN:ANNULAR

ML= 267 MG= 25.71 QFLUX= 28907 NUTP=301.6 HTP=2791 PDT= 0.896

PDF= 0.808 ALFA=0.898 XTT= 0.44 WE= 16.3 FR= 0.87

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	71.43	3841	19356.0	17.1	6.54	0.710	1.03	71.39
OUTLET	96.88	5175	18670.5	16.2	4.79	0.707	1.04	78.71
MEAN	84.15	4508	19013.6	16.6	5.62	0.708	1.03	75.12

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	3946	71.99	73.53	10.84	290.6	2650.0
4.5	4079	72.74	76.17	10.98	286.3	2620.0
7.5	4241	73.66	79.34	10.86	288.7	2653.0
11.0	4433	74.75	83.05	10.63	294.1	2717.0
16.5	4742	76.50	88.90	10.07	309.2	2878.0
21.0	5001	77.96	93.69	9.54	325.2	3046.0
22.5	5088	78.46	95.29	9.37	330.5	3102.0

TEST NO.: W3.12 FLOW PATTERN:ANNULAR

ML= 267 MG= 39.02 QFLUX= 30647 NUTP=339.7 HTP=3145 PDT= 1.376

PDF= 1.302 ALFA=0.915 XTT= 0.31 WE= 16.3 FR= 0.87

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	70.89	3814	29404.0	18.4	6.58	0.710	1.03	100.31
OUTLET	97.56	5212	28313.3	17.0	4.76	0.707	1.04	113.40
MEAN	84.22	4513	28859.0	17.7	5.61	0.708	1.03	106.94

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	3924	101.36	73.09	9.72	343.6	3132.0
4.5	4063	102.69	75.86	10.06	331.2	3029.0
7.5	4233	104.31	79.18	10.14	327.9	3013.0
11.0	4434	106.25	83.07	10.02	330.8	3055.0
16.5	4758	109.39	89.19	9.55	345.4	3217.0
21.0	5029	112.05	94.22	9.21	357.0	3346.0
22.5	5121	112.95	95.90	9.05	362.8	3408.0

TEST NO.: W3.13 FLOW PATTERN:ANNULAR-MIST

ML= 267 MG= 66.97 QFLUX= 29361 NUTP=283.1 HTP=2612 PDT= 2.110

PDF= 2.051 ALFA=0.933 XTT= 0.20 WE= 16.2 FR= 0.87

	TMIX	RESI	RESG	P	PRL	PRG	VSL	VSG
INLET	69.96	3769	50533.0	21.1	6.68	0.710	1.03	150.22
OUTLET	94.91	5067	48769.8	18.9	4.91	0.707	1.03	173.97
MEAN	82.44	4418	49651.6	20.0	5.74	0.708	1.03	162.15

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	3871	152.08	72.02	8.81	363.4	3307.0
4.5	4000	154.44	74.61	9.99	319.9	2922.0
7.5	4158	157.35	77.72	10.78	295.9	2714.0
11.0	4345	160.84	81.35	11.50	276.9	2552.0
16.5	4645	166.55	87.08	12.13	261.5	2428.0
21.0	4897	171.44	91.79	12.38	255.4	2386.0
22.5	4982	173.12	93.36	12.54	251.9	2359.0

TEST NO.: W3.14 FLOW PATTERN:ANNULAR-MIST

ML= 267 MG=110.75 QFLUX= 24678 NUTP=191.7 HTP=1761 PDT= 3.222

PDF= 3.175 ALFA=0.946 XTT= 0.14 WE= 16.2 FR= 0.87

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	70.06	3773	83560.0	24.8	6.69	0.710	1.03	211.34
OUTLET	90.28	4816	81176.9	21.5	5.19	0.707	1.03	250.79
MEAN	80.17	4295	82368.6	23.1	5.91	0.709	1.03	230.97

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	3856	214.33	71.73	8.06	333.4	3033.0
4.5	3961	218.17	73.82	10.76	249.9	2280.0
7.5	4088	222.92	76.34	12.81	209.8	1920.0
11.0	4238	228.67	79.28	14.86	180.7	1660.0
16.5	4479	238.19	83.93	17.06	157.1	1452.0
21.0	4680	246.47	87.74	18.31	146.0	1357.0
22.5	4748	249.34	89.02	18.56	144.0	1340.0

TEST NO.: W3.15 FLOW PATTERN:ANNULAR-MIST

ML= 267 MG=152.54 QFLUX= 19727 NUTP=140.0 HTP=1282 PDT= 4.038

PDF= 3.997 ALFA=0.953 XTT= 0.11 WE= 16.1 FR= 0.87

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	70.03	3772	115092.0	28.2	6.71	0.710	1.03	255.92
OUTLET	85.66	4570	112533.7	24.1	5.50	0.708	1.03	305.72
MEAN	77.84	4171	113813.2	26.1	6.08	0.709	1.03	280.60

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	3836	259.65	71.32	7.53	285.7	2597.0
4.5	3917	264.44	72.94	11.38	189.1	1723.0
7.5	4014	270.38	74.89	14.36	149.9	1370.0
11.0	4130	277.62	77.16	17.01	126.6	1160.0
16.5	4314	289.67	80.76	19.58	109.9	1011.0
21.0	4467	300.21	83.70	20.76	103.5	956.0
22.5	4519	303.86	84.69	21.01	102.2	945.0

TEST NO.: W3.16 FLOW PATTERN:ANNULAR-MIST

ML= 267 MG=193.68 QFLUX= 17083 NUTP=113.1 HTP=1034 PDT= 4.684

PDF= 4.646 ALFA=0.958 XTT= 0.10 WE= 16.1 FR= 0.86

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	70.12	3776	146115.0	31.9	6.71	0.710	1.03	287.24
OUTLET	83.23	4442	143378.1	27.2	5.67	0.708	1.03	343.01
MEAN	76.67	4109	144746.6	29.5	6.18	0.709	1.03	314.85

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	3830	291.40	71.20	7.47	249.4	2267.0
4.5	3898	296.75	72.56	12.30	151.7	1381.0
7.5	3979	303.40	74.19	15.80	118.2	1078.0
11.0	4076	311.49	76.10	18.74	99.7	912.0
16.5	4230	324.98	79.12	21.19	88.1	809.0
21.0	4357	336.81	81.59	22.06	84.5	779.0
22.5	4400	340.92	82.41	22.23	83.8	773.0

TEST NO.: W4. 1 FLOW PATTERN:BUBBLE

ML= 882 MG= 0.10 QFLUX= 12673 NUTP= 99.7 HTP= 907 PDT= 0.960

PDF= 0.173 ALFA=0.075 XTT=189.13 WE= 173.9 FR= 9.39

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	70.58	12528	77.7	17.2	6.71	0.710	3.41	0.28
OUTLET	74.04	13097	77.3	16.2	6.40	0.709	3.40	0.30
MEAN	72.31	12813	77.5	16.7	6.55	0.710	3.40	0.29

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	12575	0.29	70.87	13.23	105.3	956.0
4.5	12634	0.29	71.23	13.82	100.8	916.0
7.5	12705	0.29	71.66	14.05	99.1	901.0
11.0	12788	0.29	72.17	14.09	98.9	899.0
16.5	12919	0.30	72.96	14.01	99.3	905.0
21.0	13026	0.30	73.61	14.03	99.2	904.0
22.5	13062	0.30	73.83	14.09	98.7	900.0

TEST NO.: W4. 2 FLOW PATTERN:BUBBLE

ML= 882 MG= 0.16 QFLUX= 12668 NUTP=104.2 HTP= 948 PDT= 0.945

PDF= 0.185 ALFA=0.108 XTT=130.19 WE= 173.9 FR= 9.39

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	70.54	12521	117.7	17.1	6.71	0.710	3.41	0.43
OUTLET	74.00	13090	117.1	16.2	6.41	0.709	3.40	0.46
MEAN	72.27	12805	117.4	16.7	6.56	0.710	3.40	0.44

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	12568	0.43	70.82	12.72	109.5	994.0
4.5	12627	0.44	71.18	13.23	105.3	957.0
7.5	12697	0.44	71.62	13.42	103.8	943.0
11.0	12780	0.44	72.12	13.51	103.1	938.0
16.5	12911	0.45	72.92	13.42	103.6	944.0
21.0	13018	0.45	73.57	13.36	104.1	949.0
22.5	13054	0.46	73.78	13.38	103.9	947.0

TEST NO.: W4. 3 FLOW PATTERN:SLUG

ML= 882 MG= 0.50 OFLUX= 16763 NUTP=134.4 HTP=1225 PDT= 0.870

PDF= 0.238 ALFA=0.258 XTT= 45.57 WE= 174.2 FR= 9.39

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	70.98	12593	375.4	17.0	6.66	0.710	3.41	1.39
OUTLET	75.55	13348	372.9	16.1	6.27	0.709	3.40	1.47
MEAN	73.27	12970	374.2	16.6	6.47	0.710	3.40	1.43

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	12655	1.39	71.36	13.18	139.6	1269.0
4.5	12733	1.40	71.83	13.60	135.3	1231.0
7.5	12827	1.41	72.41	13.73	134.0	1220.0
11.0	12937	1.42	73.07	13.75	133.8	1219.0
16.5	13111	1.44	74.12	13.72	133.9	1222.0
21.0	13253	1.46	74.98	13.70	134.1	1225.0
22.5	13301	1.47	75.27	13.77	133.4	1219.0

TEST NO.: W4. 4 FLOW PATTERN:SLUG

ML= 882 MG= 1.03 OFLUX= 24822 NUTP=181.9 HTP=1662 PDT= 0.859

PDF= 0.337 ALFA=0.387 XTT= 23.53 WE= 174.6 FR= 9.40

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	71.72	12715	776.2	16.9	6.58	0.710	3.41	2.88
OUTLET	78.50	13843	768.7	16.1	6.03	0.709	3.41	3.07
MEAN	75.11	13279	772.4	16.5	6.30	0.709	3.40	2.98

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	12807	2.90	72.29	14.46	188.2	1713.0
4.5	12924	2.92	72.99	14.92	182.4	1662.0
7.5	13063	2.94	73.84	15.07	180.5	1646.0
11.0	13227	2.97	74.83	15.04	180.7	1650.0
16.5	13487	3.01	76.38	14.94	181.6	1662.0
21.0	13700	3.05	77.66	14.85	182.5	1674.0
22.5	13772	3.06	78.08	14.88	182.2	1672.0

TEST NO.: W4. 5 FLOW PATTERN:SLUG

ML= 882 MG= 1.44 OFLUX= 27060 NUTP=208.0 HTP=1902 PDT= 0.834

PDF= 0.363 ALFA=0.447 XTT= 17.43 WE= 174.7 FR= 9.40

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	71.85	12736	1082.0	16.9	6.57	0.710	3.41	4.02
OUTLET	79.24	13968	1070.7	16.1	5.97	0.709	3.41	4.28
MEAN	75.55	13352	1076.4	16.5	6.26	0.709	3.40	4.15

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	12837	4.04	72.46	13.74	215.8	1965.0
4.5	12963	4.07	73.23	14.17	209.3	1907.0
7.5	13116	4.10	74.16	14.36	206.4	1883.0
11.0	13295	4.14	75.23	14.36	206.1	1884.0
16.5	13578	4.20	76.93	14.23	207.7	1903.0
21.0	13812	4.26	78.32	14.19	208.2	1911.0
22.5	13890	4.27	78.78	14.14	208.8	1918.0

TEST NO.: W4. 6 FLOW PATTERN:SLUG

ML= 882 MG= 1.83 QFIUX= 29328 NUTP=232.8 HTP=2130 PDT= 0.773

PDF= 0.337 ALFA=0.489 XTT= 14.07 WE= 174.8 FR= 9.40

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.02	12764	1379.0	17.1	6.55	0.710	3.41	5.09
OUTLET	80.03	14102	1363.5	16.3	5.91	0.709	3.41	5.40
MEAN	76.03	13433	1371.4	16.7	6.22	0.709	3.40	5.24

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	12873	5.11	72.69	13.22	242.9	2213.0
4.5	13011	5.14	73.52	13.67	234.9	2142.0
7.5	13177	5.18	74.52	13.87	231.4	2113.0
11.0	13371	5.23	75.69	13.88	231.1	2113.0
16.5	13679	5.30	77.53	13.81	231.9	2126.0
21.0	13932	5.36	79.03	13.73	232.9	2140.0
22.5	14017	5.39	79.53	13.84	231.1	2125.0

TEST NO.: W4. 7 FLOW PATTERN:SLUG

ML= 882 MG= 2.65 QFIUX= 29327 NUTP=238.4 HTP=2182 PDT= 0.855

PDF= 0.473 ALFA=0.551 XTT= 10.08 WE= 174.9 FR= 9.40

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.23	12799	1992.0	17.1	6.53	0.710	3.41	7.35
OUTLET	80.24	14137	1970.0	16.2	5.89	0.709	3.41	7.84
MEAN	76.24	13468	1981.5	16.7	6.20	0.709	3.40	7.60

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	12908	7.39	72.90	11.94	268.8	2449.0
4.5	13045	7.44	73.73	12.62	254.2	2319.0
7.5	13211	7.50	74.73	13.19	243.2	2221.0
11.0	13406	7.58	75.90	13.54	236.7	2165.0
16.5	13714	7.69	77.74	13.84	231.4	2122.0
21.0	13968	7.79	79.24	14.28	224.1	2059.0
22.5	14053	7.82	79.74	14.31	223.5	2055.0

TEST NO.: W4. 8 FLOW PATTERN:SLUG-ANNULAR

ML= 882 MG= 5.35 QFIUX= 27525 NUTP=213.5 HTP=1953 PDT= 0.929

PDF= 0.636 ALFA=0.656 XTT= 5.37 WE= 174.7 FR= 9.40

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	71.93	12749	4025.0	17.1	6.56	0.710	3.41	14.79
OUTLET	79.44	14002	3981.6	16.2	5.95	0.709	3.41	15.82
MEAN	75.69	13376	4003.3	16.7	6.25	0.709	3.40	15.32

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	12852	14.88	72.56	12.94	232.9	2121.0
4.5	12981	14.98	73.34	13.55	222.5	2028.0
7.5	13136	15.11	74.28	13.98	215.4	1966.0
11.0	13318	15.27	75.37	14.25	211.3	1931.0
16.5	13606	15.51	77.09	14.32	210.1	1925.0
21.0	13843	15.72	78.51	14.56	206.3	1893.0
22.5	13923	15.79	78.98	14.61	205.5	1888.0

TEST NO.: W4. 9 FLOW PATTERN:ANNULAR

ML= 882 MG= 12.55 QFIUX= 35834 NUTP=287.4 HTP=2635 PDT= 1.557

PDF= 1.344 ALFA=0.751 XTT= 2.55 WE= 175.1 FR= 9.40

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.51	12844	9432.0	18.4	6.50	0.710	3.41	32.46
OUTLET	82.27	14483	9301.0	16.8	5.74	0.708	3.41	35.99
MEAN	77.39	13664	9366.8	17.6	6.11	0.709	3.40	34.24

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	12978	32.74	73.32	13.12	298.8	2724.0
4.5	13146	33.10	74.34	13.62	287.8	2627.0
7.5	13349	33.53	75.56	13.92	281.3	2572.0
11.0	13587	34.05	76.98	13.77	284.1	2603.0
16.5	13964	34.90	79.22	13.51	288.9	2655.0
21.0	14275	35.62	81.05	13.45	289.9	2670.0
22.5	14380	35.87	81.66	13.27	293.6	2706.0

TEST NO.: W4.10 FLOW PATTERN:ANNULAR

ML= 882 MG= 18.74 QFIUX= 38764 NUTP=331.4 HTP=3042 PDT= 1.927

PDF= 1.743 ALFA=0.786 XTT= 1.81 WE= 175.4 FR= 9.41

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.93	12913	14082.0	19.4	6.46	0.710	3.41	46.02
OUTLET	83.46	14689	13870.7	17.4	5.65	0.708	3.41	51.91
MEAN	78.20	13801	13976.5	18.4	6.04	0.709	3.41	48.98

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	13058	46.48	73.80	12.35	343.2	3131.0
4.5	13239	47.07	74.90	12.88	328.8	3004.0
7.5	13459	47.79	76.22	12.89	328.2	3004.0
11.0	13717	48.65	77.75	12.72	332.2	3046.0
16.5	14125	50.07	80.17	12.78	330.2	3038.0
21.0	14463	51.28	82.15	12.64	333.2	3074.0
22.5	14577	51.70	82.81	12.67	332.3	3068.0

TEST NO.: W4.11 FLOW PATTERN:ANNULAR

ML= 882 MG= 24.10 QFIUX= 40949 NUTP=354.2 HTP=3254 PDT= 2.248

PDF= 2.081 ALFA=0.805 XTT= 1.47 WE= 175.5 FR= 9.41

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	73.23	12963	18099.0	20.1	6.43	0.709	3.41	56.85
OUTLET	84.34	14841	17813.1	17.9	5.58	0.708	3.41	65.03
MEAN	78.79	13902	17956.3	19.0	6.00	0.709	3.41	60.95

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	13115	57.48	74.15	12.01	372.7	3402.0
4.5	13307	58.29	75.31	12.56	356.3	3257.0
7.5	13539	59.29	76.70	12.76	350.3	3208.0
11.0	13812	60.49	78.32	12.69	351.9	3230.0
16.5	14245	62.46	80.87	12.58	354.2	3262.0
21.0	14599	64.15	82.94	12.60	353.1	3260.0
22.5	14719	64.74	83.64	12.62	352.3	3256.0

TEST NO.: W4.12 FLOW PATTERN:ANNULAR

ML= 882 MG= 47.45 QFIUX= 45609 NUTP=397.3 HTP=3651 PDT= 3.370

PDF= 3.238 ALFA=0.846 XTT= 0.86 WE= 175.6 FR= 9.41

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	73.08	12938	35641.0	23.9	6.43	0.710	3.41	94.34
OUTLET	85.38	15021	35018.8	20.5	5.51	0.708	3.41	111.71
MEAN	79.23	13980	35330.4	22.2	5.96	0.709	3.41	102.96

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	13107	95.64	74.10	11.37	438.1	3998.0
4.5	13319	97.32	75.38	12.06	412.6	3772.0
7.5	13576	99.40	76.92	12.43	400.1	3665.0
11.0	13878	101.92	78.71	12.69	391.3	3593.0
16.5	14358	106.13	81.53	12.74	389.2	3587.0
21.0	14755	109.79	83.85	12.74	388.4	3592.0
22.5	14889	111.07	84.62	12.78	387.0	3582.0

TEST NO.: W4.13 FLOW PATTERN:ANNULAR-MIST

ML= 882 MG= 73.58 QFIUX= 53833 NUTP=439.6 HTP=4047 PDT= 4.548

PDF= 4.432 ALFA=0.865 XTT= 0.63 WE= 175.9 FR= 9.41

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	73.36	12984	55244.0	28.4	6.40	0.709	3.41	123.16
OUTLET	87.78	15439	54117.2	23.9	5.35	0.708	3.41	149.61
MEAN	80.57	14212	54680.8	26.1	5.86	0.709	3.41	136.20

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	13182	125.11	74.55	11.90	493.2	4504.0
4.5	13431	127.62	76.05	12.71	461.4	4222.0
7.5	13733	130.75	77.85	13.14	445.9	4090.0
11.0	14089	134.57	79.95	13.43	435.7	4008.0
16.5	14655	140.98	83.26	13.60	429.1	3965.0
21.0	15124	146.63	85.98	13.88	419.8	3893.0
22.5	15282	148.61	86.88	14.05	414.6	3849.0

TEST NO.: W4.14 FLOW PATTERN:ANNULAR-MIST

ML= 882 MG=107.51 QFIUX= 55707 NUTP=458.5 HTP=4218 PDT= 5.579

PDF= 5.474 ALFA=0.878 XTT= 0.49 WE= 175.8 FR= 9.41

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.66	12868	80803.0	34.4	6.46	0.710	3.41	148.37
OUTLET	87.44	15380	79111.4	28.8	5.37	0.708	3.41	180.78
MEAN	80.05	14124	79957.4	31.6	5.90	0.709	3.41	164.33

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	13071	150.75	73.88	11.33	536.4	4894.0
4.5	13326	153.82	75.42	12.22	496.9	4543.0
7.5	13634	157.65	77.26	12.74	476.3	4366.0
11.0	13998	162.33	79.42	13.21	458.7	4216.0
16.5	14577	170.19	82.81	13.91	434.5	4012.0
21.0	15058	177.13	85.60	14.36	420.3	3895.0
22.5	15220	179.55	86.53	14.25	423.2	3927.0

TEST NO.: W4.15 FLOW PATTERN:ANNUIAR-MIST

ML= 882 MG=116.03 QFLUX= 55867 NUTP=464.1 HTP=4268 PDT= 6.033

PDF= 5.930 AIFA=0.881 XTT= 0.47 WE= 175.8 FR= 9.41

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.50	12843	87228.0	35.6	6.48	0.710	3.41	154.47
OUTLET	87.30	15354	85399.8	29.6	5.38	0.708	3.41	189.75
MEAN	79.90	14099	86314.1	32.6	5.91	0.709	3.41	171.80

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	13045	157.04	73.73	11.08	550.0	5017.0
4.5	13300	160.36	75.26	12.00	507.7	4641.0
7.5	13608	164.51	77.11	12.57	483.9	4434.0
11.0	13972	169.59	79.27	13.13	462.8	4253.0
16.5	14551	178.15	82.66	13.81	439.3	4056.0
21.0	15032	185.74	85.45	14.39	420.8	3899.0
22.5	15194	188.40	86.38	14.33	422.2	3917.0

TEST NO.: W5. 1 FLOW PATTERN:BUBBLE

ML=2698 MG= 0.38 QFLUX= 30538 NUTP=266.8 HTP=2441 PDT= 1.717

PDF= 0.938 AIFA=0.083 XTT=164.23 WF= 1636.0 FR= 87.99

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	74.70	40404	287.7	19.1	6.33	0.709	10.42	0.96
OUTLET	77.43	41798	286.6	17.4	6.11	0.709	10.42	1.06
MEAN	76.06	41101	287.2	18.2	6.22	0.709	10.42	1.01

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	40520	0.97	74.93	11.97	278.9	2548.0
4.5	40664	0.98	75.21	12.38	269.6	2464.0
7.5	40838	0.99	75.55	12.55	266.1	2433.0
11.0	41041	1.00	75.95	12.59	265.1	2426.0
16.5	41361	1.02	76.57	12.56	265.6	2432.0
21.0	41623	1.05	77.09	12.58	265.1	2429.0
22.5	41711	1.05	77.26	12.63	264.1	2421.0

TEST NO.: W5. 2 FLOW PATTERN:BUBBLE-SLUG

ML=2698 MG= 1.06 QFLUX= 31742 NUTP=288.2 HTP=2638 PDT= 1.849

PDF= 1.157 ALFA=0.187 XTT= 66.47 WE= 1636.0 FR= 87.99

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	74.83	40471	792.3	19.4	6.31	0.709	10.42	2.59
OUTLET	77.66	41920	789.1	17.6	6.09	0.709	10.42	2.87
MEAN	76.25	41195	790.7	18.5	6.20	0.709	10.42	2.73

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	40590	2.61	75.06	11.37	305.2	2789.0
4.5	40741	2.64	75.36	11.89	291.9	2668.0
7.5	40922	2.68	75.71	12.10	286.7	2622.0
11.0	41133	2.72	76.13	12.06	287.5	2631.0
16.5	41466	2.78	76.78	12.13	285.9	2618.0
21.0	41739	2.84	77.31	12.14	285.4	2616.0
22.5	41830	2.86	77.49	12.21	283.8	2602.0

TEST NO.: W5. 3 FLOW PATTERN:BUBBLE-SLUG

ML=2698 MG= 1.47 QFLUX= 31732 NUTP=303.0 HTP=2774 PDT= 1.949

PDF= 1.296 ALFA=0.233 XTT= 49.77 WE= 1636.0 FR= 87.99

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	74.87	40492	1100.0	19.7	6.31	0.709	10.42	3.55
OUTLET	77.70	41942	1095.6	17.8	6.08	0.709	10.42	3.94
MEAN	76.29	41217	1097.8	18.8	6.20	0.709	10.42	3.75

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	40612	3.58	75.11	10.70	324.1	2962.0
4.5	40762	3.62	75.40	11.23	308.8	2823.0
7.5	40943	3.67	75.76	11.50	301.5	2758.0
11.0	41154	3.73	76.17	11.46	302.4	2768.0
16.5	41487	3.82	76.82	11.54	300.3	2750.0
21.0	41760	3.90	77.35	11.63	297.9	2730.0
22.5	41851	3.93	77.53	11.70	296.1	2715.0

TEST NO.: W5. 4 FLOW PATTERN:BUBBLE-SLUG

ML=2698 MG= 1.81 QFLUX= 32975 NUTP=308.2 HTP=2822 PDT= 2.021

PDF= 1.396 ALFA=0.265 XTT= 41.48 WE= 1637.0 FR= 88.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	75.05	40581	1353.0	19.9	6.29	0.709	10.42	4.32
OUTLET	77.99	42089	1347.3	17.9	6.06	0.709	10.42	4.81
MEAN	76.52	41335	1350.2	18.9	6.18	0.709	10.42	4.57

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	40706	4.36	75.29	10.79	333.9	3052.0
4.5	40862	4.41	75.60	11.42	315.6	2886.0
7.5	41050	4.47	75.97	11.76	306.5	2804.0
11.0	41270	4.54	76.40	11.69	308.1	2820.0
16.5	41616	4.66	77.07	11.84	304.1	2787.0
21.0	41900	4.76	77.62	11.93	301.8	2767.0
22.5	41995	4.80	77.81	12.00	299.9	2751.0

TEST NO.: W5. 5 FLOW PATTERN:BUBBLE-SLUG

ML=2698 MG= 2.18 QFLUX= 32973 NUTP=315.4 HTP=2889 PDT= 2.148

PDF= 1.547 ALFA=0.294 XTT= 35.28 WE= 1637.0 FR= 88.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	75.18	40648	1629.0	20.3	6.28	0.709	10.42	5.13
OUTLET	78.12	42156	1623.0	18.1	6.05	0.709	10.42	5.74
MEAN	76.65	41402	1626.4	19.2	6.17	0.709	10.42	5.44

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	40773	5.18	75.42	10.39	346.6	3169.0
4.5	40929	5.24	75.73	11.10	324.4	2967.0
7.5	41117	5.31	76.10	11.44	314.8	2880.0
11.0	41337	5.40	76.53	11.41	315.6	2889.0
16.5	41683	5.55	77.20	11.61	310.0	2841.0
21.0	41967	5.68	77.75	11.74	306.4	2810.0
22.5	42062	5.72	77.94	11.79	305.1	2799.0

TEST NO.: W5. 6 FLOW PATTERN:BUBBLE-SLUG

ML=2698 MG= 2.50 QFLUX= 32969 NUTP=320.8 HTP=2938 PDT= 2.189

PDF= 1.607 ALFA=0.316 XTT= 31.33 WE= 1637.0 FR= 88.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	75.18	40648	1869.0	20.4	6.28	0.709	10.42	5.82
OUTLET	78.12	42156	1861.8	18.3	6.05	0.709	10.42	6.53
MEAN	76.65	41402	1865.8	19.4	6.17	0.709	10.42	6.18

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	40772	5.88	75.42	10.13	355.4	3249.0
4.5	40929	5.95	75.73	10.87	331.4	3031.0
7.5	41117	6.04	76.10	11.24	320.4	2932.0
11.0	41336	6.14	76.53	11.22	320.9	2938.0
16.5	41682	6.31	77.20	11.42	315.1	2888.0
21.0	41967	6.46	77.75	11.62	309.8	2841.0
22.5	42061	6.51	77.94	11.69	307.8	2824.0

TEST NO.: W5. 7 FLOW PATTERN:SLUG-FROTH

ML=2698 MG= 2.83 QFLUX= 33470 NUTP=326.3 HTP=2988 PDT= 2.252

PDF= 1.689 ALFA=0.338 XTT= 28.05 WE= 1637.0 FR= 88.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	75.17	40647	2117.0	20.6	6.28	0.709	10.42	6.56
OUTLET	78.16	42178	2108.5	18.3	6.05	0.709	10.42	7.38
MEAN	76.67	41412	2113.1	19.4	6.16	0.709	10.42	6.98

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	40773	6.63	75.42	9.97	366.8	3353.0
4.5	40932	6.71	75.73	10.75	340.1	3110.0
7.5	41123	6.81	76.11	11.17	327.3	2995.0
11.0	41346	6.93	76.54	11.19	326.7	2992.0
16.5	41697	7.13	77.23	11.48	318.2	2916.0
21.0	41986	7.30	77.79	11.69	312.4	2865.0
22.5	42082	7.35	77.98	11.77	310.3	2846.0

TEST NO.: W5. 8 FLOW PATTERN:SLUG-FROTH

ML=2698 MG= 5.56 QFIUX= 38191 NUTP=346.8 HTP=3179 PDT= 2.742

PDF= 2.272 ALFA=0.448 XTT= 15.81 WE= 1639.0 FR= 88.02

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	75.78	40957	4156.0	22.3	6.23	0.709	10.42	11.92
OUTLET	79.19	42710	4135.7	19.5	5.96	0.709	10.42	13.62
MEAN	77.49	41833	4145.9	20.9	6.09	0.709	10.42	12.77

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	41102	12.05	76.07	10.20	408.4	3737.0
4.5	41283	12.22	76.42	11.20	372.2	3407.0
7.5	41502	12.43	76.85	11.78	353.8	3241.0
11.0	41757	12.67	77.35	12.12	343.6	3150.0
16.5	42160	13.08	78.13	12.52	332.7	3052.0
21.0	42490	13.44	78.77	12.83	324.6	2981.0
22.5	42600	13.56	78.98	12.92	322.2	2960.0

TEST NO.: W5. 9 FLOW PATTERN:SLUG-FROTH

ML=2698 MG= 9.70 QFLUX= 43774 NUTP=410.2 HTP=3760 PDT= 3.404

PDF= 3.003 AIFA=0.530 XTT= 10.00 WE= 1639.0 FR= 88.01

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	75.33	40727	7262.0	24.4	6.26	0.709	10.42	18.93
OUTLET	79.24	42734	7221.5	21.0	5.96	0.709	10.42	22.04
MEAN	77.29	41730	7241.9	22.7	6.11	0.709	10.42	20.47

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	40893	19.16	75.66	10.90	438.6	4011.0
4.5	41100	19.46	76.06	11.38	420.0	3843.0
7.5	41350	19.84	76.55	11.65	410.1	3755.0
11.0	41642	20.29	77.12	11.76	406.3	3724.0
16.5	42103	21.04	78.02	11.74	406.6	3731.0
21.0	42482	21.70	78.75	11.83	403.4	3705.0
22.5	42608	21.92	79.00	11.87	401.9	3692.0

TEST NO.: W5.10 FLOW PATTERN:ANNULAR-FROTH

ML=2698 MG= 13.06 QFLUX= 45245 NUTP=432.0 HTP=3962 PDT= 3.909

PDF= 3.541 AIFA=0.569 XTT= 7.88 WE= 1640.0 FR= 88.02

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	75.72	40925	9768.0	26.1	6.23	0.709	10.42	23.84
OUTLET	79.76	43002	9712.3	22.2	5.92	0.709	10.42	28.08
MEAN	77.74	41963	9740.5	24.2	6.07	0.709	10.42	25.94

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	41096	24.15	76.06	10.68	462.5	4232.0
4.5	41311	24.56	76.48	11.22	440.1	4030.0
7.5	41570	25.07	76.98	11.40	433.0	3967.0
11.0	41872	25.68	77.57	11.51	428.9	3933.0
16.5	42349	26.71	78.50	11.51	428.4	3933.0
21.0	42741	27.61	79.25	11.63	423.9	3896.0
22.5	42872	27.92	79.51	11.70	421.1	3871.0

TEST NO.: W5.11 FLOW PATTERN:ANNULAR-FROTH

ML=2698 MG= 16.99 QFLUX= 45526 NUTP=454.6 HTP=4170 PDT= 4.446

PDF= 4.105 AIFA=0.600 XTT= 6.42 WE= 1640.0 FR= 88.02

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	75.67	40899	12715.0	28.0	6.23	0.709	10.42	28.97
OUTLET	79.73	42987	12641.0	23.6	5.92	0.709	10.42	34.49
MEAN	77.70	41943	12678.0	25.8	6.08	0.709	10.42	31.70

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	41071	29.38	76.01	10.18	488.0	4465.0
4.5	41287	29.90	76.43	10.69	464.7	4255.0
7.5	41547	30.56	76.94	10.93	454.3	4162.0
11.0	41851	31.36	77.53	11.04	449.9	4125.0
16.5	42331	32.70	78.46	11.00	451.2	4142.0
21.0	42725	33.87	79.22	11.10	446.9	4107.0
22.5	42857	34.29	79.48	11.13	445.5	4095.0

TEST NO.: W5.12 FLOW PATTERN:ANNULAR-FROTH

ML=2698 MG= 20.17 QFLUX= 47028 NUTP=464.9 HTP=4264 PDT= 4.877

PDF= 4.552 ALFA=0.619 XTT= 5.62 WE= 1640.0 FR= 88.03

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	75.75	40941	15091.0	29.4	6.23	0.709	10.42	32.81
OUTLET	79.94	43099	15000.4	24.5	5.90	0.709	10.42	39.41
MEAN	77.85	42020	15045.7	26.9	6.06	0.709	10.42	36.06

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	41119	33.30	76.10	10.22	502.2	4596.0
4.5	41342	33.92	76.54	10.76	477.1	4368.0
7.5	41611	34.70	77.06	11.01	465.8	4268.0
11.0	41925	35.65	77.67	11.14	460.4	4222.0
16.5	42421	37.25	78.63	11.15	459.5	4219.0
21.0	42828	38.66	79.42	11.25	455.3	4185.0
22.5	42964	39.16	79.68	11.25	455.1	4185.0

TEST NO.: W5.13 FLOW PATTERN:ANNULAR-FROTH

ML=2698 MG= 22.85 QFLUX= 47017 NUTP=476.4 HTP=4369 PDT= 5.217

PDF= 4.902 ALFA=0.631 XTT= 5.13 WE= 1640.0 FR= 88.02

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	75.62	40871	17097.0	30.6	6.24	0.709	10.42	35.58
OUTLET	79.81	43028	16994.9	25.4	5.91	0.709	10.42	42.94
MEAN	77.71	41950	17046.2	28.0	6.08	0.709	10.42	39.20

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	41049	36.12	75.96	9.96	515.3	4715.0
4.5	41272	36.81	76.40	10.54	486.9	4458.0
7.5	41541	37.68	76.92	10.73	478.0	4379.0
11.0	41855	38.74	77.54	10.89	470.8	4317.0
16.5	42350	40.52	78.50	10.86	471.7	4330.0
21.0	42757	42.10	79.28	10.94	468.2	4303.0
22.5	42893	42.65	79.55	11.04	463.9	4265.0

TEST NO.: W5.14 FLOW PATTERN:ANNULAR-FROTH

ML=2698 MG= 25.09 QFLUX= 49717 NUTP=482.7 HTP=4430 PDT= 5.489

PDF= 5.181 ALFA=0.640 XTT= 4.78 WE= 1641.0 FR= 88.03

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	75.96	41049	18770.0	31.7	6.21	0.709	10.42	37.81
OUTLET	80.39	43333	18650.9	26.2	5.87	0.709	10.42	45.80
MEAN	78.18	42191	18710.4	28.9	6.04	0.709	10.42	41.74

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	41237	38.40	76.33	10.32	525.5	4810.0
4.5	41474	39.14	76.79	10.94	495.7	4541.0
7.5	41758	40.08	77.35	11.22	483.2	4430.0
11.0	42090	41.23	77.99	11.35	477.4	4380.0
16.5	42615	43.17	79.01	11.35	477.1	4383.0
21.0	43046	44.89	79.84	11.44	472.9	4350.0
22.5	43190	45.50	80.12	11.51	470.3	4327.0

TEST NO.: W5.15 FLOW PATTERN:ANNULAR-FROTH

ML=2698 MG= 34.57 QFLUX= 51074 NUTP=494.1 HTP=4536 PDT= 6.123

PDF= 5.845 ALFA=0.674 XTT= 3.70 WE= 1641.0 FR= 88.04

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	76.21	41175	25847.0	34.0	6.19	0.709	10.42	48.59
OUTLET	80.76	43522	25679.1	27.9	5.84	0.709	10.42	59.35
MEAN	78.48	42348	25763.2	30.9	6.01	0.709	10.42	53.85

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	41368	49.36	76.59	10.22	545.0	4990.0
4.5	41611	50.37	77.06	10.94	508.9	4663.0
7.5	41903	51.62	77.63	11.25	494.9	4538.0
11.0	42244	53.17	78.29	11.39	488.7	4485.0
16.5	42784	55.78	79.33	11.41	487.3	4479.0
21.0	43227	58.11	80.19	11.53	481.8	4434.0
22.5	43375	58.93	80.47	11.60	479.0	4409.0

TEST NO.: W5.16 FLOW PATTERN:ANNULAR-FROTH

ML=2698 MG= 67.21 QFLUX= 51542 NUTP=525.8 HTP=4827 PDT= 8.435

PDF= 8.198 ALFA=0.723 XTT= 2.32 WE= 1641.0 FR= 88.04

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	76.09	41115	50262.0	44.5	6.20	0.709	10.42	72.16
OUTLET	80.67	43477	49933.6	36.1	5.85	0.709	10.42	89.13
MEAN	78.38	42296	50098.2	40.3	6.02	0.709	10.42	80.44

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	41310	73.37	76.47	9.33	602.1	5513.0
4.5	41554	74.94	76.95	10.15	553.5	5071.0
7.5	41848	76.91	77.52	10.56	531.8	4876.0
11.0	42191	79.34	78.19	10.83	518.8	4761.0
16.5	42734	83.47	79.24	10.96	512.0	4705.0
21.0	43180	87.16	80.10	11.18	501.9	4618.0
22.5	43329	88.47	80.38	11.19	501.3	4614.0

TEST NO.: W5.17 FLOW PATTERN:ANNULAR-FROTH

ML=2698 MG= 92.48 QFLUX= 51536 NUTP=539.3 HTP=4951 PDT= 9.931

PDF= 9.711 ALFA=0.744 XTT= 1.87 WE= 1641.0 FR= 88.04

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	76.17	41154	69156.0	51.3	6.19	0.709	10.42	86.23
OUTLET	80.73	43511	68704.9	41.3	5.84	0.709	10.42	107.04
MEAN	78.45	42333	68930.9	46.3	6.01	0.709	10.42	96.37

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	41349	87.71	76.55	8.91	630.1	5770.0
4.5	41592	89.63	77.02	9.82	572.0	5241.0
7.5	41885	92.04	77.59	10.27	547.1	5016.0
11.0	42228	95.01	78.26	10.56	531.6	4879.0
16.5	42770	100.07	79.31	10.77	521.2	4790.0
21.0	43215	104.62	80.16	10.95	512.1	4712.0
22.5	43363	106.23	80.45	11.02	509.1	4686.0

TEST NO.: W6. 1 FLOW PATTERN:BUBBLE

ML=5397 MG= 0.36 QFLUX= 52639 NUTP=438.0 HTP=4000 PDT= 3.667

PDF= 2.846 ALFA=0.036 XTT=353.30 WE= 6531.0 FR=351.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	73.42	79511	268.2	23.0	6.44	0.710	20.84	0.74
OUTLET	75.77	81898	267.3	19.3	6.25	0.709	20.83	0.88
MEAN	74.60	80704	267.7	21.2	6.34	0.709	20.83	0.81

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	79708	0.75	73.62	12.68	454.7	4147.0
4.5	79956	0.76	73.86	13.00	443.8	4049.0
7.5	80254	0.78	74.16	13.16	438.1	3999.0
11.0	80602	0.80	74.50	13.22	436.3	3984.0
16.5	81150	0.83	75.04	13.24	435.3	3978.0
21.0	81599	0.86	75.48	13.27	434.3	3971.0
22.5	81749	0.87	75.63	13.38	430.8	3939.0

TEST NO.: W6. 2 FLOW PATTERN:BUBBLE

ML=5397 MG= 0.96 QFLUX= 52906 NUTP=451.4 HTP=4123 PDT= 3.902

PDF= 3.123 ALFA=0.085 XTT=149.32 WE= 6532.0 FR=351.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	73.51	79599	717.6	24.2	6.43	0.710	20.84	1.88
OUTLET	75.87	82000	715.1	20.3	6.24	0.709	20.83	2.24
MEAN	74.69	80800	716.4	22.2	6.34	0.709	20.83	2.06

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	79798	1.90	73.71	12.34	469.5	4283.0
4.5	80047	1.94	73.95	12.69	456.8	4168.0
7.5	80347	1.98	74.25	12.83	451.7	4123.0
11.0	80696	2.03	74.59	12.89	449.4	4104.0
16.5	81247	2.12	75.13	12.89	449.2	4105.0
21.0	81699	2.20	75.58	12.95	447.1	4088.0
22.5	81850	2.22	75.72	13.02	444.8	4068.0

TEST NO.: W6. 3 FLOW PATTERN:BUBBLE

ML=5397 MG= 1.39 QFLUX= 53458 NUTP=458.4 HTP=4187 PDT= 4.052

PDF= 3.295 ALFA=0.110 XTT=110.29 WE= 6533.0 FR=351.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	73.60	79689	1039.0	25.7	6.43	0.709	20.84	2.56
OUTLET	75.98	82115	1036.1	21.6	6.23	0.709	20.83	3.04
MEAN	74.79	80902	1037.9	23.7	6.33	0.709	20.83	2.80

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	79890	2.60	73.80	12.28	476.9	4350.0
4.5	80142	2.64	74.04	12.61	464.4	4238.0
7.5	80444	2.70	74.34	12.78	458.1	4182.0
11.0	80798	2.77	74.69	12.83	456.3	4167.0
16.5	81355	2.88	75.24	12.82	456.3	4171.0
21.0	81812	2.99	75.69	12.89	453.9	4151.0
22.5	81964	3.02	75.84	12.95	451.6	4131.0

TEST NO.: W6. 4 FLOW PATTERN:BUBBLE

ML=5397 MG= 1.67 QFIUX= 53457 NUTP=461.9 HTP=4220 PDT= 4.140

PDF= 3.397 ALFA=0.127 XTT= 93.91 WE= 6533.0 FR=351.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	73.64	79733	1251.0	26.0	6.42	0.709	20.84	3.05
OUTLET	76.03	82160	1246.7	21.9	6.22	0.709	20.83	3.62
MEAN	74.84	80947	1248.9	23.9	6.32	0.709	20.83	3.33

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	79934	3.09	73.84	12.14	482.3	4400.0
4.5	80186	3.14	74.09	12.49	468.8	4278.0
7.5	80489	3.21	74.39	12.67	461.9	4218.0
11.0	80843	3.29	74.74	12.73	459.7	4199.0
16.5	81400	3.43	75.28	12.76	458.6	4192.0
21.0	81856	3.55	75.73	12.78	457.7	4186.0
22.5	82009	3.60	75.88	12.85	455.0	4162.0

TEST NO.: W6. 5 FLOW PATTERN:BUBBLE

ML=5397 MG= 2.13 QFIUX= 54408 NUTP=463.3 HTP=4234 PDT= 4.292

PDF= 3.570 ALFA=0.151 XTT= 76.26 WE= 6535.0 FR=351.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	73.82	79912	1597.0	26.7	6.41	0.709	20.84	3.79
OUTLET	76.25	82384	1591.5	22.4	6.21	0.709	20.83	4.51
MEAN	75.03	81148	1594.3	24.6	6.31	0.709	20.83	4.15

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	80117	3.85	74.02	12.29	484.7	4423.0
4.5	80373	3.91	74.27	12.63	471.9	4307.0
7.5	80681	4.00	74.58	12.86	463.3	4231.0
11.0	81042	4.10	74.93	12.95	459.8	4201.0
16.5	81609	4.28	75.49	12.92	460.6	4212.0
21.0	82075	4.43	75.94	12.99	458.1	4192.0
22.5	82230	4.49	76.10	13.05	456.0	4173.0

TEST NO.: W6. 6 FLOW PATTERN:BUBBLE-FROTH

ML=5397 MG= 2.36 QFIUX= 54412 NUTP=468.0 HTP=4278 PDT= 4.392

PDF= 3.679 ALFA=0.162 XTT= 70.03 WE= 6537.0 FR=351.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	74.04	80136	1768.0	27.1	6.39	0.709	20.84	4.14
OUTLET	76.47	82610	1761.9	22.7	6.19	0.709	20.83	4.93
MEAN	75.25	81373	1765.0	24.9	6.29	0.709	20.83	4.53

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	80341	4.20	74.24	12.17	489.6	4469.0
4.5	80597	4.27	74.49	12.52	475.6	4343.0
7.5	80906	4.37	74.80	12.72	468.1	4276.0
11.0	81267	4.48	75.15	12.83	464.2	4243.0
16.5	81835	4.68	75.71	12.79	465.4	4257.0
21.0	82300	4.84	76.17	12.83	463.6	4243.0
22.5	82456	4.90	76.32	12.91	461.0	4220.0

TEST NO.: W6. 7 FLOW PATTERN:BUBBLE-FROTH

ML=5397 MG= 2.70 QFLUX= 53739 NUTP=471.6 HTP=4310 PDT= 4.501

PDF= 3.800 ALFA=0.177 XTT= 62.53 WE= 6537.0 FR=351.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	73.99	80090	2025.0	27.6	6.39	0.709	20.84	4.66
OUTLET	76.39	82534	2018.5	23.1	6.19	0.709	20.83	5.56
MEAN	75.19	81312	2022.1	25.3	6.29	0.709	20.83	5.10

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	80293	4.72	74.19	11.87	495.7	4525.0
4.5	80546	4.81	74.44	12.25	480.3	4385.0
7.5	80851	4.91	74.74	12.46	472.0	4312.0
11.0	81207	5.04	75.09	12.59	467.0	4268.0
16.5	81768	5.26	75.64	12.55	468.3	4283.0
21.0	82228	5.45	76.09	12.58	467.1	4274.0
22.5	82381	5.52	76.24	12.66	464.3	4250.0

TEST NO.: W6. 8 FLOW PATTERN:FROTH

ML=5397 MG= 4.79 QFLUX= 55582 NUTP=482.4 HTP=4410 PDT= 4.918

PDF= 4.276 ALFA=0.246 XTT= 39.33 WE= 6539.0 FR=351.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	74.17	80268	3590.0	30.6	6.37	0.709	20.84	7.45
OUTLET	76.65	82797	3577.4	25.7	6.17	0.709	20.84	8.86
MEAN	75.41	81533	3583.8	28.1	6.27	0.709	20.83	8.15

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	80478	7.55	74.38	11.88	512.0	4675.0
4.5	80740	7.69	74.63	12.33	493.4	4507.0
7.5	81055	7.85	74.94	12.57	483.7	4420.0
11.0	81424	8.06	75.31	12.71	478.3	4372.0
16.5	82005	8.40	75.88	12.75	476.8	4362.0
21.0	82481	8.70	76.34	12.77	475.8	4355.0
22.5	82640	8.81	76.50	12.83	473.6	4336.0

TEST NO.: W6. 9 FLOW PATTERN:FROTH

ML=5397 MG= 9.50 QFLUX= 56449 NUTP=496.1 HTP=4542 PDT= 5.897

PDF= 5.340 ALFA=0.346 XTT= 22.33 WE= 6547.0 FR=351.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	75.09	81208	7112.0	34.2	6.29	0.709	20.84	13.24
OUTLET	77.61	83786	7086.6	28.3	6.09	0.709	20.84	15.97
MEAN	76.35	82497	7099.5	31.2	6.19	0.709	20.83	14.58

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	81421	13.44	75.30	11.38	542.1	4956.0
4.5	81689	13.70	75.57	11.99	514.4	4704.0
7.5	82010	14.02	75.88	12.31	501.2	4585.0
11.0	82386	14.41	76.25	12.54	491.9	4503.0
16.5	82978	15.07	76.83	12.67	486.7	4458.0
21.0	83463	15.66	77.30	12.82	480.7	4406.0
22.5	83625	15.87	77.46	12.85	479.8	4399.0

TEST NO.: W6.10 FLOW PATTERN:FROTH

ML=5397 MG= 15.27 QFLUX= 56850 NUTP=508.4 HTP=4657 PDT= 6.849

PDF= 6.349 ALFA=0.413 XTT= 15.32 WE= 6551.0 FR=351.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	75.53	81654	11431.0	38.1	6.25	0.709	20.84	19.14
OUTLET	78.07	84255	11390.1	31.2	6.05	0.709	20.84	23.28
MEAN	76.80	82955	11411.0	34.7	6.15	0.709	20.84	21.16

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	81869	19.43	75.74	10.88	570.5	5218.0
4.5	82139	19.82	76.01	11.59	535.7	4902.0
7.5	82463	20.30	76.32	12.02	516.5	4728.0
11.0	82842	20.90	76.69	12.35	502.5	4602.0
16.5	83440	21.91	77.28	12.55	494.4	4531.0
21.0	83929	22.80	77.75	12.74	487.2	4468.0
22.5	84093	23.12	77.91	12.82	483.9	4439.0

TEST NO.: W6.11 FLOW PATTERN:FROTH

ML=5397 MG= 20.75 QFLUX= 59719 NUTP=543.1 HTP=4981 PDT= 8.050

PDF= 7.580 ALFA=0.448 XTT= 12.30 WE= 6560.0 FR=352.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	76.41	82554	15511.0	43.0	6.18	0.709	20.84	23.07
OUTLET	79.08	85296	15452.1	34.9	5.97	0.709	20.84	28.32
MEAN	77.75	83925	15481.8	39.0	6.07	0.709	20.84	25.64

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	82781	23.45	76.63	10.86	599.7	5492.0
4.5	83065	23.93	76.91	11.52	565.3	5179.0
7.5	83407	24.54	77.25	11.85	549.6	5038.0
11.0	83807	25.30	77.63	12.09	538.6	4939.0
16.5	84436	26.57	78.24	12.24	532.0	4883.0
21.0	84953	27.71	78.74	12.44	523.3	4806.0
22.5	85125	28.12	78.91	12.53	519.6	4773.0

TEST NO.: W6.12 FLOW PATTERN:FROTH

ML=5397 MG= 36.51 QFLUX= 60702 NUTP=571.7 HTP=5248 PDT= 9.727

PDF= 9.318 ALFA=0.521 XTT= 7.98 WE= 6565.0 FR=352.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	76.94	83092	27274.0	50.3	6.13	0.709	20.84	34.74
OUTLET	79.64	85884	27168.4	40.6	5.92	0.709	20.84	42.96
MEAN	78.29	84488	27221.4	45.4	6.03	0.709	20.84	38.75

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	83323	35.32	77.16	10.32	641.1	5876.0
4.5	83612	36.08	77.44	11.05	598.8	5489.0
7.5	83960	37.03	77.78	11.38	581.2	5331.0
11.0	84367	38.21	78.18	11.69	565.8	5192.0
16.5	85008	40.21	78.80	11.84	558.6	5130.0
21.0	85534	42.00	79.31	12.12	545.7	5015.0
22.5	85710	42.64	79.48	12.15	544.2	5002.0

TEST NO.: W6.13 FLOW PATTERN:FROTH

ML=5397 MG= 52.19 QFLUX= 60769 NUTP=578.8 HTP=5315 PDT=11.246

PDF=10.869 ALFA=0.559 XTT= 6.15 WE= 6568.0 FP=352.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	77.33	83494	38962.0	57.1	6.10	0.709	20.84	43.77
OUTLET	80.04	86292	38811.6	45.9	5.89	0.709	20.84	54.36
MEAN	78.68	84893	38887.1	51.5	6.00	0.709	20.84	48.93

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	83726	44.52	77.55	10.05	658.6	6039.0
4.5	84016	45.50	77.84	10.85	610.4	5599.0
7.5	84364	46.72	78.18	11.25	588.3	5399.0
11.0	84772	48.23	78.57	11.56	572.5	5257.0
16.5	85414	50.81	79.19	11.77	562.2	5166.0
21.0	85941	53.13	79.70	12.02	550.6	5063.0
22.5	86117	53.95	79.87	12.05	549.1	5050.0

TEST NO.: W7. 1 FLOW PATTERN:BUBBLE

ML=8995 MG= 0.44 QFLUX= 65372 NUTP=645.9 HTP=5959 PDT= 8.367

PDF= 7.534 ALFA=0.018 XTT=567.87 WE= 18331.0 FR=978.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	81.17	145788	324.2	36.6	5.79	0.709	34.73	0.58
OUTLET	82.92	148847	323.4	28.2	5.67	0.708	34.75	0.74
MEAN	82.05	147317	323.8	32.4	5.73	0.708	34.75	0.66

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	146041	0.59	81.32	10.58	670.5	6179.0
4.5	146359	0.60	81.50	10.80	656.8	6055.0
7.5	146741	0.62	81.72	10.90	650.8	6000.0
11.0	147187	0.64	81.97	11.02	643.2	5933.0
16.5	147889	0.69	82.38	11.05	641.6	5921.0
21.0	148465	0.72	82.70	11.15	635.4	5867.0
22.5	148657	0.74	82.81	11.22	631.4	5831.0

TEST NO.: W7. 2 FLOW PATTERN:BUBBLE

ML=8995 MG= 0.77 QFLUX= 65378 NUTP=647.3 HTP=5972 PDT= 8.435

PDF= 7.612 ALFA=0.030 XTT=347.07 WE= 18334.0 FR=979.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	81.30	146017	568.8	37.5	5.78	0.709	34.73	0.99
OUTLET	83.05	149077	567.4	29.1	5.66	0.708	34.75	1.26
MEAN	82.18	147547	568.1	33.3	5.72	0.708	34.75	1.12

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	146270	1.00	81.45	10.55	672.0	6194.0
4.5	146588	1.03	81.63	10.78	657.6	6063.0
7.5	146970	1.06	81.85	10.88	651.5	6009.0
11.0	147417	1.10	82.11	10.99	645.2	5952.0
16.5	148119	1.17	82.51	11.02	642.9	5935.0
21.0	148695	1.23	82.84	11.14	636.2	5875.0
22.5	148887	1.25	82.95	11.17	634.5	5860.0

TEST NO.: W7. 3 FLOW PATTERN:BUBBLE

ML=8995 MG= 1.06 QFLUX= 69857 NUTP=638.7 HTP=5898 PDT= 8.558

PDF= 7.743 ALFA=0.040 XTT=261.13 WE= 18349.0 FR=979.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	81.83	146932	788.8	38.4	5.74	0.708	34.73	1.34
OUTLET	83.70	150210	786.6	29.8	5.61	0.708	34.76	1.71
MEAN	82.76	148571	787.7	34.1	5.67	0.708	34.75	1.52

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	147203	1.36	81.98	11.41	663.4	6119.0
4.5	147544	1.40	82.18	11.66	649.2	5990.0
7.5	147953	1.44	82.41	11.79	642.2	5927.0
11.0	148431	1.49	82.69	11.88	637.4	5885.0
16.5	149184	1.59	83.11	11.93	634.2	5859.0
21.0	149801	1.67	83.47	12.04	628.2	5806.0
22.5	150007	1.70	83.58	12.11	624.9	5776.0

TEST NO.: W7. 4 FLOW PATTERN:BUBBLE

ML=8995 MG= 1.56 QFLUX= 71260 NUTP=646.4 HTP=5969 PDT= 8.685

PDF= 7.883 ALFA=0.055 XTT=188.29 WE= 18353.0 FR=979.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	81.96	147160	1154.0	39.6	5.73	0.708	34.73	1.90
OUTLET	83.87	150507	1151.5	30.9	5.60	0.708	34.76	2.42
MEAN	82.91	148834	1153.1	35.2	5.66	0.708	34.75	2.15

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	147438	1.94	82.12	11.50	671.4	6194.0
4.5	147785	1.98	82.32	11.75	657.4	6066.0
7.5	148203	2.04	82.55	11.89	649.4	5995.0
11.0	148691	2.12	82.83	11.98	644.4	5950.0
16.5	149459	2.24	83.27	12.01	642.8	5939.0
21.0	150089	2.36	83.63	12.15	634.9	5869.0
22.5	150299	2.40	83.75	12.20	632.3	5846.0

TEST NO.: W7. 5 FLOW PATTERN:BUBBLE

ML=8995 MG= 2.08 QFLUX= 71645 NUTP=651.0 HTP=6019 PDT= 8.786

PDF= 7.998 ALFA=0.071 XTT=146.56 WE= 18375.0 FR=979.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	82.79	148614	1540.0	40.5	5.67	0.708	34.73	2.49
OUTLET	84.71	151990	1536.6	31.7	5.54	0.708	34.76	3.16
MEAN	83.75	150302	1538.7	36.1	5.60	0.708	34.76	2.81

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	148893	2.53	82.95	11.44	677.7	6259.0
4.5	149244	2.59	83.15	11.73	661.2	6108.0
7.5	149666	2.67	83.39	11.84	655.0	6053.0
11.0	150158	2.77	83.67	11.98	647.2	5983.0
16.5	150933	2.93	84.11	11.97	647.5	5990.0
21.0	151568	3.08	84.47	12.09	640.8	5930.0
22.5	151780	3.13	84.59	12.15	637.6	5902.0

TEST NO.: W7. 6 FLOW PATTERN:BUBBLE

ML=8995 MG= 2.48 QFLUX= 71653 NUTP=650.1 HTP=6013 PDT= 8.979

PDF= 8.199 ALFA=0.081 XTT=126.58 WE= 18379.0 FR=979.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	82.96	148920	1837.0	41.5	5.65	0.708	34.73	2.90
OUTLET	84.88	152299	1832.0	32.5	5.52	0.708	34.76	3.68
MEAN	83.92	150610	1834.5	37.0	5.59	0.708	34.76	3.27

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	149200	2.95	83.12	11.47	676.1	6245.0
4.5	149551	3.02	83.32	11.73	660.8	6106.0
7.5	149973	3.11	83.56	11.86	653.5	6041.0
11.0	150466	3.22	83.84	11.96	647.9	5991.0
16.5	151241	3.41	84.28	12.02	644.9	5967.0
21.0	151877	3.58	84.64	12.09	641.0	5933.0
22.5	152089	3.64	84.76	12.15	637.9	5905.0

TEST NO.: W7. 7 FLOW PATTERN:BUBBLE

ML=8995 MG= 2.85 OFLUX= 73437 NUTP=655.8 HTP=6067 PDT= 9.124

PDF= 8.350 ALFA=0.087 XTT=114.45 WE= 18386.0 FR=979.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	83.18	149302	2110.0	43.4	5.64	0.708	34.73	3.18
OUTLET	85.15	152768	2104.3	34.3	5.50	0.708	34.76	4.01
MEAN	84.17	151035	2107.3	38.9	5.57	0.708	34.76	3.58

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	149588	3.24	83.35	11.62	683.5	6316.0
4.5	149949	3.31	83.55	11.90	667.4	6169.0
7.5	150381	3.40	83.80	12.05	659.3	6096.0
11.0	150887	3.52	84.08	12.16	653.0	6040.0
16.5	151682	3.72	84.53	12.18	651.9	6033.0
21.0	152335	3.91	84.90	12.33	644.0	5964.0
22.5	152552	3.97	85.03	12.36	642.2	5947.0

TEST NO.: W7. 8 FLOW PATTERN:BUBBLE-FROTH

ML=8995 MG= 5.27 OFLUX= 73800 NUTP=662.1 HTP=6127 PDT= 9.636

PDF= 8.906 ALFA=0.139 XTT= 67.75 WE= 18391.0 FR=979.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	83.40	149683	3897.0	46.0	5.62	0.708	34.73	5.55
OUTLET	85.38	153169	3886.5	36.3	5.49	0.708	34.76	6.99
MEAN	84.39	151426	3892.0	41.1	5.55	0.708	34.76	6.24

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	149971	5.65	83.56	11.57	689.6	6374.0
4.5	150334	5.78	83.77	11.85	673.3	6226.0
7.5	150769	5.94	84.02	11.99	665.8	6158.0
11.0	151277	6.15	84.30	12.09	660.1	6107.0
16.5	152078	6.50	84.76	12.14	657.3	6086.0
21.0	152734	6.82	85.13	12.26	650.6	6026.0
22.5	152952	6.93	85.25	12.27	649.9	6020.0

TEST NO.: W7. 9 FLOW PATTERN:BUBBLE-FROTH

ML=8995 MG= 10.54 OFLUX= 75365 NUTP=688.5 HTP=6371 PDT=11.042

PDF=10.366 ALFA=0.204 XTT= 39.77 WE= 18392.0 FR=979.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	83.39	149676	7801.0	55.0	5.62	0.708	34.73	9.29
OUTLET	85.41	153236	7778.9	43.9	5.49	0.708	34.76	11.57
MEAN	84.40	151456	7790.0	49.4	5.55	0.708	34.76	10.40

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	149971	9.45	83.56	11.36	717.2	6629.0
4.5	150340	9.66	83.77	11.65	699.6	6468.0
7.5	150785	9.92	84.03	11.80	690.7	6388.0
11.0	151304	10.25	84.32	11.92	683.8	6327.0
16.5	152121	10.80	84.78	11.96	680.9	6304.0
21.0	152791	11.30	85.16	11.89	684.9	6344.0
22.5	153015	11.48	85.29	11.89	684.8	6344.0

TEST NO.: W7.10 FLOW PATTERN:FROTH

ML=8995 MG= 15.50 QFLUX= 77045 NUTP=707.3 HTP=6548 PDT=12.220

PDF=11.582 ALFA=0.249 XTT= 29.43 WE= 18402.0 FR=979.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	83.74	150287	11463.0	60.4	5.60	0.708	34.73	12.44
OUTLET	85.81	153931	11429.6	48.1	5.46	0.708	34.76	15.53
MEAN	84.77	152109	11446.3	54.3	5.53	0.708	34.76	13.94

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	150589	12.66	83.91	11.35	733.9	6787.0
4.5	150967	12.94	84.13	11.68	712.9	6595.0
7.5	151422	13.30	84.39	11.81	704.9	6523.0
11.0	151954	13.73	84.69	11.84	703.2	6510.0
16.5	152790	14.49	85.16	11.75	708.3	6561.0
21.0	153476	15.17	85.55	11.88	700.5	6492.0
22.5	153705	15.41	85.68	11.93	697.6	6466.0

TEST NO.: W7.11 FLOW PATTERN:FROTH

ML=8995 MG= 20.07 QFLUX= 78895 NUTP=728.6 HTP=6750 PDT=13.331

PDF=12.717 ALFA=0.277 XTT= 24.37 WE= 18415.0 FR=979.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	84.22	151128	14838.0	66.1	5.56	0.708	34.73	14.73
OUTLET	86.33	154867	14794.1	52.7	5.42	0.708	34.77	18.39
MEAN	85.28	152998	14816.2	59.4	5.49	0.708	34.76	16.51

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	151438	14.99	84.40	11.21	759.9	7032.0
4.5	151826	15.33	84.62	11.54	738.3	6834.0
7.5	152293	15.75	84.88	11.63	732.9	6786.0
11.0	152838	16.27	85.19	11.71	727.7	6741.0
16.5	153696	17.15	85.67	11.74	725.3	6723.0
21.0	154400	17.96	86.07	11.93	713.6	6618.0
22.5	154635	18.24	86.20	11.99	710.1	6587.0

TEST NO.: W7.12 FLOW PATTERN:FROTH

ML=8995 MG= 24.81 QFLUX= 77053 NUTP=723.6 HTP=6703 PDT=14.237

PDF=13.644 ALFA=0.302 XTT= 20.81 WE= 18413.0 FR=979.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	84.18	151049	18344.0	70.6	5.56	0.708	34.73	17.05
OUTLET	86.24	154699	18290.6	56.3	5.43	0.708	34.77	21.27
MEAN	85.21	152874	18317.4	63.4	5.50	0.708	34.76	19.10

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	151351	17.35	84.35	10.90	763.4	7063.0
4.5	151730	17.74	84.56	11.27	738.6	6837.0
7.5	152186	18.22	84.82	11.42	728.6	6746.0
11.0	152718	18.82	85.12	11.51	722.9	6696.0
16.5	153556	19.85	85.59	11.59	717.8	6653.0
21.0	154243	20.78	85.98	11.81	704.2	6530.0
22.5	154472	21.11	86.11	11.85	701.8	6509.0

TEST NO.: W7.13 FLOW PATTERN:FROTH

ML=8995 MG= 30.19 QFIUX= 80390 NUTP=734.6 HTP=6807 PDT=14.856

PDF=14.286 ALFA=0.330 XTT= 17.80 WE= 18420.0 FR=979.00

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	84.39	151431	22314.0	73.6	5.55	0.708	34.73	19.91
OUTLET	86.54	155242	22246.8	58.7	5.41	0.708	34.77	24.85
MEAN	85.47	153336	22280.7	66.1	5.48	0.708	34.76	22.31

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	151746	20.26	84.57	11.07	783.9	7256.0
4.5	152142	20.71	84.79	11.53	752.6	6968.0
7.5	152617	21.28	85.06	11.70	742.1	6873.0
11.0	153173	21.98	85.38	11.86	732.0	6782.0
16.5	154048	23.19	85.87	11.94	726.4	6735.0
21.0	154766	24.27	86.28	12.17	712.9	6613.0
22.5	155005	24.65	86.41	12.21	710.2	6590.0

TABLE D.2 SURFACTANT SOLUTION-AIR DATA

TEST NO.: S1. 1 FLOW PATTERN:SLUG

ML= 48 MG= 0.49 QFLUX= 5825 NUTP= 55.2 HTP= 511 PDT= 0.344

PDF= 0.113 ALFA=0.729 XTT= 3.20 WE= 1.8 FR= 0.03 STN= 20.94

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	70.45	680	367.6	15.8	6.62	0.710	0.19	1.46
OUTLET	99.62	955	352.7	15.4	4.64	0.706	0.19	1.57
MEAN	85.04	818	360.2	15.6	5.56	0.708	0.19	1.52

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	702	1.47	72.87	11.52	55.1	502.0
4.5	729	1.48	75.89	11.69	54.2	495.0
7.5	762	1.50	79.53	13.18	48.0	441.0
11.0	802	1.52	83.78	12.16	51.8	479.0
16.5	866	1.54	90.49	12.32	50.9	475.0
21.0	919	1.56	95.99	9.15	68.1	640.0
22.5	937	1.57	97.82	7.15	87.0	819.0

TEST NO.: S1. 2 FLOW PATTERN:SLUG

ML= 48 MG= 1.07 QFLUX= 6498 NUTP= 49.3 HTP= 460 PDT= 0.169

PDF= 0.007 ALFA=0.810 XTT= 1.53 WE= 1.8 FR= 0.03 STN= 20.66

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	71.42	689	808.7	14.9	6.51	0.710	0.19	3.40
OUTLET	103.87	998	772.6	14.8	4.42	0.706	0.19	3.64
MEAN	87.65	844	790.6	14.9	5.39	0.708	0.19	3.53

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	713	3.42	74.11	24.50	29.0	264.0
4.5	744	3.45	77.49	21.49	32.9	301.0
7.5	781	3.48	81.54	20.50	34.4	316.0
11.0	825	3.52	86.28	18.35	38.2	354.0
16.5	897	3.57	93.73	13.56	51.3	480.0
21.0	958	3.62	99.83	7.91	87.3	824.0
22.5	978	3.64	101.87	6.24	110.3	1044.0

TEST NO.: S1. 3 FLOW PATTERN:SLUG

ML= 48 MG= 1.62 QFLUX= 5897 NUTP= 48.5 HTP= 451 PDT= 0.095

PDF=-0.039 ALFA=0.842 XTT= 1.05 WE= 1.8 FR= 0.03 STN= 20.39

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	71.21	687	1223.0	14.7	6.54	0.710	0.19	5.23
OUTLET	100.57	965	1173.3	14.6	4.59	0.706	0.19	5.55
MEAN	85.89	826	1198.2	14.6	5.50	0.708	0.19	5.39

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	709	5.26	73.65	21.00	30.7	279.0
4.5	736	5.29	76.70	20.37	31.6	289.0
7.5	770	5.33	80.37	19.55	32.8	301.0
11.0	810	5.38	84.66	17.25	37.0	342.0
16.5	875	5.45	91.40	13.17	48.1	449.0
21.0	929	5.52	96.92	7.43	84.6	796.0
22.5	947	5.54	98.76	4.60	136.2	1284.0

TEST NO.: S1. 4 FLOW PATTERN:CHURN

ML= 48 MG= 2.13 QFLUX= 6234 NUTP= 49.4 HTP= 460 PDT= 0.097

PDF=-0.022 ALFA=0.861 XTT= 0.82 WE= 1.8 FR= 0.03 STN= 20.39

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	71.55	690	1604.0	14.7	6.50	0.710	0.19	6.87
OUTLET	102.51	985	1536.3	14.6	4.49	0.706	0.19	7.31
MEAN	87.03	837	1570.6	14.6	5.43	0.708	0.19	7.10

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	713	6.91	74.12	21.63	31.5	287.0
4.5	742	6.95	77.34	21.09	32.2	295.0
7.5	778	7.01	81.21	19.62	34.5	317.0
11.0	820	7.08	85.73	17.42	38.6	358.0
16.5	889	7.18	92.84	13.59	49.2	460.0
21.0	946	7.26	98.67	7.89	84.0	792.0
22.5	965	7.29	100.61	4.93	134.0	1266.0

TEST NO.: S1. 5 FLOW PATTERN:CHURN

ML= 48 MG= 2.60 QFLUX= 6306 NUTP= 55.9 HTP= 521 PDT= 0.132

PDF= 0.024 ALFA=0.873 XTT= 0.68 WE= 1.8 FR= 0.03 STN= 20.66

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	71.66	691	1953.0	14.7	6.49	0.710	0.19	8.36
OUTLET	102.91	989	1869.0	14.6	4.47	0.706	0.19	8.92
MEAN	87.28	840	1911.1	14.6	5.41	0.708	0.19	8.65

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	714	8.41	74.24	15.68	43.8	399.0
4.5	744	8.47	77.49	16.23	42.2	387.0
7.5	780	8.54	81.39	16.12	42.4	390.0
11.0	822	8.63	85.95	15.91	42.8	396.0
16.5	891	8.76	93.14	12.99	52.0	487.0
21.0	949	8.87	99.02	7.17	93.6	882.0
22.5	969	8.90	100.98	4.79	139.6	1320.0

TEST NO.: S1. 6 FLOW PATTERN:CHURN

ML= 48 MG= 2.85 QFLUX= 6341 NUTP= 60.0 HTP= 558 PDT= 0.148

PDF= 0.044 ALFA=0.878 XTT= 0.63 WE= 1.8 FR= 0.03 STN= 20.21

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.08	695	2147.0	14.7	6.45	0.710	0.19	9.21
OUTLET	103.47	994	2054.3	14.6	4.44	0.706	0.19	9.83
MEAN	87.77	844	2100.6	14.6	5.38	0.708	0.19	9.53

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	718	9.26	74.68	12.80	53.9	492.0
4.5	748	9.33	77.93	12.37	55.6	509.0
7.5	784	9.41	81.84	12.74	53.9	496.0
11.0	827	9.50	86.42	12.42	55.1	510.0
16.5	896	9.65	93.63	11.61	58.6	548.0
21.0	955	9.77	99.55	9.18	73.7	695.0
22.5	975	9.81	101.53	6.98	96.6	913.0

TEST NO.: S1. 7 FLOW PATTERN:CHURN

ML= 48 MG= 4.80 QFIUX= 6270 NUTP= 82.9 HTP= 770 PDT= 0.155

PDF= 0.073 ALFA=0.905 XTT= 0.40 WE= 1.8 FR= 0.03 STN= 20.21

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	71.93	693	3611.0	14.9	6.47	0.710	0.19	15.22
OUTLET	102.67	986	3458.2	14.8	4.48	0.706	0.19	16.24
MEAN	87.30	840	3534.7	14.9	5.41	0.708	0.19	15.75

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	716	15.31	74.48	8.51	80.1	731.0
4.5	745	15.42	77.66	8.96	75.9	695.0
7.5	780	15.55	81.49	8.87	76.4	704.0
11.0	823	15.70	85.97	8.26	81.8	758.0
16.5	890	15.94	93.03	7.98	84.2	788.0
21.0	948	16.14	98.83	7.33	91.3	860.0
22.5	967	16.21	100.76	6.40	104.3	986.0

TEST NO.: S1. 8 FLOW PATTERN:CHURN-ANNULAR

ML= 48 MG= 9.26 QFIUX= 6728 NUTP= 90.1 HTP= 837 PDT= 0.140

PDF= 0.083 ALFA=0.933 XTT= 0.22 WE= 1.8 FR= 0.03 STN= 20.21

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	70.61	682	6979.0	14.7	6.59	0.710	0.19	29.79
OUTLET	102.89	988	6668.9	14.6	4.47	0.706	0.19	31.84
MEAN	86.75	835	6824.3	14.6	5.45	0.708	0.19	30.85

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	705	29.96	73.28	8.72	83.9	765.0
4.5	736	30.18	76.62	8.78	83.1	761.0
7.5	773	30.44	80.64	8.67	84.0	773.0
11.0	817	30.75	85.34	8.41	86.3	799.0
16.5	888	31.24	92.76	7.74	93.2	871.0
21.0	948	31.64	98.85	7.00	102.5	967.0
22.5	968	31.77	100.88	6.76	106.0	1002.0

TEST NO.: S1. 9 FLOW PATTERN:ANNULAR

ML= 48 MG= 13.34 QFIUX= 8546 NUTP= 95.6 HTP= 893 PDT= 0.137

PDF= 0.090 ALFA=0.945 XTT= 0.16 WE= 1.9 FR= 0.03 STN= 19.75

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	69.79	674	10064.0	14.7	6.64	0.710	0.19	42.84
OUTLET	110.01	1061	9513.6	14.6	4.14	0.705	0.19	46.41
MEAN	89.90	868	9789.3	14.6	5.27	0.707	0.19	44.68

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	704	43.14	73.11	11.74	79.1	721.0
4.5	742	43.52	77.27	10.66	86.9	796.0
7.5	788	43.98	82.27	10.51	87.8	810.0
11.0	843	44.51	88.13	10.15	90.4	841.0
16.5	933	45.36	97.37	9.50	96.0	903.0
21.0	1009	46.06	104.97	7.69	117.9	1120.0
22.5	1035	46.29	107.51	7.03	128.6	1226.0

TEST NO.: S1.10 FLOW PATTERN:ANNULAR

ML= 48 MG= 17.18 QFLUX= 8718 NUTP=110.7 HTP=1033 PDT= 0.157

PDF= 0.116 ALFA=0.953 XTT= 0.12 WE= 1.8 FR= 0.03 STN= 20.66

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	69.09	668	12983.0	14.7	6.70	0.710	0.19	55.13
OUTLET	109.39	1055	12270.3	14.5	4.17	0.705	0.19	59.82
MEAN	89.24	862	12627.1	14.6	5.32	0.708	0.19	57.55

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	698	55.53	72.41	9.36	101.3	922.0
4.5	735	56.03	76.58	9.71	97.3	891.0
7.5	781	56.63	81.60	9.83	95.8	883.0
11.0	837	57.33	87.47	9.39	99.9	928.0
16.5	927	58.44	96.73	7.80	119.4	1122.0
21.0	1003	59.36	104.34	6.81	135.8	1290.0
22.5	1029	59.67	106.88	6.27	147.3	1403.0

TEST NO.: S1.11 FLOW PATTERN:ANNULAR

ML= 48 MG= 20.23 QFLUX= 9269 NUTP=117.2 HTP=1094 PDT= 0.187

PDF= 0.150 ALFA=0.957 XTT= 0.11 WE= 1.9 FR= 0.03 STN= 20.21

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	68.41	662	15298.0	14.8	6.76	0.710	0.19	64.38
OUTLET	110.67	1068	14418.2	14.6	4.11	0.705	0.19	70.23
MEAN	89.54	865	14858.2	14.7	5.31	0.707	0.19	67.39

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	693	64.87	71.90	9.28	108.6	988.0
4.5	732	65.49	76.27	9.79	102.7	939.0
7.5	781	66.24	81.52	9.86	101.6	936.0
11.0	839	67.11	87.68	9.45	105.4	980.0
16.5	933	68.50	97.40	8.22	120.3	1132.0
21.0	1014	69.65	105.38	6.51	150.9	1435.0
22.5	1041	70.04	108.05	5.87	167.2	1595.0

TEST NO.: S1.12 FLOW PATTERN:ANNULAR

ML= 48 MG= 23.43 QFLUX= 9767 NUTP=143.4 HTP=1344 PDT= 0.229

PDF= 0.194 ALFA=0.961 XTT= 0.10 WE= 1.8 FR= 0.03 STN= 20.66

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	69.44	671	17696.0	15.2	6.65	0.710	0.19	72.60
OUTLET	113.33	1096	16644.7	15.0	3.99	0.705	0.19	79.59
MEAN	91.38	884	17170.5	15.1	5.19	0.707	0.19	76.19

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	703	73.18	73.06	8.66	122.4	1115.0
4.5	745	73.92	77.60	9.32	113.4	1040.0
7.5	795	74.81	83.06	9.15	115.1	1063.0
11.0	856	75.86	89.45	8.62	121.5	1131.0
16.5	955	77.52	99.54	7.00	148.6	1402.0
21.0	1039	78.90	107.83	4.93	209.4	1998.0
22.5	1068	79.36	110.60	4.25	242.4	2321.0

TEST NO.: S1.13 FLOW PATTERN:ANNULAR

ML= 48 MG= 23.70 QFLUX= 9595 NUTP=128.6 HTP=1201 PDT= 0.227

PDF= 0.193 ALFA=0.961 XTT= 0.09 WE= 1.8 FR= 0.03 STN= 21.12

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	68.21	660	17926.0	15.2	6.78	0.710	0.19	73.40
OUTLET	111.27	1075	16876.7	15.0	4.08	0.705	0.19	80.37
MEAN	89.74	867	17401.6	15.1	5.30	0.707	0.19	76.98

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	692	73.99	71.76	8.69	120.1	1093.0
4.5	732	74.72	76.21	9.51	109.4	1001.0
7.5	781	75.61	81.57	9.48	109.3	1007.0
11.0	840	76.65	87.84	9.08	113.6	1056.0
16.5	937	78.31	97.75	7.58	135.0	1271.0
21.0	1019	79.68	105.88	6.06	167.7	1596.0
22.5	1047	80.14	108.60	5.41	187.4	1789.0

TEST NO.: S1.14 FLOW PATTERN:ANNULAR

ML= 48 MG= 25.11 QFIUX= 9840 NUTP=148.2 HTP=1390 PDT= 0.247

PDF= 0.214 ALFA=0.962 XTT= 0.09 WE= 1.8 FR= 0.03 STN= 20.66

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	69.76	674	18954.0	15.5	6.62	0.710	0.19	76.58
OUTLET	113.64	1099	17829.0	15.2	3.98	0.705	0.19	84.03
MEAN	91.70	887	18391.9	15.4	5.17	0.707	0.19	80.41

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	706	77.21	73.38	8.25	129.4	1179.0
4.5	747	77.99	77.91	9.59	111.1	1019.0
7.5	798	78.95	83.38	9.22	115.0	1063.0
11.0	859	80.06	89.77	8.55	123.3	1149.0
16.5	958	81.83	99.86	6.84	153.0	1444.0
21.0	1042	83.29	108.15	4.59	226.5	2162.0
22.5	1071	83.79	110.92	3.93	263.9	2528.0

TEST NO.: S1.15 FLOW PATTERN:ANNULAR

ML= 48 MG= 39.88 QFIUX= 10864 NUTP=132.6 HTP=1241 PDT= 0.714

PDF= 0.689 ALFA=0.972 XTT= 0.06 WE= 1.8 FR= 0.03 STN= 20.66

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	68.34	662	30160.0	15.9	6.75	0.710	0.19	118.23
OUTLET	113.81	1101	28304.1	15.2	3.97	0.705	0.19	133.92
MEAN	91.08	881	29232.3	15.5	5.22	0.707	0.19	126.24

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	695	119.51	72.09	8.07	146.1	1330.0
4.5	737	121.14	76.79	10.12	116.3	1065.0
7.5	789	123.11	82.44	10.81	108.5	1001.0
11.0	852	125.45	89.07	10.59	110.1	1025.0
16.5	955	129.20	99.53	8.71	132.8	1253.0
21.0	1042	132.33	108.12	6.37	180.3	1721.0
22.5	1072	133.39	110.99	5.27	217.3	2081.0

TEST NO.: S1.16 FLOW PATTERN:ANNULAR

ML= 48 MG= 66.09 QFLUX= 10838 NUTP=118.1 HTP=1096 PDT= 0.739

PDF= 0.721 ALFA=0.980 XTT= 0.04 WE= 1.7 FR= 0.03 STN= 21.58

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	66.08	642	50157.0	16.9	7.00	0.710	0.19	183.22
OUTLET	106.97	1030	47344.7	16.2	4.28	0.705	0.19	205.74
MEAN	86.52	836	48750.9	16.5	5.51	0.708	0.19	194.72

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	671	185.06	69.45	6.41	184.1	1670.0
4.5	709	187.40	73.67	9.90	119.1	1086.0
7.5	755	190.23	78.76	11.61	101.3	930.0
11.0	811	193.59	84.73	12.11	96.7	895.0
16.5	901	198.97	94.14	10.60	109.6	1027.0
21.0	978	203.46	101.86	8.12	142.2	1346.0
22.5	1004	204.98	104.44	7.01	164.3	1560.0

TEST NO.: S1.17 FLOW PATTERN:ANNULAR

ML= 48 MG= 91.58 QFLUX= 10161 NUTP= 98.9 HTP= 912 PDT= 1.217

PDF= 1.202 ALFA=0.984 XTT= 0.03 WE= 1.8 FR= 0.03 STN= 21.12

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	64.85	631	69624.0	18.2	7.16	0.710	0.19	235.84
OUTLET	99.84	958	66239.6	16.9	4.64	0.706	0.19	268.52
MEAN	82.35	794	67931.9	17.6	5.79	0.708	0.19	252.42

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	656	238.47	67.74	6.08	182.5	1651.0
4.5	688	241.80	71.35	10.57	105.0	955.0
7.5	727	245.87	75.71	12.97	85.4	781.0
11.0	774	250.71	80.82	13.84	79.8	735.0
16.5	850	258.54	88.87	12.41	88.4	822.0
21.0	914	265.15	95.47	9.68	112.6	1057.0
22.5	936	267.39	97.68	8.64	125.9	1185.0

TEST NO.: S1.18 FLOW PATTERN:ANNULAR

ML= 48 MG=123.79 QFIUX= 9835 NUTP= 99.0 HTP= 910 PDT= 1.772

PDF= 1.760 ALFA=0.987 XTT= 0.02 WE= 1.8 FR= 0.03 STN= 21.12

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	64.82	631	94120.0	20.1	7.18	0.710	0.19	288.59
OUTLET	95.31	913	90100.1	18.3	4.89	0.707	0.19	333.39
MEAN	80.07	772	92110.4	19.2	5.95	0.709	0.19	311.18

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	653	292.13	67.34	5.29	203.5	1840.0
4.5	681	296.63	70.49	10.23	105.2	955.0
7.5	715	302.14	74.29	12.87	83.5	762.0
11.0	755	308.75	78.74	13.74	78.0	716.0
16.5	821	319.51	85.76	12.15	87.7	813.0
21.0	876	328.68	91.51	9.57	110.8	1034.0
22.5	894	331.81	93.43	8.54	123.8	1159.0

TEST NO.: S1.19 FLOW PATTERN:ANNULAR-MIST

ML= 48 MG=170.49 QFIUX= 9632 NUTP= 92.5 HTP= 847 PDT= 2.919

PDF= 2.908 ALFA=0.989 XTT= 0.02 WE= 1.8 FR= 0.03 STN= 21.12

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	64.10	625	129766.0	24.0	7.28	0.711	0.19	332.32
OUTLET	90.20	863	124976.4	21.0	5.21	0.707	0.19	394.99
MEAN	77.15	744	127371.4	22.5	6.18	0.709	0.19	363.60

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	643	337.11	66.26	5.79	182.5	1648.0
4.5	667	343.25	68.96	11.30	93.6	848.0
7.5	696	350.83	72.22	13.79	76.6	697.0
11.0	730	359.99	76.03	14.32	73.6	673.0
16.5	786	375.11	82.03	12.35	84.9	783.0
21.0	832	388.20	86.95	9.83	106.1	985.0
22.5	848	392.71	88.59	8.86	117.5	1093.0

TEST NO.: S1.20 FLOW PATTERN:ANNULAR-MIST

ML= 48 MG=195.87 QFIUX= 9626 NUTP=102.7 HTP= 941 PDT= 3.449

PDF= 3.439 ALFA=0.990 XTT= 0.02 WE= 1.8 FR= 0.03 STN= 21.12

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	65.01	632	148886.0	26.3	7.19	0.710	0.19	348.96
OUTLET	89.42	855	143740.4	22.8	5.26	0.708	0.19	417.88
MEAN	77.21	744	146313.3	24.5	6.17	0.709	0.19	383.25

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	650	354.18	67.02	4.71	223.7	2022.0
4.5	672	360.87	69.55	10.26	103.0	934.0
7.5	699	369.16	72.60	12.74	82.9	754.0
11.0	731	379.21	76.16	13.21	79.7	729.0
16.5	783	395.86	81.78	11.30	92.7	854.0
21.0	826	410.33	86.38	8.87	117.5	1090.0
22.5	841	415.34	87.91	7.93	131.2	1219.0

TEST NO.: S2. 1 FLOW PATTERN:SLUG

ML= 94 MG= 0.55 QFLUX= 7420 NUTP= 66.8 HTP= 615 PDT= 0.328

PDF= 0.039 ALFA=0.660 XTT= 5.33 WE= 7.3 FR= 0.11 STN= 19.85

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	71.22	1359	415.4	15.7	6.58	0.710	0.37	1.66
OUTLET	90.02	1704	404.4	15.4	5.21	0.707	0.37	1.76
MEAN	80.62	1532	409.9	15.5	5.86	0.709	0.37	1.71

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1387	1.67	72.78	12.89	62.9	573.0
4.5	1422	1.68	74.73	12.62	64.2	586.0
7.5	1464	1.69	77.07	11.78	68.6	628.0
11.0	1514	1.70	79.82	12.68	63.6	585.0
16.5	1593	1.73	84.14	12.54	64.1	593.0
21.0	1660	1.75	87.68	11.05	72.6	674.0
22.5	1682	1.75	88.86	9.15	87.4	814.0

TEST NO.: S2. 2 FLOW PATTERN:SLUG

ML= 94 MG= 1.09 QFLUX= 7384 NUTP= 62.9 HTP= 580 PDT= 0.169

PDF=-0.048 ALFA=0.746 XTT= 2.83 WE= 6.9 FR= 0.11 STN= 21.12

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	71.88	1371	822.4	15.1	6.52	0.710	0.37	3.43
OUTLET	90.57	1714	800.8	14.9	5.17	0.707	0.37	3.59
MEAN	81.23	1543	811.6	15.0	5.82	0.709	0.37	3.51

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1399	3.44	73.43	14.29	56.5	514.0
4.5	1433	3.46	75.38	14.20	56.8	518.0
7.5	1475	3.48	77.71	14.10	57.0	523.0
11.0	1525	3.50	80.44	13.40	59.9	551.0
16.5	1604	3.54	84.73	12.64	63.3	585.0
21.0	1670	3.57	88.24	10.57	75.4	700.0
22.5	1692	3.58	89.41	9.08	87.6	815.0

TEST NO.: S2. 3 FLOW PATTERN:SLUG

ML= 94 MG= 1.68 QFLUX= 7424 NUTP= 63.1 HTP= 581 PDT= 0.144

PDF=-0.036 ALFA=0.789 XTT= 1.91 WE= 6.9 FR= 0.11 STN= 21.12

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	71.36	1362	1267.0	14.9	6.57	0.710	0.37	5.35
OUTLET	90.12	1706	1234.1	14.8	5.20	0.707	0.37	5.58
MEAN	80.74	1534	1250.9	14.8	5.85	0.709	0.37	5.47

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1389	5.37	72.92	15.09	53.8	490.0
4.5	1424	5.39	74.87	15.26	53.1	485.0
7.5	1466	5.42	77.21	14.77	54.8	502.0
11.0	1516	5.46	79.95	13.65	59.2	544.0
16.5	1595	5.51	84.26	12.74	63.1	584.0
21.0	1662	5.56	87.79	9.78	81.9	761.0
22.5	1684	5.57	88.96	8.13	98.3	915.0

TEST NO.: S2. 4 FLOW PATTERN:CHURN

ML= 94 MG= 2.30 QFLUX= 7680 NUTP= 67.0 HTP= 618 PDT= 0.169

PDF= 0.010 ALFA=0.814 XTT= 1.45 WE= 6.9 FR= 0.11 STN= 21.12

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	71.46	1364	1734.0	15.2	6.56	0.710	0.37	7.17
OUTLET	90.84	1720	1686.7	15.0	5.15	0.707	0.37	7.51
MEAN	81.15	1542	1710.4	15.1	5.82	0.709	0.37	7.35

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1392	7.20	73.07	13.71	61.2	557.0
4.5	1428	7.24	75.08	13.95	60.1	549.0
7.5	1472	7.28	77.50	13.75	60.9	558.0
11.0	1523	7.33	80.33	14.16	59.0	542.0
16.5	1605	7.41	84.78	12.71	65.4	605.0
21.0	1674	7.48	88.43	9.30	89.0	828.0
22.5	1697	7.50	89.64	8.28	99.9	930.0

TEST NO.: S2. 5 FLOW PATTERN:CHURN

ML= 94 MG= 2.89 QFLUX= 8201 NUTP= 73.5 HTP= 677 PDT= 0.194

PDF= 0.050 ALFA=0.831 XTT= 1.19 WE= 6.9 FR= 0.11 STN= 21.12

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	71.13	1358	2173.0	15.3	6.58	0.710	0.37	8.92
OUTLET	91.79	1738	2110.3	15.1	5.09	0.707	0.37	9.37
MEAN	81.46	1548	2141.9	15.2	5.80	0.708	0.37	9.15

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1388	8.96	72.84	11.65	76.9	700.0
4.5	1426	9.01	74.99	12.48	71.7	654.0
7.5	1473	9.07	77.56	12.71	70.3	644.0
11.0	1528	9.13	80.58	12.51	71.2	655.0
16.5	1615	9.24	85.32	12.48	71.1	658.0
21.0	1689	9.33	89.21	10.91	81.1	755.0
22.5	1713	9.36	90.51	10.03	88.0	821.0

TEST NO.: S2. 6 FLOW PATTERN:CHURN

ML= 94 MG= 4.80 QFLUX= 11511 NUTP= 91.0 HTP= 844 PDT= 0.216

PDF= 0.102 ALFA=0.867 XTT= 0.74 WE= 6.9 FR= 0.11 STN= 21.12

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	71.52	1365	3613.0	15.2	6.52	0.710	0.37	14.95
OUTLET	100.38	1905	3469.4	15.0	4.60	0.706	0.37	15.96
MEAN	85.95	1635	3541.6	15.1	5.50	0.708	0.37	15.47

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1407	15.04	73.91	13.55	92.4	843.0
4.5	1461	15.14	76.90	13.94	89.7	821.0
7.5	1526	15.27	80.49	14.04	88.8	817.0
11.0	1604	15.42	84.70	13.85	89.7	830.0
16.5	1729	15.66	91.33	13.32	92.9	867.0
21.0	1834	15.86	96.77	13.36	92.2	867.0
22.5	1870	15.93	98.59	13.15	93.6	882.0

TEST NO.: S2. 7 FLOW PATTERN:CHURN-ANNULAR

ML= 94 MG= 8.54 QFLUX= 12093 NUTP=105.8 HTP= 982 PDT= 0.205

PDF= 0.119 ALFA=0.899 XTT= 0.44 WE= 6.9 FR= 0.11 STN= 21.12

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	71.26	1360	6434.0	15.2	6.54	0.710	0.37	26.60
OUTLET	101.30	1924	6167.0	15.0	4.55	0.706	0.37	28.43
MEAN	86.28	1642	6300.6	15.1	5.48	0.708	0.37	27.54

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1404	26.75	73.75	12.71	103.5	944.0
4.5	1460	26.95	76.86	12.73	103.1	944.0
7.5	1528	27.18	80.60	12.73	102.9	947.0
11.0	1609	27.46	84.98	12.57	103.9	961.0
16.5	1739	27.89	91.88	12.10	107.3	1002.0
21.0	1849	28.25	97.54	11.63	111.2	1046.0
22.5	1887	28.37	99.44	11.47	112.6	1062.0

TEST NO.: S2. 8 FLOW PATTERN:ANNULAR

ML= 94 MG= 13.08 QFLUX= 13646 NUTP=126.9 HTP=1180 PDT= 0.231

PDF= 0.161 ALFA=0.919 XTT= 0.30 WE= 6.9 FR= 0.11 STN= 21.30

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	71.00	1355	9856.0	15.2	6.55	0.710	0.37	40.71
OUTLET	104.52	1988	9402.3	15.0	4.39	0.706	0.37	43.85
MEAN	87.76	1672	9629.4	15.1	5.39	0.708	0.37	42.32

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1404	40.97	73.76	11.95	124.2	1133.0
4.5	1467	41.31	77.23	12.19	121.4	1112.0
7.5	1543	41.71	81.41	12.18	121.1	1116.0
11.0	1634	42.18	86.29	11.88	123.7	1147.0
16.5	1780	42.92	94.00	11.32	129.1	1209.0
21.0	1904	43.54	100.32	10.57	137.5	1299.0
22.5	1946	43.74	102.43	10.49	138.4	1311.0

TEST NO.: S2. 9 FLOW PATTERN:ANNULAR

ML= 94 MG= 17.16 QFIUX= 14443 NUTP=146.6 HTP=1365 PDT= 0.285

PDF= 0.223 ALFA=0.929 XTT= 0.24 WE= 6.9 FR= 0.11 STN= 21.30

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	70.59	1348	12938.0	15.5	6.58	0.710	0.37	52.33
OUTLET	105.72	2012	12314.6	15.2	4.33	0.706	0.37	56.70
MEAN	88.16	1680	12626.4	15.4	5.37	0.708	0.37	54.58

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1400	52.70	73.49	10.93	143.6	1309.0
4.5	1465	53.16	77.13	11.20	139.9	1281.0
7.5	1544	53.72	81.50	11.20	139.4	1284.0
11.0	1640	54.37	86.62	10.99	141.5	1313.0
16.5	1794	55.41	94.69	10.32	149.7	1404.0
21.0	1924	56.27	101.32	9.62	159.8	1512.0
22.5	1968	56.56	103.54	9.24	166.1	1576.0

TEST NO.: S2.10 FLOW PATTERN:ANNULAR

ML= 94 MG= 20.81 QFLUX= 15504 NUTP=172.7 HTP=1610 PDT= 0.346

PDF= 0.291 ALFA=0.936 XTT= 0.20 WE= 6.9 FR= 0.11 STN= 21.12

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	70.34	1344	15690.0	15.7	6.59	0.710	0.37	62.61
OUTLET	107.72	2053	14889.0	15.4	4.24	0.705	0.37	68.34
MEAN	89.03	1698	15289.9	15.5	5.32	0.708	0.37	65.55

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1398	63.09	73.43	10.26	164.2	1497.0
4.5	1468	63.69	77.29	10.61	158.3	1451.0
7.5	1553	64.42	81.95	10.51	159.3	1469.0
11.0	1654	65.28	87.39	10.23	163.0	1514.0
16.5	1819	66.64	95.98	9.23	179.5	1686.0
21.0	1958	67.77	103.04	8.30	198.6	1883.0
22.5	2006	68.15	105.40	7.91	208.0	1978.0

TEST NO.: S2.11 FLOW PATTERN:ANNULAR

ML= 94 MG= 23.49 QFLUX= 16125 NUTP=178.3 HTP=1663 PDT= 0.398

PDF= 0.346 ALFA=0.940 XTT= 0.18 WE= 6.8 FR= 0.11 STN= 21.58

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	70.17	1341	17721.0	15.9	6.60	0.710	0.37	70.00
OUTLET	108.80	2075	16787.1	15.5	4.19	0.705	0.37	76.82
MEAN	89.49	1708	17254.1	15.7	5.29	0.707	0.37	73.50

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1397	70.57	73.36	12.64	138.8	1265.0
4.5	1469	71.29	77.36	10.36	168.6	1545.0
7.5	1557	72.15	82.16	10.45	166.6	1536.0
11.0	1662	73.17	87.79	10.13	171.0	1590.0
16.5	1832	74.79	96.67	9.36	184.0	1730.0
21.0	1977	76.14	103.96	8.27	206.9	1964.0
22.5	2026	76.59	106.40	7.74	220.7	2102.0

TEST NO.: S2.12 FLOW PATTERN:ANNULAR

ML= 94 MG= 25.74 QFLUX= 16478 NUTP=173.9 HTP=1622 PDT= 0.449

PDF= 0.399 ALFA=0.943 XTT= 0.17 WE= 6.8 FR= 0.11 STN= 21.58

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	70.07	1339	19417.0	16.0	6.61	0.710	0.37	76.19
OUTLET	109.33	2086	18377.8	15.5	4.17	0.705	0.37	83.95
MEAN	89.70	1713	18897.5	15.7	5.28	0.707	0.37	80.17

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1396	76.84	73.31	10.11	176.9	1613.0
4.5	1469	77.65	77.37	10.73	166.4	1525.0
7.5	1558	78.64	82.26	10.93	162.6	1500.0
11.0	1665	79.80	87.97	10.77	164.5	1529.0
16.5	1839	81.64	97.00	9.92	177.2	1667.0
21.0	1986	83.18	104.42	9.06	193.1	1834.0
22.5	2036	83.69	106.90	8.65	201.7	1922.0

TEST NO.: S2.13 FLOW PATTERN:ANNULAR

ML= 94 MG= 45.23 QFLUX= 18646 NUTP=222.0 HTP=2073 PDT= 0.786

PDF= 0.750 ALFA=0.958 XTT= 0.10 WE= 7.0 FR= 0.11 STN= 20.85

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	68.58	1313	34195.0	16.8	6.74	0.710	0.37	126.76
OUTLET	111.04	2121	32220.8	16.0	4.09	0.705	0.37	143.12
MEAN	89.81	1717	33208.3	16.4	5.29	0.707	0.37	135.11

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1374	128.10	72.08	8.81	230.0	2093.0
4.5	1453	129.79	76.46	9.94	203.4	1862.0
7.5	1549	131.85	81.75	10.37	194.3	1791.0
11.0	1664	134.28	87.93	10.20	196.5	1826.0
16.5	1853	138.19	97.70	8.90	223.6	2105.0
21.0	2013	141.46	105.73	7.06	279.9	2663.0
22.5	2067	142.57	108.41	6.38	308.9	2949.0

TEST NO.: S2.14 FLOW PATTERN:ANNULAR-MIST

ML= 94 MG= 79.40 QFLUX= 15328 NUTP=108.3 HTP= 998 PDT= 1.319

PDF= 1.292 ALFA=0.970 XTT= 0.07 WE= 7.1 FR= 0.11 STN= 20.66

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	66.63	1279	60211.0	18.6	6.98	0.710	0.37	200.29
OUTLET	99.02	1879	57498.7	17.3	4.68	0.706	0.37	227.88
MEAN	82.82	1579	58854.9	17.9	5.75	0.708	0.37	214.27

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1326	202.50	69.30	8.80	189.8	1721.0
4.5	1384	205.30	72.64	12.80	130.4	1188.0
7.5	1457	208.73	76.67	15.37	108.5	993.0
11.0	1543	212.82	81.40	17.11	97.3	896.0
16.5	1682	219.43	88.85	17.77	93.2	867.0
21.0	1799	225.03	94.98	16.91	97.4	914.0
22.5	1839	226.93	97.02	16.47	99.9	939.0

TEST NO.: S2.15 FLOW PATTERN:ANNULAR-MIST

ML= 94 MG=149.09 QFLUX= 13517 NUTP= 83.4 HTP= 764 PDT= 2.706

PDF= 2.686 ALFA=0.979 XTT= 0.04 WE= 7.1 FR= 0.11 STN= 20.39

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	65.26	1256	113280.0	23.6	7.16	0.710	0.37	295.63
OUTLET	90.17	1707	109290.4	20.9	5.21	0.707	0.37	347.87
MEAN	77.71	1481	111285.4	22.3	6.13	0.709	0.37	321.75

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1291	299.65	67.31	8.04	183.7	1661.0
4.5	1336	304.79	69.88	14.68	100.8	914.0
7.5	1391	311.13	72.99	18.71	79.1	721.0
11.0	1456	318.78	76.63	20.88	70.8	648.0
16.5	1560	331.38	82.36	21.12	69.7	643.0
21.0	1648	342.24	87.06	19.84	73.9	686.0
22.5	1678	345.98	88.63	19.17	76.4	710.0

TEST NO.: S2.16 FLOW PATTERN:ANNULAR-MIST

ML= 94 MG=160.97 QFLUX= 12911 NUTP= 85.6 HTP= 783 PDT= 2.987

PDF= 2.968 ALFA=0.980 XTT= 0.04 WE= 7.1 FR= 0.11 STN= 20.39

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	64.91	1250	122375.0	24.7	7.20	0.711	0.37	304.79
OUTLET	88.20	1669	118331.1	21.7	5.34	0.708	0.37	360.09
MEAN	76.55	1460	120353.2	23.2	6.22	0.709	0.37	332.39

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1283	309.02	66.83	7.31	193.1	1745.0
4.5	1325	314.43	69.24	13.66	103.6	939.0
7.5	1376	321.13	72.14	17.50	80.9	736.0
11.0	1436	329.21	75.54	19.54	72.4	661.0
16.5	1533	342.55	80.90	19.78	71.2	655.0
21.0	1615	354.09	85.30	18.60	75.4	699.0
22.5	1642	358.07	86.76	18.04	77.6	720.0

TEST NO.: S2.17 FLOW PATTERN:ANNULAR-MIST

ML= 94 MG=184.60 QFIUX= 13027 NUTP= 90.6 HTP= 828 PDT= 3.549

PDF= 3.531 ALFA=0.981 XTT= 0.04 WE= 7.2 FR= 0.11 STN= 20.21

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	65.13	1253	140295.0	26.9	7.18	0.710	0.37	321.08
OUTLET	87.67	1659	135803.6	23.4	5.37	0.708	0.37	383.46
MEAN	76.40	1456	138049.3	25.1	6.23	0.709	0.37	352.11

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	1285	325.80	66.99	6.55	217.6	1967.0
4.5	1326	331.86	69.32	12.96	110.2	999.0
7.5	1375	339.36	72.13	16.84	84.8	772.0
11.0	1434	348.45	75.42	18.88	75.6	690.0
16.5	1528	363.52	80.60	19.14	74.3	683.0
21.0	1607	376.63	84.86	18.03	78.5	727.0
22.5	1633	381.16	86.28	17.49	80.9	750.0

TEST NO.: S3. 1 FLOW PATTERN:BUBBLE

ML= 267 MG= 0.60 QFLUX= 11388 NUTP= 98.1 HTP= 898 PDT= 0.501

PDF= 0.085 ALFA=0.511 XTT= 12.80 WE= 51.4 FR= 0.86 STN= 22.49

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	71.35	3837	451.2	16.1	6.60	0.710	1.03	1.76
OUTLET	81.60	4358	444.6	15.6	5.79	0.709	1.03	1.85
MEAN	76.48	4098	447.9	15.8	6.19	0.709	1.03	1.81

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	3880	1.77	72.20	12.10	103.1	938.0
4.5	3933	1.78	73.27	12.54	99.4	906.0
7.5	3997	1.79	74.55	12.49	99.7	910.0
11.0	4073	1.80	76.04	12.87	96.7	884.0
16.5	4193	1.82	78.39	12.77	97.2	892.0
21.0	4292	1.84	80.32	12.79	97.0	892.0
22.5	4325	1.85	80.96	12.90	96.1	885.0

TEST NO.: S3. 2 FLOW PATTERN:SLUG

ML= 267 MG= 1.10 QFIUX= 11635 NUTP=101.6 HTP= 929 PDT= 0.420

PDF= 0.088 ALFA=0.610 XTT= 7.36 WE= 52.5 FR= 0.86 STN= 22.03

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	70.57	3799	830.9	15.8	6.68	0.710	1.03	3.29
OUTLET	81.04	4329	818.4	15.4	5.83	0.709	1.03	3.44
MEAN	75.81	4064	824.7	15.6	6.25	0.709	1.03	3.37

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	3842	3.30	71.44	11.08	115.1	1046.0
4.5	3896	3.32	72.53	11.80	107.9	983.0
7.5	3962	3.34	73.84	12.33	103.3	942.0
11.0	4038	3.36	75.36	12.54	101.5	927.0
16.5	4160	3.40	77.77	12.96	98.0	898.0
21.0	4261	3.43	79.73	13.25	95.8	880.0
22.5	4295	3.44	80.39	13.31	95.3	876.0

TEST NO.: S3. 3 FLOW PATTERN:SLUG

ML= 267 MG= 1.50 QFLUX= 11673 NUTP= 88.2 HTP= 807 PDT= 0.339

PDF= 0.045 ALFA=0.655 XTT= 5.53 WE= 53.6 FR= 0.86 STN= 21.58

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	70.64	3802	1133.0	15.6	6.67	0.710	1.03	4.55
OUTLET	81.14	4334	1116.4	15.3	5.82	0.709	1.03	4.73
MEAN	75.89	4068	1124.9	15.5	6.24	0.709	1.03	4.64

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	3846	4.56	71.51	13.91	92.0	836.0
4.5	3900	4.58	72.61	14.38	89.0	810.0
7.5	3966	4.60	73.92	14.43	88.6	808.0
11.0	4043	4.63	75.45	14.47	88.2	806.0
16.5	4165	4.68	77.86	14.79	86.2	790.0
21.0	4266	4.71	79.83	14.43	88.1	810.0
22.5	4300	4.73	80.49	14.00	90.8	836.0

TEST NO.: S3. 4 FLOW PATTERN:SLUG

ML= 267 MG= 1.90 QFLUX= 12120 NUTP= 88.9 HTP= 814 PDT= 0.301

PDF= 0.034 ALFA=0.687 XTT= 4.46 WE= 53.6 FR= 0.86 STN= 21.58

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	71.78	3859	1429.0	15.5	6.56	0.710	1.03	5.79
OUTLET	82.68	4414	1407.1	15.2	5.71	0.708	1.03	6.02
MEAN	77.23	4136	1418.3	15.4	6.12	0.709	1.03	5.91

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	3904	5.81	72.68	14.80	89.7	816.0
4.5	3961	5.83	73.82	14.95	88.7	809.0
7.5	4029	5.86	75.18	15.24	86.9	794.0
11.0	4110	5.90	76.77	15.16	87.3	799.0
16.5	4237	5.95	79.27	14.87	88.8	816.0
21.0	4343	6.00	81.32	14.41	91.5	843.0
22.5	4378	6.01	82.00	13.73	95.9	884.0

TEST NO.: S3. 5 FLOW PATTERN:SLUG

ML= 267 MG= 2.26 QFLUX= 12178 NUTP= 89.5 HTP= 821 PDT= 0.281

PDF= 0.032 ALFA=0.708 XTT= 3.81 WE= 54.7 FR= 0.87 STN= 21.12

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.69	3904	1696.0	15.5	6.48	0.710	1.03	6.89
OUTLET	83.64	4464	1670.0	15.3	5.63	0.708	1.03	7.16
MEAN	78.16	4184	1683.2	15.4	6.05	0.709	1.03	7.03

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	3950	6.92	73.60	14.56	91.4	833.0
4.5	4007	6.94	74.74	14.91	89.3	815.0
7.5	4076	6.98	76.11	15.00	88.6	811.0
11.0	4157	7.02	77.70	14.95	88.8	814.0
16.5	4286	7.08	80.21	14.99	88.4	813.0
21.0	4393	7.13	82.27	14.47	91.5	843.0
22.5	4428	7.15	82.96	13.90	95.1	878.0

TEST NO.: S3. 6 FLOW PATTERN:CHURN

ML= 267 MG= 2.55 QFLUX= 13076 NUTP= 91.5 HTP= 841 PDT= 0.298

PDF= 0.062 ALFA=0.723 XTT= 3.39 WE= 54.8 FR= 0.87 STN= 21.12

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	73.33	3936	1911.0	15.4	6.41	0.709	1.03	7.86
OUTLET	85.08	4540	1880.0	15.1	5.53	0.708	1.03	8.18
MEAN	79.21	4238	1896.0	15.2	5.96	0.709	1.03	8.03

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	3985	7.89	74.31	15.30	93.4	852.0
4.5	4047	7.92	75.53	15.67	91.1	832.0
7.5	4121	7.96	77.00	15.79	90.3	827.0
11.0	4209	8.01	78.71	15.76	90.4	829.0
16.5	4348	8.09	81.41	15.69	90.6	834.0
21.0	4463	8.15	83.62	15.01	94.5	873.0
22.5	4501	8.17	84.35	14.54	97.5	902.0

TEST NO.: S3. 7 FLOW PATTERN:CHURN

ML= 267 MG= 2.88 QFLUX= 13574 NUTP= 95.9 HTP= 881 PDT= 0.314

PDF= 0.088 ALFA=0.735 XTT= 3.06 WE= 57.2 FR= 0.87 STN= 20.21

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	73.14	3927	2160.0	15.5	6.43	0.709	1.03	8.79
OUTLET	85.34	4553	2122.6	15.2	5.51	0.708	1.03	9.16
MEAN	79.24	4240	2141.3	15.4	5.96	0.709	1.03	8.98

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	3978	8.82	74.16	14.77	100.3	915.0
4.5	4041	8.86	75.42	15.19	97.5	891.0
7.5	4119	8.91	76.95	15.50	95.4	874.0
11.0	4209	8.97	78.72	15.49	95.4	876.0
16.5	4354	9.06	81.52	15.63	94.4	870.0
21.0	4473	9.13	83.82	15.38	95.8	885.0
22.5	4513	9.15	84.58	15.04	97.8	905.0

TEST NO.: S3. 8 FLOW PATTERN:CHURN-ANNULAR

ML= 267 MG= 5.61 QFLUX= 16013 NUTP=122.7 HTP=1130 PDT= 0.390

PDF= 0.219 ALFA=0.800 XTT= 1.67 WE= 56.0 FR= 0.87 STN= 20.66

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	73.58	3949	4213.0	15.7	6.38	0.709	1.03	17.01
OUTLET	87.93	4690	4128.4	15.3	5.34	0.708	1.03	17.88
MEAN	80.76	4320	4171.2	15.5	5.84	0.709	1.03	17.46

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	4009	17.08	74.77	13.72	127.3	1162.0
4.5	4084	17.18	76.26	14.09	123.8	1133.0
7.5	4175	17.29	78.05	14.37	121.2	1112.0
11.0	4283	17.42	80.15	14.24	122.1	1123.0
16.5	4454	17.63	83.44	14.06	123.4	1140.0
21.0	4595	17.80	86.14	14.29	121.3	1124.0
22.5	4643	17.86	87.04	14.18	122.1	1133.0

TEST NO.: S3. 9 FLOW PATTERN:CHURN-ANNULAR

ML= 267 MG= 9.70 QFIUX= 19748 NUTP=159.4 HTP=1470 PDT= 0.433

PDF= 0.298 ALFA=0.842 XTT= 1.02 WE= 57.2 FR= 0.87 STN= 20.21

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	73.02	3921	7290.0	15.8	6.42	0.709	1.03	29.19
OUTLET	90.66	4836	7109.8	15.4	5.16	0.707	1.03	30.95
MEAN	81.84	4379	7200.3	15.6	5.77	0.708	1.03	30.09

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	3994	29.34	74.49	13.51	159.4	1455.0
4.5	4087	29.52	76.32	13.76	156.3	1431.0
7.5	4199	29.75	78.52	13.68	156.9	1440.0
11.0	4331	30.01	81.09	13.54	158.2	1457.0
16.5	4542	30.43	85.14	13.29	160.8	1489.0
21.0	4718	30.77	88.45	13.04	163.4	1520.0
22.5	4777	30.89	89.56	13.00	163.8	1526.0

TEST NO.: S3.10 FLOW PATTERN:ANNULAR

ML= 267 MG= 13.73 QFIUX= 22142 NUTP=193.7 HTP=1789 PDT= 0.523

PDF= 0.407 ALFA=0.865 XTT= 0.75 WE= 57.2 FR= 0.87 STN= 20.21

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.89	3914	10313.0	16.0	6.42	0.709	1.03	40.76
OUTLET	92.59	4941	10028.8	15.5	5.04	0.707	1.03	43.60
MEAN	82.74	4428	10171.3	15.7	5.70	0.708	1.03	42.22

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	3996	41.00	74.53	12.53	192.6	1758.0
4.5	4100	41.29	76.57	12.80	188.2	1723.0
7.5	4225	41.65	79.03	12.77	188.3	1730.0
11.0	4373	42.08	81.90	12.59	190.7	1758.0
16.5	4610	42.76	86.42	12.10	197.7	1834.0
21.0	4808	43.32	90.13	11.89	200.6	1870.0
22.5	4875	43.51	91.37	11.77	202.4	1890.0

TEST NO.: S3.11 FLOW PATTERN:ANNULAR

ML= 267 MG= 17.07 QFIUX= 23830 NUTP=218.2 HTP=2018 PDT= 0.613

PDF= 0.508 ALFA=0.878 XTT= 0.62 WE= 58.6 FR= 0.87 STN= 19.75

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	73.24	3932	12816.0	16.2	6.39	0.709	1.03	50.08
OUTLET	94.38	5038	12438.0	15.6	4.93	0.707	1.03	53.99
MEAN	83.81	4485	12627.4	15.9	5.63	0.708	1.03	52.08

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	4020	50.41	74.99	12.11	214.3	1957.0
4.5	4131	50.82	77.19	12.34	209.9	1924.0
7.5	4266	51.31	79.83	12.20	211.8	1948.0
11.0	4426	51.89	82.91	12.03	214.4	1980.0
16.5	4681	52.82	87.76	11.49	223.6	2078.0
21.0	4895	53.60	91.74	11.24	227.9	2129.0
22.5	4967	53.86	93.07	11.07	231.2	2164.0

TEST NO.: S3.12 FLOW PATTERN:ANNULAR

ML= 267 MG= 21.22 QFLUX= 26027 NUTP=253.7 HTP=2349 PDT= 0.743

PDF= 0.648 ALFA=0.889 XTT= 0.51 WE= 57.3 FR= 0.87 STN= 20.21

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.95	3917	15945.0	16.6	6.41	0.709	1.03	60.89
OUTLET	95.96	5124	15433.6	15.8	4.84	0.707	1.04	66.32
MEAN	84.46	4521	15689.3	16.2	5.58	0.708	1.03	63.67

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	4013	61.34	74.86	11.52	245.8	2245.0
4.5	4134	61.90	77.25	11.68	242.1	2218.0
7.5	4281	62.59	80.11	11.59	243.4	2239.0
11.0	4455	63.40	83.47	11.34	248.1	2293.0
16.5	4734	64.70	88.75	10.79	259.9	2418.0
21.0	4967	65.78	93.08	10.26	272.1	2547.0
22.5	5046	66.14	94.53	10.22	272.9	2559.0

TEST NO.: S3.13 FLOW PATTERN:ANNULAR

ML= 267 MG= 22.98 QFLUX= 28359 NUTP=258.7 HTP=2399 PDT= 0.791

PDF= 0.700 ALFA=0.893 XTT= 0.48 WE= 57.3 FR= 0.87 STN= 20.21

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	73.21	3930	17258.0	16.7	6.38	0.709	1.03	65.41
OUTLET	98.23	5250	16658.4	15.9	4.72	0.706	1.04	71.68
MEAN	85.72	4590	16958.3	16.3	5.50	0.708	1.03	68.61

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	4034	65.93	75.28	12.11	254.6	2327.0
4.5	4166	66.58	77.87	12.32	249.8	2291.0
7.5	4326	67.37	80.99	12.33	249.1	2294.0
11.0	4516	68.30	84.64	12.11	252.8	2340.0
16.5	4822	69.79	90.39	11.57	263.5	2457.0
21.0	5077	71.04	95.10	11.04	275.1	2582.0
22.5	5164	71.47	96.68	10.91	278.1	2615.0

TEST NO.: S3.14 FLOW PATTERN:ANNULAR

ML= 267 MG= 26.20 QFLUX= 28343 NUTP=272.7 HTP=2528 PDT= 0.894

PDF= 0.807 ALFA=0.899 XTT= 0.43 WE= 57.3 FR= 0.87 STN= 20.21

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.94	3917	19681.0	17.0	6.40	0.709	1.03	73.21
OUTLET	97.88	5231	18999.5	16.1	4.74	0.707	1.04	80.65
MEAN	85.41	4574	19340.6	16.6	5.52	0.708	1.03	77.01

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	4020	73.82	75.01	11.40	270.3	2469.0
4.5	4152	74.59	77.59	11.64	264.4	2424.0
7.5	4311	75.52	80.70	11.70	262.3	2415.0
11.0	4500	76.63	84.34	11.55	265.1	2453.0
16.5	4804	78.40	90.06	10.97	277.9	2591.0
21.0	5059	79.89	94.76	10.48	289.8	2719.0
22.5	5145	80.40	96.33	10.32	293.9	2762.0

TEST NO.: S3.15 FLOW PATTERN:ANNULAR

ML= 267 MG= 43.08 QFLUX= 29539 NUTP=311.1 HTP=2884 PDT= 1.421

PDF= 1.351 ALFA=0.919 XTT= 0.28 WE= 56.0 FR= 0.87 STN= 20.66

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.64	3902	32383.0	18.5	6.43	0.709	1.03	110.29
OUTLET	98.25	5251	31231.8	17.1	4.72	0.706	1.04	124.68
MEAN	85.45	4576	31807.9	17.8	5.52	0.708	1.03	117.57

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	4008	111.44	74.76	9.90	324.2	2962.0
4.5	4142	112.90	77.41	10.38	309.0	2832.0
7.5	4306	114.68	80.61	10.61	301.6	2776.0
11.0	4501	116.81	84.34	10.58	301.5	2789.0
16.5	4813	120.26	90.22	10.10	314.6	2933.0
21.0	5075	123.19	95.05	9.81	322.7	3028.0
22.5	5163	124.18	96.66	9.65	327.5	3080.0

TEST NO.: S3.16 FLOW PATTERN:ANNULAR-MIST

ML= 267 MG= 89.88 QFLUX= 26035 NUTP=203.2 HTP=1872 PDT= 2.542

PDF= 2.491 ALFA=0.941 XTT= 0.16 WE= 55.3 FR= 0.87 STN= 20.94

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	71.04	3822	67714.0	22.5	6.59	0.710	1.03	188.68
OUTLET	92.74	4949	65651.6	20.0	5.04	0.707	1.03	220.22
MEAN	81.89	4385	66682.9	21.3	5.77	0.708	1.03	204.47

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	3911	191.11	72.83	8.72	324.7	2958.0
4.5	4024	194.22	75.08	11.02	257.0	2348.0
7.5	4161	198.06	77.78	12.79	221.1	2027.0
11.0	4324	202.68	80.94	14.51	194.8	1794.0
16.5	4584	210.28	85.93	16.38	172.1	1595.0
21.0	4802	216.83	90.02	17.59	159.9	1490.0
22.5	4876	219.08	91.39	17.82	157.7	1472.0

TEST NO.: S3.17 FLOW PATTERN:ANNULAR-MIST

ML= 267 MG=119.74 QFLUX= 21881 NUTP=139.0 HTP=1276 PDT= 3.064

PDF= 3.018 ALFA=0.948 XTT= 0.13 WE= 56.0 FR= 0.87 STN= 20.66

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	70.52	3796	90279.0	24.9	6.65	0.710	1.03	227.41
OUTLET	88.32	4711	88005.0	21.8	5.32	0.708	1.03	266.60
MEAN	79.42	4254	89142.1	23.4	5.96	0.709	1.03	246.96

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	3869	230.41	71.99	8.64	275.6	2508.0
4.5	3961	234.24	73.83	12.69	187.8	1713.0
7.5	4073	238.98	76.05	15.78	151.1	1382.0
11.0	4205	244.70	78.64	18.73	127.3	1168.0
16.5	4417	254.16	82.73	21.88	108.8	1004.0
21.0	4593	262.35	86.09	23.27	102.1	947.0
22.5	4652	265.17	87.21	23.63	100.5	933.0

TEST NO.: S3.18 FLOW PATTERN:ANNULAR-MIST

ML= 267 MG=161.22 QFLUX= 18244 NUTP=105.4 HTP= 964 PDT= 3.630

PDF= 3.590 ALFA=0.954 XTT= 0.11 WE= 55.9 FR= 0.86 STN= 20.66

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	69.78	3760	121683.0	28.5	6.74	0.710	1.03	266.67
OUTLET	84.14	4490	119191.3	24.9	5.61	0.708	1.03	312.14
MEAN	76.96	4125	120437.5	26.7	6.15	0.709	1.03	289.32

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	3818	270.13	70.97	8.75	227.2	2064.0
4.5	3892	274.56	72.45	14.20	140.3	1277.0
7.5	3982	280.04	74.24	18.11	110.1	1005.0
11.0	4088	286.68	76.34	21.39	93.3	853.0
16.5	4256	297.66	79.64	24.02	83.0	763.0
21.0	4396	307.18	82.34	24.93	79.8	736.0
22.5	4443	310.47	83.25	25.06	79.4	733.0

TEST NO.: S3.19 FLOW PATTERN:ANNULAR-MIST

ML= 267 MG=192.81 QFLUX= 16117 NUTP= 93.4 HTP= 853 PDT= 4.038

PDF= 4.000 ALFA=0.958 XTT= 0.10 WE= 54.7 FR= 0.86 STN= 21.12

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	69.66	3754	145559.0	31.3	6.76	0.710	1.03	290.37
OUTLET	82.03	4380	142978.8	27.3	5.76	0.708	1.03	339.31
MEAN	75.85	4067	144268.9	29.3	6.25	0.709	1.03	314.74

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	3804	294.09	70.68	8.53	205.9	1870.0
4.5	3868	298.85	71.96	14.38	122.5	1115.0
7.5	3945	304.75	73.51	18.45	95.6	871.0
11.0	4036	311.89	75.31	21.47	82.2	751.0
16.5	4180	323.71	78.16	23.78	74.2	680.0
21.0	4300	333.97	80.49	24.48	71.9	662.0
22.5	4340	337.51	81.27	24.52	71.8	661.0

TEST NO.: S4. 1 FLOW PATTERN:BUBBLE

ML= 882 MG= 0.14 QFLUX= 10682 NUTP= 93.4 HTP= 848 PDT= 0.941

PDF= 0.175 ALFA=0.100 XTT=140.71 WE= 526.2 FR= 9.39 STN= 23.87

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	69.82	12404	108.2	17.1	6.78	0.710	3.41	0.40
OUTLET	72.74	12882	107.7	16.2	6.52	0.710	3.40	0.42
MEAN	71.28	12643	107.9	16.6	6.65	0.710	3.40	0.41

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	12444	0.40	70.06	11.88	98.9	898.0
4.5	12493	0.40	70.37	12.46	94.3	856.0
7.5	12553	0.40	70.73	12.72	92.4	840.0
11.0	12622	0.41	71.16	12.77	92.1	836.0
16.5	12732	0.41	71.83	12.56	93.5	850.0
21.0	12822	0.42	72.37	12.66	92.8	844.0
22.5	12852	0.42	72.56	12.54	93.6	852.0

TEST NO.: S4. 2 FLOW PATTERN:BUBBLE

ML= 882 MG= 0.62 QFLUX= 16124 NUTP=111.0 HTP=1011 PDT= 0.869

PDF= 0.267 ALFA=0.293 XTT= 37.66 WE= 506.8 FR= 9.39 STN= 24.79

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	70.97	12591	465.4	17.1	6.66	0.710	3.41	1.71
OUTLET	75.37	13318	462.4	16.2	6.29	0.709	3.40	1.81
MEAN	73.17	12955	463.9	16.7	6.47	0.710	3.40	1.76

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	12651	1.72	71.34	15.07	117.5	1068.0
4.5	12726	1.73	71.79	15.78	112.3	1021.0
7.5	12817	1.74	72.34	16.09	110.0	1001.0
11.0	12923	1.76	72.99	16.15	109.6	998.0
16.5	13090	1.78	74.00	15.95	110.9	1011.0
21.0	13227	1.80	74.82	15.95	110.8	1012.0
22.5	13273	1.81	75.10	16.01	110.3	1008.0

TEST NO.: S4. 3 FLOW PATTERN:BUBBLE

ML= 882 MG= 1.10 QFLUX= 18750 NUTP=152.4 HTP=1393 PDT= 0.813

PDF= 0.302 ALFA=0.399 XTT= 22.14 WE= 497.6 FR= 9.40 STN= 25.25

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.43	12830	827.8	16.9	6.52	0.710	3.41	3.10
OUTLET	77.55	13682	821.7	16.0	6.10	0.709	3.40	3.28
MEAN	74.99	13256	824.8	16.4	6.31	0.709	3.40	3.19

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	12900	3.11	72.85	12.84	160.0	1458.0
4.5	12988	3.13	73.38	13.35	153.9	1403.0
7.5	13094	3.16	74.02	13.60	151.0	1377.0
11.0	13218	3.18	74.77	13.66	150.3	1372.0
16.5	13414	3.23	75.95	13.47	152.2	1393.0
21.0	13575	3.26	76.91	13.39	153.1	1402.0
22.5	13628	3.28	77.23	13.46	152.2	1395.0

TEST NO.: S4. 4 FLOW PATTERN:BUBBLE

ML= 882 MG= 1.46 QFLUX= 22257 NUTP=176.7 HTP=1614 PDT= 0.831

PDF= 0.363 ALFA=0.451 XTT= 17.16 WE= 488.7 FR= 9.40 STN= 25.71

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	71.85	12735	1101.0	16.9	6.57	0.710	3.41	4.10
OUTLET	77.92	13745	1092.1	16.1	6.07	0.709	3.41	4.36
MEAN	74.89	13240	1097.0	16.5	6.32	0.709	3.40	4.23

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	12818	4.13	72.35	14.21	171.9	1564.0
4.5	12922	4.15	72.98	13.62	179.1	1632.0
7.5	13048	4.18	73.74	13.88	175.7	1602.0
11.0	13195	4.22	74.63	13.93	175.0	1598.0
16.5	13427	4.28	76.02	13.71	177.6	1624.0
21.0	13618	4.33	77.17	13.62	178.5	1635.0
22.5	13682	4.35	77.55	13.76	176.8	1620.0

TEST NO.: S4. 5 FLOW PATTERN:BUBBLE-SLUG

ML= 882 MG= 1.89 QFLUX= 25933 NUTP=199.8 HTP=1828 PDT= 0.883

PDF= 0.453 ALFA=0.494 XTT= 13.69 WF= 651.0 FR= 9.40 STN= 19.30

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.20	12793	1420.0	17.1	6.54	0.710	3.41	5.24
OUTLET	79.28	13974	1406.0	16.2	5.96	0.709	3.41	5.58
MEAN	75.74	13383	1413.2	16.7	6.25	0.709	3.40	5.41

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	12889	5.27	72.79	13.63	208.4	1898.0
4.5	13011	5.30	73.52	14.08	201.8	1840.0
7.5	13158	5.35	74.41	14.35	197.8	1806.0
11.0	13329	5.40	75.44	14.43	196.6	1797.0
16.5	13601	5.48	77.06	14.17	199.9	1832.0
21.0	13825	5.55	78.39	14.06	201.2	1847.0
22.5	13900	5.57	78.84	14.13	200.2	1839.0

TEST NO.: S4. 6 FLOW PATTERN:BUBBLE-SLUG

ML= 882 MG= 2.35 QFLUX= 25938 NUTP=200.0 HTP=1830 PDT= 0.836

PDF= 0.439 ALFA=0.534 XTT= 11.17 WF= 516.5 FR= 9.40 STN= 24.33

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.46	12835	1768.0	16.9	6.51	0.710	3.41	6.60
OUTLET	79.54	14018	1750.4	16.1	5.94	0.709	3.41	7.02
MEAN	76.00	13427	1759.4	16.5	6.22	0.709	3.40	6.82

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	12932	6.64	73.05	13.62	208.5	1900.0
4.5	13054	6.68	73.78	13.45	211.0	1925.0
7.5	13201	6.73	74.67	14.24	199.3	1820.0
11.0	13373	6.80	75.70	14.26	198.9	1819.0
16.5	13644	6.90	77.32	14.38	197.0	1806.0
21.0	13869	6.98	78.65	14.51	195.0	1790.0
22.5	13944	7.01	79.10	14.44	195.9	1799.0

TEST NO.: S4. 7 FLOW PATTERN:CHURN

ML= 882 MG= 2.79 QFLUX= 28281 NUTP=180.8 HTP=1655 PDT= 0.775

PDF= 0.403 ALFA=0.563 XTT= 9.53 WF= 492.3 FR= 9.40 STN= 25.52

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.45	12834	2099.0	16.8	6.51	0.710	3.41	7.91
OUTLET	80.17	14125	2076.1	16.0	5.89	0.709	3.41	8.40
MEAN	76.31	13480	2087.7	16.4	6.20	0.709	3.40	8.16

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	12940	7.95	73.09	16.18	191.3	1743.0
4.5	13073	8.00	73.90	16.89	183.3	1672.0
7.5	13233	8.06	74.86	17.18	180.0	1645.0
11.0	13420	8.13	75.99	17.30	178.6	1634.0
16.5	13717	8.25	77.76	17.22	179.3	1644.0
21.0	13962	8.35	79.21	17.03	181.1	1664.0
22.5	14044	8.38	79.69	17.17	179.5	1651.0

TEST NO.: S4. 8 FLOW PATTERN:CHURN-ANNULAR

ML= 882 MG= 4.87 QFLUX= 29480 NUTP=197.6 HTP=1809 PDT= 0.898

PDF= 0.594 ALFA=0.643 XTT= 5.83 WE= 488.8 FR= 9.40 STN= 25.71

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.43	12830	3660.0	17.1	6.51	0.710	3.41	13.51
OUTLET	80.47	14176	3617.9	16.2	5.87	0.709	3.41	14.44
MEAN	76.45	13503	3639.1	16.6	6.19	0.709	3.40	13.98

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	12941	13.58	73.10	15.48	208.5	1900.0
4.5	13079	13.68	73.93	16.11	200.3	1827.0
7.5	13246	13.80	74.94	16.32	197.5	1804.0
11.0	13441	13.93	76.11	16.42	196.2	1795.0
16.5	13751	14.16	77.95	16.44	195.6	1795.0
21.0	14006	14.34	79.47	16.35	196.5	1806.0
22.5	14091	14.41	79.97	16.44	195.4	1797.0

TEST NO.: S4. 9 FLOW PATTERN:CHURN-ANNULAR

ML= 882 MG= 9.48 QFLUX= 33140 NUTP=246.1 HTP=2253 PDT= 1.237

PDF= 1.000 ALFA=0.723 XTT= 3.25 WE= 427.1 FR= 9.40 STN= 29.42

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.03	12765	7134.0	17.8	6.54	0.710	3.41	25.26
OUTLET	81.06	14277	7041.9	16.6	5.83	0.709	3.41	27.52
MEAN	76.55	13521	7088.0	17.2	6.18	0.709	3.40	26.41

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	12889	25.44	72.78	14.23	255.0	2323.0
4.5	13044	25.67	73.72	14.80	245.0	2235.0
7.5	13231	25.95	74.85	15.00	241.6	2207.0
11.0	13450	26.29	76.17	14.87	243.5	2228.0
16.5	13798	26.83	78.24	14.65	246.7	2264.0
21.0	14085	27.29	79.93	14.43	250.1	2301.0
22.5	14181	27.45	80.50	14.51	248.6	2289.0

TEST NO.: S4.10 FLOW PATTERN:CHURN-ANNULAR

ML= 882 MG= 9.89 QFLUX= 34050 NUTP=252.4 HTP=2312 PDT= 1.281

PDF= 1.047 ALFA=0.726 XTT= 3.14 WE= 471.8 FR= 9.40 STN= 26.63

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.06	12770	7439.0	18.0	6.54	0.710	3.41	26.04
OUTLET	81.34	14324	7340.3	16.7	5.81	0.709	3.41	28.45
MEAN	76.70	13547	7389.8	17.4	6.17	0.709	3.40	27.26

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	12897	26.24	72.83	14.24	261.7	2384.0
4.5	13056	26.48	73.80	14.79	251.9	2298.0
7.5	13249	26.78	74.96	15.00	248.2	2267.0
11.0	13474	27.14	76.31	14.91	249.5	2283.0
16.5	13832	27.71	78.44	14.69	252.8	2321.0
21.0	14127	28.20	80.18	14.44	256.8	2362.0
22.5	14226	28.36	80.76	14.49	255.7	2354.0

TEST NO.: S4.11 FLOW PATTERN:ANNULAR

ML= 882 MG= 13.09 QFLUX= 37029 NUTP=272.9 HTP=2503 PDI= 1.455

PDF= 1.245 ALFA=0.754 XTT= 2.47 WE= 485.3 FR= 9.40 STN= 25.89

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.49	12840	9839.0	18.5	6.50	0.710	3.41	33.56
OUTLET	82.56	14534	9697.3	17.1	5.71	0.708	3.41	37.00
MEAN	77.52	13687	9768.1	17.8	6.10	0.709	3.41	35.30

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	12978	33.84	73.32	14.36	282.0	2571.0
4.5	13151	34.19	74.37	14.96	270.6	2470.0
7.5	13361	34.61	75.63	15.14	267.1	2443.0
11.0	13607	35.12	77.10	15.04	268.7	2462.0
16.5	13997	35.94	79.41	14.65	275.3	2530.0
21.0	14319	36.64	81.31	14.45	278.7	2568.0
22.5	14427	36.88	81.94	14.46	278.3	2567.0

TEST NO.: S4.12 FLOW PATTERN:ANNULAR

ML= 882 MG= 18.24 QFLUX= 38223 NUTP=311.1 HTP=2852 PDI= 1.787

PDF= 1.601 ALFA=0.783 XTT= 1.87 WE= 434.0 FR= 9.40 STN= 28.96

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.06	12769	13720.0	19.4	6.54	0.710	3.41	44.68
OUTLET	82.45	14514	13516.8	17.6	5.72	0.708	3.41	50.00
MEAN	77.25	13642	13618.8	18.5	6.12	0.709	3.40	47.37

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	12911	45.10	72.92	13.15	318.1	2899.0
4.5	13090	45.64	74.00	13.67	305.9	2792.0
7.5	13306	46.29	75.30	13.73	304.3	2781.0
11.0	13559	47.08	76.81	13.55	307.9	2820.0
16.5	13960	48.35	79.20	13.27	313.7	2882.0
21.0	14292	49.44	81.15	13.01	319.6	2944.0
22.5	14403	49.82	81.80	13.13	316.5	2918.0

TEST NO.: S4.13 FLOW PATTERN:ANNULAR

ML= 882 MG= 22.70 QFLUX= 41278 NUTP=328.7 HTP=3016 PDI= 1.991

PDF= 1.819 ALFA=0.800 XTT= 1.55 WE= 471.9 FR= 9.40 STN= 26.63

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.29	12807	17073.0	20.0	6.51	0.710	3.41	53.84
OUTLET	83.49	14694	16800.5	18.0	5.65	0.708	3.41	60.80
MEAN	77.89	13751	16937.0	19.0	6.07	0.709	3.41	57.34

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	12961	54.38	73.22	13.33	338.6	3086.0
4.5	13153	55.08	74.38	13.80	327.0	2985.0
7.5	13386	55.93	75.78	14.01	321.7	2943.0
11.0	13660	56.96	77.42	13.96	322.6	2957.0
16.5	14094	58.63	79.99	13.53	332.0	3054.0
21.0	14454	60.06	82.09	13.36	335.6	3096.0
22.5	14574	60.55	82.80	13.35	335.8	3101.0

TEST NO.: S4.14 FLOW PATTERN:ANNULAR

ML= 882 MG= 25.49 QFLUX= 41545 NUTP=337.6 HTP=3096 PDT= 2.225

PDF= 2.061 ALFA=0.808 XTT= 1.41 WE= 441.1 FR= 9.40 STN= 28.49

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	71.92	12748	19177.0	20.4	6.55	0.710	3.41	59.21
OUTLET	83.19	14643	18868.5	18.2	5.67	0.708	3.41	67.57
MEAN	77.56	13695	19022.9	19.3	6.10	0.709	3.41	63.40

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	12902	59.86	72.86	13.01	349.4	3183.0
4.5	13095	60.69	74.03	13.53	335.7	3063.0
7.5	13329	61.71	75.44	13.69	331.6	3032.0
11.0	13604	62.94	77.08	13.68	331.4	3037.0
16.5	14040	64.95	79.67	13.29	340.3	3129.0
21.0	14401	66.68	81.79	13.10	344.6	3178.0
22.5	14522	67.27	82.49	13.21	341.6	3153.0

TEST NO.: S4.15 FLOW PATTERN:ANNULAR

ML= 882 MG= 48.32 QFLUX= 46797 NUTP=420.0 HTP=3858 PDT= 3.313

PDF= 3.181 ALFA=0.846 XTT= 0.86 WE= 471.9 FR= 9.41 STN= 26.63

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.41	12828	36332.0	24.4	6.50	0.710	3.41	94.14
OUTLET	85.03	14960	35680.1	21.0	5.54	0.708	3.41	110.93
MEAN	78.72	13894	36006.2	22.7	6.00	0.709	3.41	102.49

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	13001	95.41	73.46	11.81	433.1	3949.0
4.5	13218	97.04	74.77	12.40	412.0	3763.0
7.5	13481	99.05	76.35	12.60	405.0	3708.0
11.0	13790	101.49	78.19	12.67	402.3	3691.0
16.5	14281	105.55	81.08	12.45	408.4	3763.0
21.0	14687	109.09	83.45	10.41	487.1	4502.0
22.5	14824	110.31	84.25	12.43	408.2	3776.0

TEST NO.: S4.16 FLOW PATTERN:ANNULAR-MIST

ML= 882 MG= 91.48 QFLUX= 48364 NUTP=449.6 HTP=4129 PDT= 4.900

PDF= 4.789 ALFA=0.873 XTT= 0.55 WE= 488.9 FR= 9.41 STN= 25.71

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.36	12819	68788.0	31.6	6.50	0.710	3.41	137.33
OUTLET	85.25	14998	67527.0	26.7	5.52	0.708	3.41	165.40
MEAN	78.80	13909	68157.6	29.1	6.00	0.709	3.41	151.19

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	12996	139.41	73.43	10.44	506.1	4615.0
4.5	13218	142.08	74.77	11.14	474.0	4330.0
7.5	13486	145.41	76.38	11.51	458.2	4195.0
11.0	13801	149.48	78.26	11.86	444.1	4076.0
16.5	14303	156.27	81.21	12.04	436.7	4023.0
21.0	14719	162.26	83.64	12.19	430.7	3981.0
22.5	14859	164.34	84.45	12.41	422.6	3911.0

TEST NO.: S4.17 FLOW PATTERN:ANNULAR-MIST

ML= 882 MG=133.53 QFLUX= 48355 NUTP=451.6 HTP=4144 PDT= 6.169

PDF= 6.069 ALFA=0.885 XTT= 0.43 WE= 503.3 FR= 9.41 STN= 24.97

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.10	12777	100444.0	38.1	6.52	0.710	3.41	166.18
OUTLET	84.84	14928	98622.4	31.9	5.55	0.708	3.41	201.67
MEAN	78.47	13852	99533.6	35.0	6.02	0.709	3.41	183.66

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	12951	168.79	73.16	9.55	553.1	5041.0
4.5	13170	172.15	74.48	10.51	502.1	4584.0
7.5	13435	176.34	76.07	11.14	473.4	4332.0
11.0	13746	181.47	77.93	11.76	447.9	4109.0
16.5	14242	190.07	80.85	12.43	423.1	3896.0
21.0	14653	197.67	83.25	12.97	405.1	3743.0
22.5	14791	200.32	84.05	13.12	400.3	3702.0

TEST NO.: S4.18 FLOW PATTERN:ANNULAR-MIST

ML= 882 MG=170.04 QFLUX= 48375 NUTP=421.1 HTP=3863 PDT= 6.973

PDF= 6.879 ALFA=0.892 XTT= 0.37 WE= 516.7 FR= 9.41 STN= 24.33

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	71.92	12748	127942.0	44.1	6.54	0.710	3.41	182.77
OUTLET	84.55	14877	125640.6	37.1	5.57	0.708	3.41	220.80
MEAN	78.24	13813	126791.5	40.6	6.04	0.709	3.41	201.53

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	12920	185.57	72.97	10.26	515.0	4693.0
4.5	13137	189.19	74.28	10.47	503.9	4601.0
7.5	13399	193.69	75.86	11.47	459.9	4207.0
11.0	13707	199.19	77.70	12.59	418.7	3840.0
16.5	14198	208.41	80.60	13.84	380.3	3501.0
21.0	14605	216.53	82.97	14.85	354.2	3272.0
22.5	14741	219.36	83.77	15.24	344.9	3189.0

TEST NO.: S4.19 FLOW PATTERN:ANNULAR-MIST

ML= 882 MG=188.02 QFLUX= 48372 NUTP=413.2 HTP=3788 PDT= 7.438

PDF= 7.346 ALFA=0.895 XTT= 0.35 WE= 516.6 FR= 9.40 STN= 24.33

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	71.55	12687	141545.0	46.6	6.58	0.710	3.41	191.11
OUTLET	84.12	14802	139008.5	39.2	5.60	0.708	3.41	231.26
MEAN	77.84	13745	140277.0	42.9	6.08	0.709	3.41	210.90

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	12858	194.07	72.59	9.12	579.1	5275.0
4.5	13073	197.88	73.90	10.55	500.6	4567.0
7.5	13333	202.63	75.46	11.70	450.9	4123.0
11.0	13640	208.43	77.30	12.98	406.3	3724.0
16.5	14127	218.16	80.18	14.49	363.6	3345.0
21.0	14532	226.74	82.55	15.62	337.0	3110.0
22.5	14667	229.74	83.34	16.01	328.6	3037.0

TEST NO.: S5. 1 FLOW PATTERN:BUBBLE

ML=2698 MG= 0.56 QFLUX= 30512 NUTP=262.6 HTP=2398 PDT= 1.695

PDF= 0.946 ALFA=0.121 XTT=113.73 WE= 4744.0 FR= 87.95 STN= 24.79

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	73.06	39574	421.3	18.0	6.47	0.710	10.42	1.48
OUTLET	75.78	40957	419.6	16.3	6.25	0.709	10.42	1.64
MEAN	74.42	40265	420.5	17.2	6.36	0.709	10.41	1.56

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	39688	1.49	73.29	12.32	271.5	2475.0
4.5	39832	1.51	73.57	12.66	264.2	2410.0
7.5	40004	1.53	73.91	12.88	259.5	2368.0
11.0	40206	1.55	74.31	12.83	260.5	2378.0
16.5	40523	1.59	74.93	12.73	262.4	2398.0
21.0	40783	1.62	75.44	12.65	264.1	2414.0
22.5	40870	1.63	75.61	12.68	263.3	2408.0

TEST NO.: S5. 2 FLOW PATTERN:BUBBLE

ML=2698 MG= 1.07 QFLUX= 30503 NUTP=267.6 HTP=2443 PDT= 1.740

PDF= 1.055 ALFA=0.195 XTT= 64.41 WE= 5023.0 FR= 87.95 STN= 23.41

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.79	39439	805.5	18.5	6.50	0.710	10.42	2.75
OUTLET	75.51	40820	802.3	16.8	6.27	0.709	10.42	3.04
MEAN	74.15	40129	803.9	17.6	6.38	0.709	10.41	2.89

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	39553	2.77	73.02	12.02	278.1	2534.0
4.5	39696	2.80	73.30	12.41	269.5	2457.0
7.5	39869	2.84	73.64	12.66	264.2	2409.0
11.0	40070	2.88	74.04	12.59	265.4	2422.0
16.5	40387	2.95	74.66	12.48	267.6	2444.0
21.0	40647	3.01	75.18	12.43	268.6	2455.0
22.5	40733	3.03	75.35	12.45	268.3	2453.0

TEST NO.: S5. 3 FLOW PATTERN:BUBBLE

ML=2698 MG= 1.49 QFLUX= 32694 NUTP=285.0 HTP=2601 PDT= 1.817

PDF= 1.173 ALFA=0.243 XTT= 48.05 WE= 4573.0 FR= 87.95 STN= 25.71

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.57	39327	1120.0	18.7	6.52	0.710	10.42	3.78
OUTLET	75.49	40806	1116.2	16.9	6.27	0.709	10.42	4.20
MEAN	74.03	40066	1118.6	17.8	6.40	0.709	10.41	3.99

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	39449	3.82	72.81	12.09	296.5	2701.0
4.5	39602	3.86	73.12	12.49	287.1	2616.0
7.5	39787	3.91	73.48	12.76	281.0	2562.0
11.0	40002	3.97	73.91	12.69	282.5	2577.0
16.5	40342	4.07	74.58	12.57	284.8	2601.0
21.0	40620	4.16	75.12	12.49	286.7	2620.0
22.5	40713	4.19	75.31	12.51	286.2	2616.0

TEST NO.: S5. 4 FLOW PATTERN:BUBBLE-FROTH

ML=2698 MG= 1.91 QFLUX= 35535 NUTP=284.4 HTP=2600 PDT= 1.844

PDF= 1.234 ALFA=0.283 XTT= 38.48 WE= 4744.0 FR= 87.97 STN= 24.79

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	73.85	39974	1436.0	18.9	6.40	0.709	10.42	4.81
OUTLET	77.02	41591	1429.8	17.1	6.14	0.709	10.42	5.35
MEAN	75.44	40782	1433.1	18.0	6.27	0.709	10.42	5.08

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	40108	4.85	74.11	12.96	300.1	2739.0
4.5	40275	4.91	74.44	13.51	287.9	2629.0
7.5	40477	4.97	74.84	13.86	280.6	2563.0
11.0	40712	5.05	75.30	13.77	282.3	2580.0
16.5	41084	5.18	76.03	13.73	282.9	2588.0
21.0	41388	5.29	76.63	13.66	284.3	2603.0
22.5	41490	5.33	76.83	13.60	285.5	2615.0

TEST NO.: S5. 5 FLOW PATTERN:BUBBLE-FROTH

ML=2698 MG= 2.42 QFLUX= 35530 NUTP=277.7 HTP=2537 PDT= 1.908

PDF= 1.329 ALFA=0.321 XTT= 31.45 WE= 5337.0 FR= 87.96 STN= 22.03

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	73.32	39705	1815.0	19.2	6.45	0.710	10.42	5.98
OUTLET	76.49	41318	1807.6	17.3	6.19	0.709	10.42	6.65
MEAN	74.90	40511	1811.7	18.3	6.32	0.709	10.42	6.32

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	39838	6.03	73.58	13.19	295.0	2690.0
4.5	40005	6.10	73.91	13.80	281.9	2572.0
7.5	40206	6.18	74.31	14.29	272.4	2487.0
11.0	40441	6.28	74.77	14.13	275.2	2514.0
16.5	40812	6.44	75.50	14.02	277.3	2535.0
21.0	41115	6.58	76.09	14.06	276.5	2530.0
22.5	41217	6.63	76.29	13.96	278.2	2547.0

TEST NO.: S5. 6 FLOW PATTERN:BUBBLE-FROTH

ML=2698 MG= 2.82 QFLUX= 36851 NUTP=286.2 HTP=2616 PDT= 1.962

PDF= 1.406 ALFA=0.346 XTT= 27.49 WE= 4493.0 FR= 87.97 STN= 26.17

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	73.71	39905	2119.0	19.5	6.41	0.709	10.42	6.90
OUTLET	77.00	41582	2109.1	17.5	6.14	0.709	10.42	7.69
MEAN	75.36	40743	2114.2	18.5	6.28	0.709	10.42	7.30

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	40044	6.96	73.99	13.15	306.8	2799.0
4.5	40217	7.04	74.33	13.77	293.0	2674.0
7.5	40426	7.14	74.74	14.28	282.5	2580.0
11.0	40671	7.25	75.22	14.20	283.9	2594.0
16.5	41055	7.44	75.98	14.19	284.0	2598.0
21.0	41371	7.61	76.59	14.22	283.2	2593.0
22.5	41477	7.66	76.80	14.22	283.2	2594.0

TEST NO.: S5. 7 FLOW PATTERN:SLUG-FROTH

ML=2698 MG= 5.13 QFLUX= 36805 NUTP=318.1 HTP=2905 PDT= 2.293

PDF= 1.816 ALFA=0.440 XTT= 16.74 WE= 4833.0 FR= 87.96 STN= 24.33

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.87	39478	3850.0	21.1	6.49	0.710	10.42	11.52
OUTLET	76.15	41145	3832.3	18.8	6.22	0.709	10.42	12.95
MEAN	74.51	40311	3841.4	20.0	6.35	0.709	10.41	12.24

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	39615	11.63	73.14	11.59	347.9	3171.0
4.5	39788	11.77	73.48	12.33	327.0	2982.0
7.5	39996	11.95	73.89	12.69	317.7	2898.0
11.0	40239	12.16	74.37	12.84	314.0	2867.0
16.5	40622	12.51	75.13	12.85	313.5	2865.0
21.0	40936	12.80	75.74	12.84	313.5	2868.0
22.5	41041	12.90	75.95	12.90	312.3	2857.0

TEST NO.: S5. 8 FLOW PATTERN:SLUG-FROTH

ML=2698 MG= 9.64 QFLUX= 43146 NUTP=389.0 HTP=3554 PDT= 3.191

PDF= 2.791 ALFA=0.531 XTT= 10.02 WE= 4266.0 FR= 87.96 STN= 27.56

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.90	39495	7246.0	24.0	6.48	0.710	10.42	19.11
OUTLET	76.75	41452	7205.8	20.8	6.17	0.709	10.42	22.09
MEAN	74.83	40474	7226.0	22.4	6.32	0.709	10.42	20.59

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	39657	19.33	73.22	11.45	412.9	3764.0
4.5	39859	19.62	73.62	11.99	394.2	3595.0
7.5	40103	19.98	74.10	12.20	387.4	3536.0
11.0	40388	20.42	74.67	12.31	383.7	3505.0
16.5	40837	21.14	75.55	12.21	386.7	3536.0
21.0	41206	21.76	76.27	12.16	388.1	3552.0
22.5	41330	21.98	76.51	12.18	387.2	3545.0

TEST NO.: S5. 9 FLOW PATTERN:ANNULAR-FROTH

ML=2698 MG= 13.46 QFLUX= 43722 NUTP=410.1 HTP=3748 PDT= 3.630

PDF= 3.270 ALFA=0.577 XTT= 7.60 WE= 4493.0 FR= 87.97 STN= 26.17

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	73.25	39671	10107.0	25.3	6.45	0.710	10.42	25.26
OUTLET	77.15	41656	10051.0	21.7	6.13	0.709	10.42	29.54
MEAN	75.20	40663	10079.4	23.5	6.29	0.709	10.42	27.38

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	39835	25.58	73.57	10.94	437.4	3989.0
4.5	40040	25.99	73.98	11.48	416.9	3804.0
7.5	40287	26.51	74.47	11.73	408.2	3727.0
11.0	40576	27.13	75.04	11.81	405.1	3702.0
16.5	41032	28.16	75.93	11.74	407.3	3726.0
21.0	41407	29.07	76.66	11.72	407.7	3733.0
22.5	41532	29.38	76.91	11.76	406.4	3723.0

TEST NO.: S5.10 FLOW PATTERN:ANNULAR-FROTH

ML=2698 MG= 16.96 QFLUX= 45497 NUTP=414.9 HTP=3794 PDT= 4.265

PDF= 3.926 ALFA=0.602 XTT= 6.39 WE= 3997.0 FR= 87.98 STN= 29.42

	TMIX	RESI	RESG	P	PRL	PRG	VSL	VSG
INLET	73.51	39802	12734.0	27.3	6.43	0.709	10.42	29.52
OUTLET	77.57	41871	12660.5	23.1	6.10	0.709	10.42	35.04
MEAN	75.54	40836	12697.8	25.2	6.26	0.709	10.42	32.25

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	39973	29.93	73.85	11.18	445.6	4065.0
4.5	40187	30.46	74.27	11.79	422.2	3854.0
7.5	40444	31.11	74.78	12.05	413.2	3775.0
11.0	40745	31.91	75.37	12.14	409.9	3747.0
16.5	41221	33.25	76.30	12.09	411.2	3764.0
21.0	41611	34.42	77.06	12.05	412.6	3780.0
22.5	41741	34.83	77.31	12.18	408.1	3741.0

TEST NO.: S5.11 FLOW PATTERN:ANNULAR-FROTH

ML=2698 MG= 20.40 QFLUX= 46684 NUTP=446.4 HTP=4084 PDT= 4.537

PDF= 4.215 ALFA=0.623 XTT= 5.54 WE= 3874.0 FR= 87.98 STN= 30.35

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	73.77	39935	15305.0	28.7	6.40	0.709	10.42	33.84
OUTLET	77.93	42060	15213.6	24.1	6.07	0.709	10.42	40.27
MEAN	75.85	40997	15259.4	26.4	6.23	0.709	10.42	37.01

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	40110	34.32	74.12	10.69	477.9	4362.0
4.5	40330	34.93	74.55	11.25	454.0	4146.0
7.5	40595	35.69	75.07	11.51	443.5	4053.0
11.0	40904	36.62	75.68	11.58	440.7	4031.0
16.5	41392	38.18	76.63	11.52	442.7	4054.0
21.0	41793	39.55	77.42	11.47	444.6	4076.0
22.5	41927	40.03	77.68	11.49	443.5	4067.0

TEST NO.: S5.12 FLOW PATTERN:ANNULAR-FROTH

ML=2698 MG= 23.40 QFLUX= 46548 NUTP=457.1 HTP=4180 PDT= 4.900

PDF= 4.589 ALFA=0.636 XTT= 5.00 WE= 3649.0 FR= 87.98 STN= 32.23

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	73.51	39799	17570.0	30.0	6.43	0.709	10.42	37.07
OUTLET	77.65	41915	17465.0	25.1	6.09	0.709	10.42	44.36
MEAN	75.58	40857	17517.5	27.6	6.26	0.709	10.42	40.66

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	39974	37.60	73.85	10.34	492.5	4493.0
4.5	40193	38.29	74.28	10.96	464.6	4242.0
7.5	40456	39.15	74.80	11.20	454.9	4155.0
11.0	40764	40.21	75.41	11.32	449.7	4112.0
16.5	41250	41.98	76.36	11.22	453.3	4150.0
21.0	41649	43.54	77.14	11.15	456.1	4179.0
22.5	41782	44.09	77.39	11.24	452.3	4146.0

TEST NO.: S5.13 FLOW PATTERN:ANNULAR-FROTH

ML=2698 MG= 23.36 QFLUX= 46818 NUTP=458.4 HTP=4198 PDT= 4.945

PDF= 4.635 ALFA=0.637 XTT= 4.99 WE= 4416.0 FR= 88.00 STN= 26.63

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	74.56	40334	17510.0	29.9	6.33	0.709	10.42	37.20
OUTLET	78.73	42471	17405.4	25.0	6.00	0.709	10.42	44.62
MEAN	76.65	41403	17458.0	27.4	6.17	0.709	10.42	40.85

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	40510	37.74	74.91	10.35	494.4	4517.0
4.5	40731	38.44	75.34	10.97	466.6	4266.0
7.5	40997	39.32	75.86	11.19	457.0	4180.0
11.0	41309	40.39	76.47	11.31	452.0	4138.0
16.5	41800	42.19	77.43	11.24	454.7	4168.0
21.0	42203	43.78	78.21	11.23	454.6	4172.0
22.5	42338	44.34	78.47	11.30	451.8	4147.0

TEST NO.: S5.14 FLOW PATTERN:ANNULAR-FROTH

ML=2698 MG= 25.79 QFLUX= 46072 NUTP=463.7 HTP=4243 PDT= 5.172

PDF= 4.870 ALFA=0.647 XTT= 4.63 WE= 4415.0 FR= 87.99 STN= 26.63

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	73.90	39998	19352.0	30.8	6.39	0.709	10.42	39.88
OUTLET	78.00	42095	19237.9	25.6	6.06	0.709	10.42	48.00
MEAN	75.95	41047	19295.1	28.2	6.23	0.709	10.42	43.87

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	40171	40.48	74.24	10.11	498.7	4552.0
4.5	40388	41.24	74.67	10.68	472.0	4311.0
7.5	40649	42.20	75.18	10.95	460.3	4207.0
11.0	40954	43.37	75.78	11.01	457.4	4183.0
16.5	41436	45.34	76.72	10.95	459.8	4211.0
21.0	41832	47.08	77.49	10.88	462.3	4239.0
22.5	41964	47.69	77.75	10.94	459.6	4215.0

TEST NO.: S5.15 FLOW PATTERN:ANNULAR

ML=2698 MG= 43.86 QFLUX= 49663 NUTP=517.3 HTP=4740 PDT= 6.468

PDF= 6.209 ALFA=0.697 XTT= 3.08 WE= 4416.0 FR= 88.01 STN= 26.63

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	74.90	40504	32860.0	35.9	6.30	0.709	10.42	58.21
OUTLET	79.31	42772	32652.1	29.4	5.95	0.709	10.42	71.07
MEAN	77.10	41638	32756.3	32.7	6.13	0.709	10.42	64.51

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	40691	59.13	75.26	9.53	569.4	5205.0
4.5	40926	60.34	75.72	10.25	529.4	4842.0
7.5	41208	61.84	76.27	10.53	515.0	4714.0
11.0	41538	63.68	76.92	10.69	507.2	4647.0
16.5	42059	66.81	77.93	10.61	510.6	4684.0
21.0	42487	69.60	78.76	10.53	514.3	4723.0
22.5	42630	70.57	79.04	10.57	512.1	4705.0

TEST NO.: S5.16 FLOW PATTERN:ANNULAR

ML=2698 MG= 98.03 QFLUX= 49630 NUTP=561.4 HTP=5142 PDT= 8.752

PDF= 8.541 ALFA=0.754 XTT= 1.74 WE= 4575.0 FR= 88.00 STN= 25.71

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	74.60	40353	73472.0	48.7	6.33	0.709	10.42	95.86
OUTLET	78.99	42605	73008.4	40.0	5.98	0.709	10.42	116.99
MEAN	76.79	41479	73240.4	44.3	6.15	0.709	10.42	106.20

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	40538	97.38	74.96	8.42	644.0	5884.0
4.5	40771	99.35	75.42	9.19	590.2	5397.0
7.5	41051	101.82	75.97	9.61	563.9	5160.0
11.0	41379	104.85	76.61	9.84	550.7	5043.0
16.5	41897	109.99	77.62	9.92	545.9	5006.0
21.0	42322	114.56	78.44	9.95	544.0	4994.0
22.5	42464	116.17	78.72	9.94	544.3	4999.0

TEST NO.: S6. 1 FLOW PATTERN:BUBBLE

ML=5397 MG= 0.47 QFLUX= 52060 NUTP=458.9 HTP=4188 PDT= 3.590

PDF= 2.779 ALFA=0.047 XTT=274.58 WE= 20493.0 FR=351.00 STN= 22.95

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	72.88	78967	352.7	22.6	6.49	0.710	20.84	0.99
OUTLET	75.21	81323	351.5	19.1	6.30	0.709	20.83	1.17
MEAN	74.05	80145	352.1	20.8	6.39	0.709	20.83	1.07

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	79162	1.00	73.08	12.08	472.6	4307.0
4.5	79407	1.02	73.32	12.34	462.6	4217.0
7.5	79701	1.04	73.61	12.52	455.8	4157.0
11.0	80044	1.06	73.95	12.55	454.8	4150.0
16.5	80585	1.11	74.48	12.43	458.9	4191.0
21.0	81028	1.15	74.92	12.41	459.5	4198.0
22.5	81176	1.16	75.06	12.42	458.9	4194.0

TEST NO.: S6. 2 FLOW PATTERN:BUBBLE

ML=5397 MG= 1.09 QFLUX= 52384 NUTP=469.8 HTP=4299 PDT= 3.721

PDF= 2.954 ALFA=0.098 XTT=129.53 WE= 18296.0 FR=351.00 STN= 25.71

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	74.83	80937	815.8	23.1	6.31	0.709	20.84	2.24
OUTLET	77.17	83327	813.0	19.4	6.13	0.709	20.84	2.67
MEAN	76.00	82132	814.4	21.3	6.22	0.709	20.83	2.45

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	81135	2.27	75.02	11.77	486.8	4448.0
4.5	81383	2.31	75.27	12.03	476.3	4354.0
7.5	81681	2.36	75.56	12.22	468.9	4288.0
11.0	82030	2.43	75.90	12.26	467.1	4273.0
16.5	82578	2.53	76.44	12.39	462.1	4231.0
21.0	83028	2.62	76.88	12.07	474.2	4344.0
22.5	83178	2.65	77.02	12.11	472.4	4328.0

TEST NO.: S6. 3 FLOW PATTERN:BUBBLE

ML=5397 MG= 1.50 OFIUX= 55713 NUTP=487.5 HTP=4461 PDT= 3.993

PDF= 3.249 ALFA=0.125 XTT= 98.75 WE= 20497.0 FR=351.00 STN= 22.95

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	74.78	80892	1123.0	24.0	6.32	0.709	20.84	2.98
OUTLET	77.27	83434	1119.1	20.0	6.12	0.709	20.84	3.57
MEAN	76.03	82163	1121.1	22.0	6.22	0.709	20.83	3.27

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	81102	3.02	74.99	12.24	497.7	4548.0
4.5	81366	3.08	75.25	12.43	490.0	4479.0
7.5	81683	3.15	75.56	12.51	487.1	4454.0
11.0	82053	3.23	75.92	12.62	482.4	4414.0
16.5	82637	3.37	76.49	12.53	486.0	4450.0
21.0	83115	3.50	76.96	12.36	492.4	4511.0
22.5	83275	3.54	77.12	12.57	483.9	4434.0

TEST NO.: S6. 4 FLOW PATTERN:FROTH

ML=5397 MG= 1.95 OFIUX= 55810 NUTP=490.0 HTP=4481 PDT= 4.147

PDF= 3.424 ALFA=0.150 XTT= 79.30 WE= 15495.0 FR=351.00 STN= 30.35

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	74.39	80487	1463.0	24.8	6.35	0.709	20.84	3.74
OUTLET	76.88	83029	1457.8	20.7	6.15	0.709	20.84	4.48
MEAN	75.63	81758	1460.4	22.8	6.25	0.709	20.83	4.11

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	80697	3.80	74.59	12.18	501.3	4578.0
4.5	80961	3.87	74.85	12.35	494.4	4517.0
7.5	81278	3.95	75.16	12.46	490.2	4480.0
11.0	81649	4.06	75.53	12.57	485.5	4440.0
16.5	82232	4.24	76.10	12.50	488.3	4468.0
21.0	82711	4.40	76.57	12.41	491.4	4500.0
22.5	82871	4.46	76.72	12.54	486.2	4453.0

TEST NO.: S6. 5 FLOW PATTERN:FROTH

ML=5397 MG= 2.38 OFLUX= 56238 NUTP=487.8 HTP=4457 PDT= 4.206

PDF= 3.503 ALFA=0.174 XTT= 66.68 WE= 12729.0 FR=351.00 STN= 36.95

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	73.63	79725	1788.0	25.1	6.42	0.709	20.84	4.52
OUTLET	76.14	82278	1782.1	20.9	6.22	0.709	20.83	5.42
MEAN	74.89	81001	1785.4	23.0	6.32	0.709	20.83	4.96

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	79936	4.58	73.84	12.26	502.4	4584.0
4.5	80201	4.67	74.10	12.52	491.9	4489.0
7.5	80519	4.77	74.42	12.72	484.1	4420.0
11.0	80891	4.90	74.78	12.76	482.5	4407.0
16.5	81478	5.12	75.36	12.63	487.3	4455.0
21.0	81958	5.32	75.83	12.54	490.5	4487.0
22.5	82119	5.38	75.99	12.60	488.3	4468.0

TEST NO.: S6. 6 FLOW PATTERN:FROTH

ML=5397 MG= 2.60 QFIUX= 57960 NUTP=490.8 HTP=4488 PDT= 4.265

PDF= 3.570 ALFA=0.183 XTT= 62.05 WE= 12730.0 FR=351.00 STN= 36.95

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	74.21	80307	1947.0	25.4	6.37	0.709	20.84	4.86
OUTLET	76.79	82945	1940.7	21.2	6.16	0.709	20.84	5.83
MEAN	75.50	81626	1944.3	23.3	6.26	0.709	20.83	5.34

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	80525	4.93	74.42	12.54	505.9	4619.0
4.5	80799	5.02	74.69	12.85	493.8	4510.0
7.5	81128	5.14	75.02	13.03	486.9	4449.0
11.0	81512	5.28	75.39	13.03	486.5	4448.0
16.5	82118	5.51	75.99	12.92	490.5	4488.0
21.0	82615	5.72	76.47	12.85	493.0	4514.0
22.5	82781	5.79	76.63	12.91	490.6	4493.0

TEST NO.: S6. 7 FLOW PATTERN:FROTH

ML=5397 MG= 2.92 QFIUX= 58103 NUTP=494.9 HTP=4525 PDT= 4.405

PDF= 3.721 ALFA=0.196 XTT= 56.48 WE= 12106.0 FR=351.00 STN= 38.85

	TMIX	RESL	RESG	P	PRL	PRG	VSL	VSG
INLET	74.12	80217	2192.0	26.1	6.38	0.709	20.84	5.34
OUTLET	76.71	82861	2184.8	21.7	6.17	0.709	20.84	6.41
MEAN	75.42	81539	2188.9	23.9	6.27	0.709	20.83	5.86

Z	RESL	VSG	TBULK	(TW-TB)	NUTP	HTP
2.0	80436	5.41	74.34	12.47	509.8	4655.0
4.5	80710	5.51	74.61	12.74	498.8	4556.0
7.5	81040	5.64	74.93	12.94	491.1	4487.0
11.0	81425	5.80	75.31	12.94	491.1	4489.0
16.5	82031	6.06	75.90	12.88	493.1	4511.0
21.0	82529	6.29	76.39	12.75	497.7	4556.0
22.5	82695	6.37	76.55	12.80	495.7	4539.0