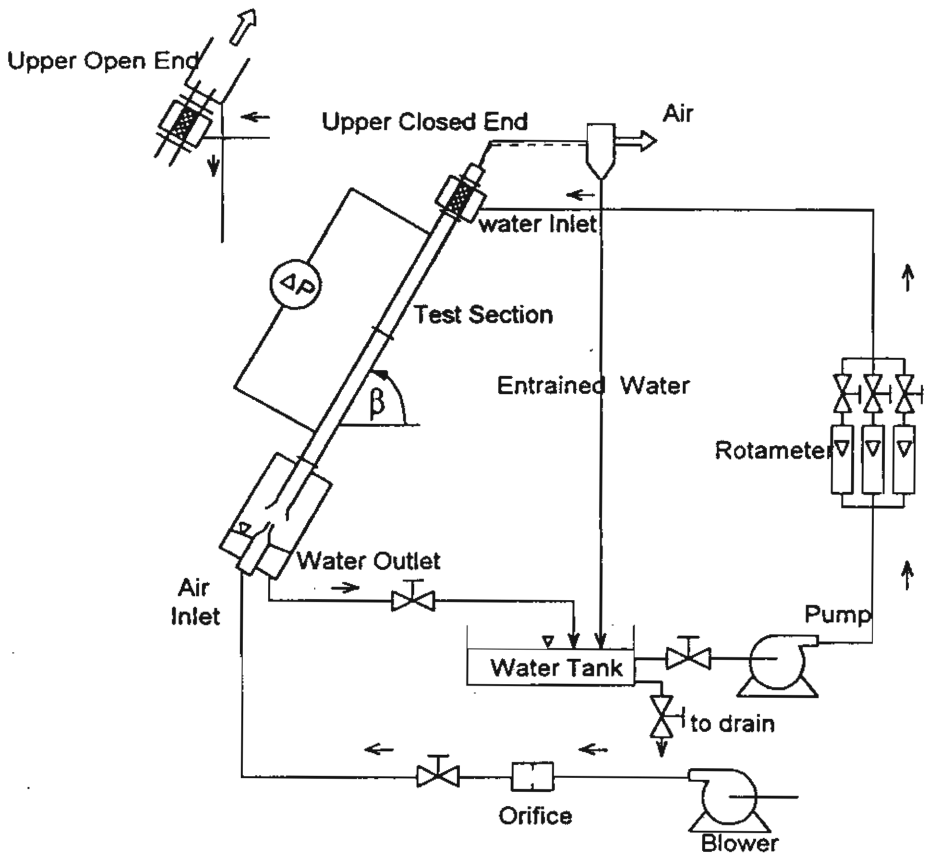

Figure 2. Schematic diagram of experimental apparatus

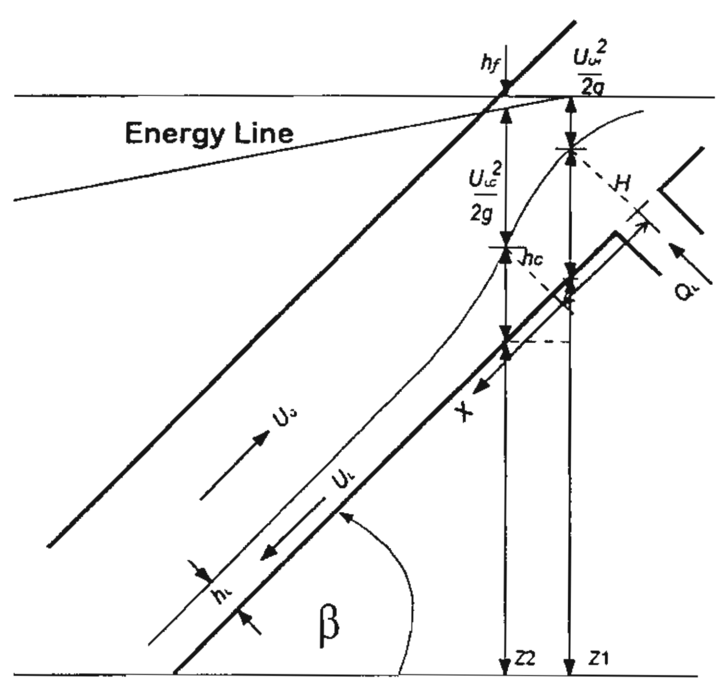

Figure 3. Local disturbance at the water inlet section

3. Analytical Model

For comparison with the experimental results, the theoretical flooding curves will be derived to show the curves as functions of the gas and liquid superficial velocities. Barnea et al. [7] presented a model based on a local disturbance generated at the liquid entrance. The model will be modified for this study.The flow phenomenon which is used as the basis for the calculation is shown in Fig. 3. Water is ejected through the water inlet section in the radial direction. The water film thickness at this position, therefore, increases and the air passage is restricted. Because the water flow along the inclined pipe is accelerated by gravity, the film thickness is gradually decreased until an equilibrium film thickness is reached. The reduction of the cross sectional area of air flow caused by large film thickness at the water inlet section creates higher air flow in the vicinity of this position and lead to the blowing up of the wave crests. At first, consider the specific energy which is defined as the energy of the fluid referred to the bottom of the channel as the datum. The specific energy, E at any section is given by

$$E = y + \frac{(Q/A)^2}{2g}$$

If the specific energy equation is differentiated and set equal to zero, critical velocity is obtained; then

$$\frac{dE}{dy} = 1 - \frac{Q^2}{gA^3}\frac{dA}{dy} = 0$$

$$U_C = \left(\frac{gA}{S_i}\right)^{1/2}$$

Because the pipe is inclined, the above equation is , therefore, modified to

$$U_C = \left(\frac{gA_L}{S_i\cos(\beta)}\right)^{1/2}$$

which $$S_i = D\sqrt{1-\left(\frac{2h_C}{D}-1\right)^2}$$

The values of A_L and S_i at the critical position are determined by assuming the critical level (h_c).

Taitel and Dukler [14] considered growth of a solitary wave in stratified flow and suggested the following slugging criterion:

$$U_G > \left(1-\frac{h_L}{D}\right)\left[\frac{(\rho_L-\rho_G)g\cos(\beta)A_G}{\rho_G\frac{dA_L}{dh_L}}\right]^{1/2}$$

The above criterion is used to determine the gas velocity at the oneset of flooding. The liquid level h_L in the criterion is replaced by the water level at inlet section, H. The value of H is calculated from the modified Bernoulli's equation which is taken between the inlet of the test section and the critical position as follows:

$$\frac{H}{\cos\beta} + Z_1 + \frac{P_H}{\rho g} + \frac{\alpha U_H^2}{2g} = \frac{h_C}{\cos\beta} + Z_2 + \frac{P_C}{\rho g} + \frac{\alpha U_C^2}{2g} + h_{fc}$$

The present flooding curves show the relationship between the square root of the dimensionless superficial velocity of water $(j_L^*)^{1/2}$ with the square root of the dimensionless superficial velocity of air $(j_G^*)^{1/2}$. The variables j_L^* , j_G^* are defined by

$$j_k^* = j_k\left[\frac{\rho_k}{(\rho_L-\rho_G)gD}\right]^{1/2}, \qquad j_k = \frac{U_k A_k}{A}$$

where j_k and ρ_k denote the superficial velocity and density, respectively, of phase k; g is the gravitational acceleration; and D is the pipe diameter.

4. Results and Discussion

The CCFL is determined by keeping the injected water flow rates constant, while the air flow rate is increased in small increments up to the onset of flooding. Flooding is observed visually in conjuction with the pressure drop. For small air flow rates, the water flows downward from the water inlet section through the test section to the storage tank. In this case the superficial velocities of the water phase at the water inlet and water outlet section are equal. As the air flow rate is gradually increased, the pressure drop of two-phase flow increases slightly. At the onset of flooding, due to instabilities at the interface, slugging occurrs and the pressure drop suddenly increases. The slugs carry a fraction of the injected water to the upper end section; the water flow at the water outlet section is thus smaller, and afterwards the pressure drop decreases.

Typical flooding curves connecting all points of the onset of flooding are shown in Figs. 4 to 9. At specific experimental conditions the onset of flooding is found to depend on the inlet feed water flow rate. The air flow rate creating the onset of flooding decreases as the water flow rate increases. The effect of the inclination angle is shown in Fig. 4. In the case of an upper open end and larger inclination angles, the water flows along inclined pipes are accelerated by gravity and tended to depress the growth of unstable waves. A greater air flow rate is, therefore, required to cause flooding. The effect of inclination angles is closely related to the condition of the upper end. For an upper closed end condition, the onset of flooding is nearly the same for all inclination angles. This means that the flooding points of the open system and the closed system become more distinct as the inclination angle is decreased. (Figs. 5 to 9). The results are also compared with those from Barnea et.al. [7], D = 51 mm and Celata et.al. [8,9], D = 20 mm and shown in Figs. 7 to 9. The data points from Barnea et.al. [7] are taken from a log-log plot, thus causing some uncertainties. Only some points are, therefore, shown in the figures. However the results from Barnea et.al. correlate quite well with those of this study in the case of an upper closed end system.

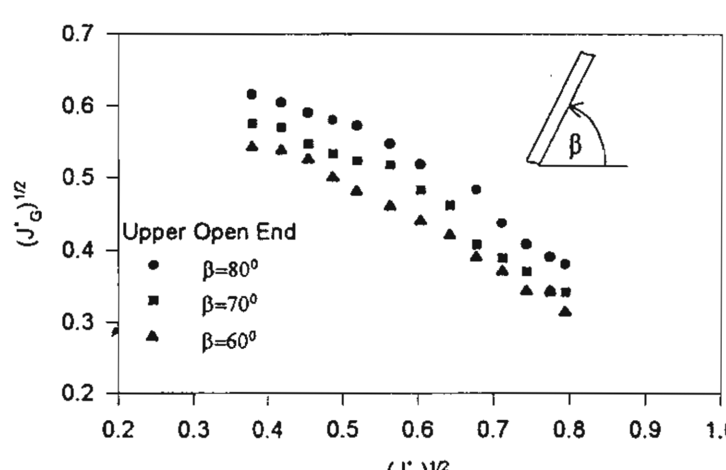

Figure 4. Effect of inclination angle (β) on flooding

The results obtained from the calculation using the methods described above are also shown in Figs. 4-9. The agreement of the present model with the experimental data is satisfactory for smaller inclination angles, especially for higher water flow rates. That is reasonable. At higher water flow rates, the radial velocity of the water entering at the water inlet section increases. The water film thickness increases, and the air flow is accerelated. In the case of higher inclination angles, the prediction fails, because of a change in the flooding mechanism. Due to the effect of gravity, the axial velocity of water from the water inlet increases and the local disturbance at the water inlet decreases. In this case, flooding is formed due to an instability of interfaces somewhere along the pipe.

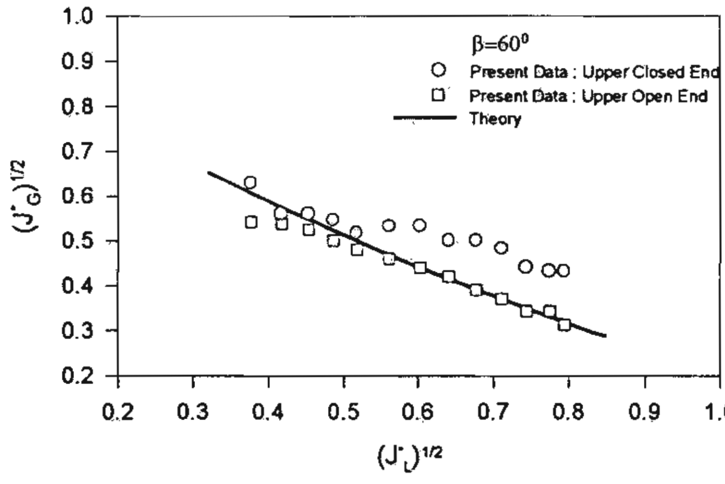

Figure 5. Effect of upper end condition on flooding for the inclination angle (β) = 60°

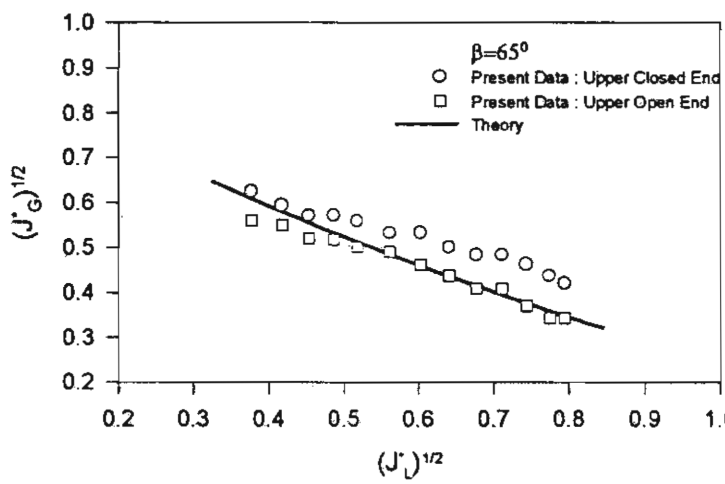

Figure 6. Effect of upper end condition on flooding for the inclination angle (β) = 65°

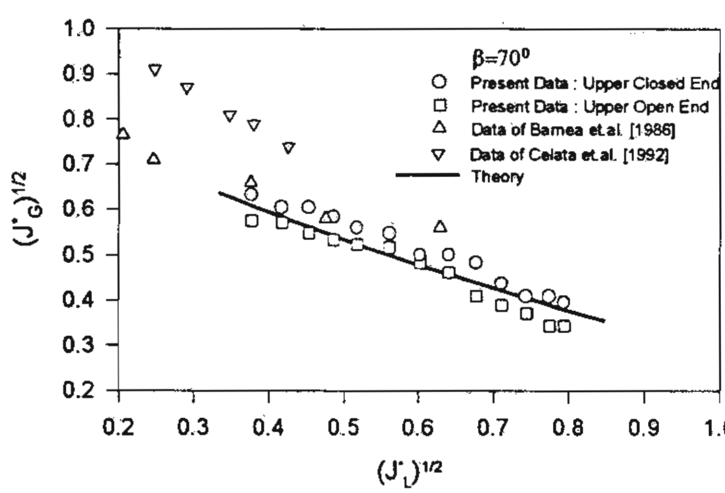

Figure 7. Effect of upper end condition on flooding for the inclination angle (β) = 70°

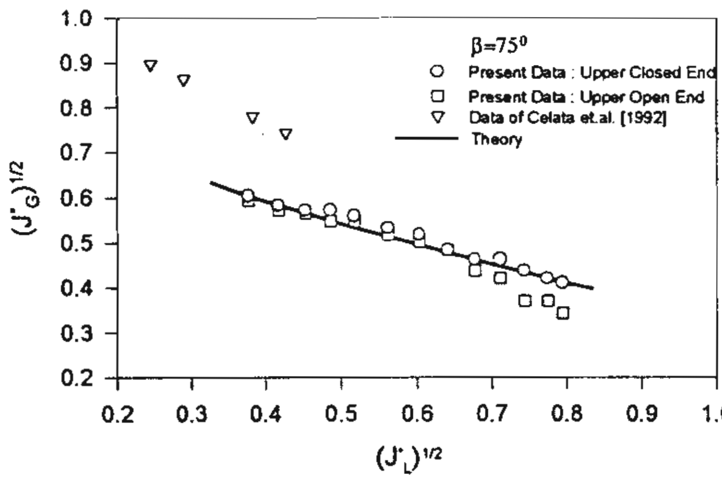

Figure 8. Effect of upper end condition on flooding for the inclination angle (β) = 75°

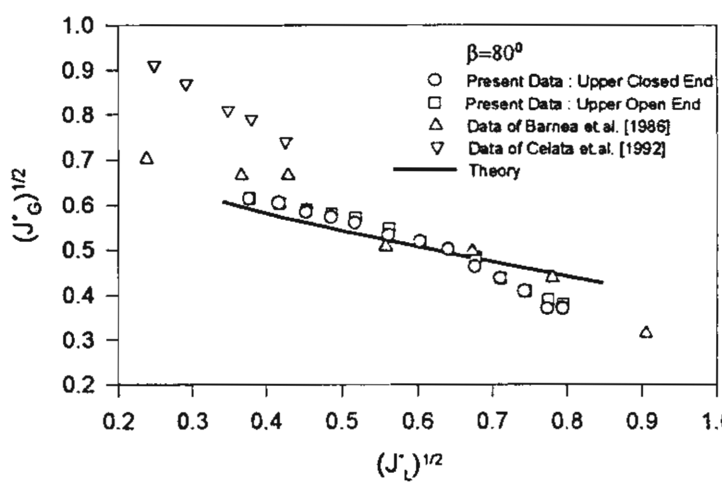

Figure 9. Effect of upper end condition on flooding for the inclination angle (β) = 80°

5. Conclusions

Experiments are performed to determine the countercurrent flow limitation (or onset of flooding). Water is ejected through the test section while air flows countercurrently and the phenomena is visually observed. The general flooding points depend on the water feed rate. The air flow rate which causes the onset of flooding decreases while the water flow rate increases. The influence of the inclination angle and upper end conditions is of significance for the onset of flooding. For an upper-open end system, with decreasing inclination angles, the flooding curves shift to lower gas velocities. For an upper-closed end system, the onset of flooding is nearly the same for all inclination angles. The difference of flooding points between two types of upper end conditions become large when the inclination angle is decreased. The predictions of CCFL are in favorable agreement with experimental data in the case of upper open end and smaller inclination angles, especially at a higher water flow rate.

Acknowledgments

The present study has been supported financially by the Thailand Research Fund (TRF) whose guidance and assistance are gratefully acknowledged. The authors also express gratitude to Mr. Amnaj Koomanee, Mr. Opas Klaengnuan, Mr. Weerachai Kanchanamai, Mr. Thammasak Saengnoi and Mr. Pitiporn Hasuankwan from the Department of Mechanical Engineering, King Mongkut's Institute of Technology Thonburi for their assistance in some of experimental work.

Nomenclature

A	cross-sectional area of the flow, m^2	D	pipe diameter, m
E	specific energy, m	g	gravitational acceleration, m/s^2
h	water level, m	h_f	friction head, m
H	water level at the entrance, m	j	superficial velocity, m/s
j^*	dimensionless superficial velocity	P	pressure, Pa
Q	flow rate, m^3/s	S	perimeter, m
U	velocity, m/s	y	water level, m
z	elevation (in Fig. 2), m		

Greek Symbols

β	inclination angle from the horizontal, deg.	ρ	density, kg/m^3
ΔP	pressure drop, Pa	α	kinetic energy correction factor

Subscripts

c	critical	i	interface
k	gas or liquid	G	gas
H	water inlet section	L	liquid

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Prediction of Liquid Holdup in Horizontal Stratified Two-Phase Flow

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Abstract

This paper provides a combined theoretical and experimental investigation into the prediction of hold-up for a stratified two-phase concurrent flow in a horizontal circular pipe. The test section, 10 m long, with an inside diameter 54 mm was made of transparent acrylic glass to permit visual observation of the flow patterns. The experiments were carried out under various air and water flow rates in the regime of smooth and wavy stratified flows. Stainless ring electrodes were mounted flush in the tube wall for measuring the liquid hold-up which is defined as the ratio of the cross-sectional area filled with liquid to the total crossectional area of the pipe. Calculation method for predicting the liquid hold-up was developed by using the Taitel and Dukler momentum balance.The ratio of interfacial friction factor and superficial gas-wall friction factor,(f_i/f_{SG}) was assumed to be constant. Hold-up curves calculated by this method are compared with present experimental data and those of other researchers. A ratio of f_i/f_{SG} ,which corresponds with the flow conditions, (laminar or turbulent) are presented.

Key Words: Two-Phase Flow, Co-Current Flow, Stratified Flow, Liquid Hold-Up

1. Introduction

Stratified two-phase flow regime is frequently encountered in various chemical and industrial processes; e.g. the flows of steam and water, or oil and natural gas in pipelines etc. One of the main problems in two-phase flow is the calculation to determine the liquid hold-up and pressure loss. Lockhart and Martinelli [1] have developed a procedure for calculating the frictional pressure loss for adiabatic two-phase flow using their data on the horizontal flow of air and water and various other liquids at atmospheric pressure. Their correlations have been applied to all regions of two-phase flow both by the originators and by several other investigators. Chisholm [2] has developed the Martinelli models in such a way that the original Martinelli curves for the various flow regimes can be fitted quite well by selecting a fixed value of a parameter for each flow regime. Johannessen [3] has developed a theoretical solution of the original Lockhart and Martinelli flow model for calculating two-phase pressure drop and holdup in the stratified and wavy flow region. He has shown that his theoretical solutions of pressure drop and holdup agree much better than those of Lockhart and Martinelli in the separated flow region.

The semi-empirical methods for calculating the two-phase flow pressure drop have been proposed by numerous investigators. Wallis [4] correlation which has been improved further by Hewitt and Hall-Taylor [5] can be used in the annular flow region. Hughmark [6] developed a semi-empirical pressure drop correlation independently which is applicable in slug flow region. Kadambi [7] proposed an analytical procedure to determine the pressure drop and void fraction in two-phase stratified flow between parallel plates.

Most stratified flow models were based on an iterative solution of the two phase momentum balance, but differed in the model of the interfacial shear stress. To solve this problem, Taitel and Dukler [8] made the assumption that the interface was smooth and interfacial friction [illegible] equal to the gas-wall friction factor and the g[illegible]ial shear stress was evaluated with the same [illegible] the gas wall shear stress.

In another paper (Taitel and Dukler [9]), they demonstrated that the hold up and the dimensionless pressure drop for stratified flow are unique functions of X under the assumption that $f_G/f_i \cong$ constant. Kawaji [10] predicted holdup successfully by substituting the ratio of the gas-wall friction factor and the gas interfacial shear stress into the Taitel and Dukler momentum balance.

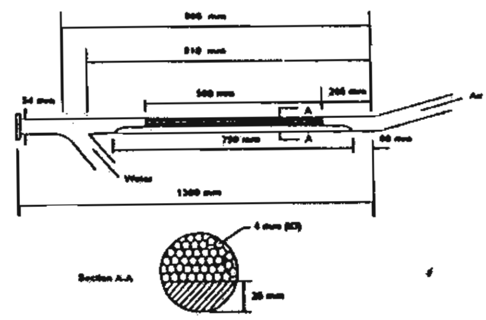
Inaccuracies in previous stratified flow models are found to be a result of the interfacial shear stress used in the model. In the present study, the method for prediction of liquid hold-up will be presented. The method is based on that of Spedding et al. [11,12] and Wongwises [13] where the ratio of the interfacial friction factor and gas-wall friction factor is assumed to be a constant. With this technique a mathematical model of interfacial friction factor is not necessary. The value of the constant depends on whether the phases are in turbulent or laminar flow.

2. Experimental Apparatus and Method

The experimental facility used is shown schematically in Fig 1.The main components of the system consisted of the test section, air supply, water supply, instrumentation, and data acquisition system.The horizontal test section, with an inside diameter of 54 mm and length of 10 m was made of transparent acrylic glass to permit visual observation of the flow patterns.Water was pumped from the storage tank through the rotameter to the water inlet section at the bottom of the pipe. Air was supplied to the test section by a suction-type blower. The air flow could be controlled by a valve at the outlet of the blower. Many small rods were used as guide vanes at the air inlet section to maintain a uniform flow. Both the air and water streams were brought together in a mixer and then passed through the test section concurrently.The inlet flow rate of air was measured by means of a round-type orifice and [illegible] of water was measured by two sets of rotame[illegible]

The temperature of the air and water was measured by thermocouples. Stainless ring electrodes were mounted flush in the tube wall for measuring the liquid hold up. They operate on the principle of the variation of electrical resistance following changes in the water level between two parallel electrode rings. The same description of the calibration procedures for stratified flow can be found in Andreussi [14]. Due to the variation of conductivity caused by temperature change and coating of the electrodes with impurities, the gauges were calibrated before and after each run.

Experiments were conducted with various flow rates of air and water at ambient condition. In the experiments the air flow rate was increased by small increments while the water flow rate was kept constant at a preselected value. After each change in inlet air flow rate, both the air and water flow rates were recorded. The liquid hold-up was registered through the transducers. The flow phenomena was detected by visual observation.



Mixing section

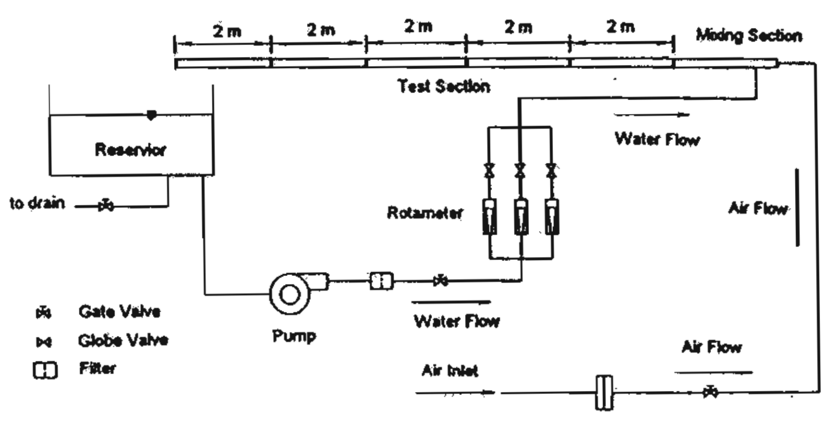


Figure 1. Test facility

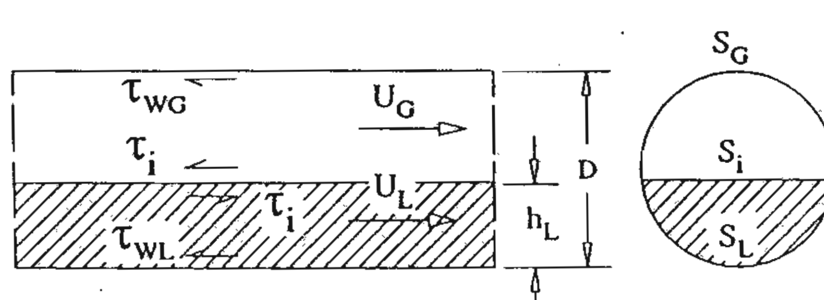


Figure 2. Stratified co-current two-phase flow

3. Mathematical Model

Consider an equilibrium horizontal stratified flow as shown in Fig. 2. A momentum balance on each phase yields:

$$-A_L\left(\frac{dP}{dx}\right)-\tau_{WL}S_L+\tau_i S_i = 0 \quad (1)$$

$$-A_G\left(\frac{dP}{dx}\right)-\tau_{WG}S_G-\tau_i S_i = 0 \quad (2)$$

Equating pressure drop in the two phases and assuming that the hydraulic gradient in the liquid is negligible, the following result is obtained;

$$\tau_{WG}\frac{S_G}{A_G}-\tau_{WL}\frac{S_L}{A_L}+\tau_i S_i\left(\frac{1}{A_L}+\frac{1}{A_G}\right) = 0 \quad (3)$$

The shear stresses are evaluated in a conventional manner

$$\tau_{WL}=f_L\frac{\rho_L u_L^2}{2} \quad (4)$$

$$\tau_{WG}=f_G\frac{\rho_G u_G^2}{2} \quad (5)$$

$$\tau_i=f_i\frac{\rho_G(u_G-u_L)^2}{2} \quad (6)$$

Normally for equilibrium flow $u_G \geq u_L$ such that u_L in eq.(6) can be neglected. A widely used method for the correlation of the liquid and gas friction factors is in the form of Blasius equation:

$$f_L=C_L\left(\frac{D_L u_L}{\upsilon_L}\right)^{-n} \quad (7)$$

$$f_G=C_G\left(\frac{D_G u_G}{\upsilon_G}\right)^{-m} \quad (8)$$

where D_L and D_G are the hydraulic diameter evaluated in the manner as suggested by Agrawal et al.[15]. The liquid is visualized as if it was flowing in an open channel .

$$D_L=\frac{4A_L}{S_L} \quad (9)$$

The gas is visualized as flowing in a closed duct and thus

$$D_G=\frac{4A_G}{S_G+S_i} \quad (10)$$

Furthermore, the coefficients C_L, n, C_G and m used in Eq. (7) and Eq. (8) are those used by Taitel and Dukler [8] in their co-current studies,

in turbulent flows; $C_G = C_L = 0.046$, $m = n = 0.20$

in laminar flows; $C_G = C_L = 16$, $m = n = 1.0$.

Turbulent or laminar flow conditions in each phase are identified by calculating the Reynolds number for each phase using the superficial velocity and diameter of the pipe, i.e.

$$\mathrm{Re}_{SK} = \frac{U_{SK}D}{\upsilon_K}$$

where $K = G, L$

Laminar flow is also assumed for superficial Reynold number < 2000.
Substituting τ_{WL}, τ_{WG}, τ_i from Eq.(4), Eq.(5) and Eq.(6) into Eq.(3),the following equation is obtained;

$$\frac{f_G\rho_G u_G^2 S_G}{2A_G}-\frac{f_L\rho_L u_L^2 S_L}{2A_L}+\frac{f_i\rho_G u_G^2 S_i}{2}\left[\frac{1}{A_L}+\frac{1}{A_G}\right] = 0 \quad (11)$$

In the case of the single phase flow, the pressure gradient is determined from;

$$\left(\frac{dP}{dx}\right)_{SG}=\frac{2f_{SG}\rho_G u_{SG}^2}{D} \quad (12)$$

where $f_{SG} = C_G\left(\frac{Du_{SG}}{\upsilon_G}\right)^{-m}$

Equation (11) is non-dimensionalized by dividing by $\left(\frac{dP}{dx}\right)_{SG}$

Finally the following equation is obtained;

$$\frac{f_G u_G^2 S_G D}{4 f_{SG} A_G u_{SG}^2} - \frac{f_L \rho_L u_L^2 S_L D}{4 f_{SG} \rho_G A_L u_{SG}^2} + \frac{f_i \rho_G u_G^2 S_i D}{4 f_{SG} \rho_G u_{SG}^2}\left[\frac{1}{A_L} + \frac{1}{A_G}\right] = 0 \quad (13)$$

or in dimensionless form

$$(\tilde{u}_G)^2(\tilde{D}_G\tilde{u}_G)^{-m}\frac{\tilde{S}_G}{\tilde{A}_G} - \left[(\tilde{u}_L)^2(\tilde{D}_L\tilde{u}_L)^{-n}\frac{\tilde{S}_L}{\tilde{A}_L}\right]X^2 + \frac{f_i}{f_{SG}}(\tilde{u}_G)^2\left[\frac{\tilde{S}_i}{\tilde{A}_L} + \frac{\tilde{S}_i}{\tilde{A}_G}\right] = 0 \quad (14)$$

where $X^2 = (dP/dx)_{SL}/(dP/dx)_{SG}$ is the ratio of the frictional pressure gradient of the liquid to that of the gas when each phase flows along in the pipe.

$$X^2 = \frac{\frac{4C_L}{D}\left(\frac{u_{SL}D}{\upsilon_L}\right)^{-n}\cdot\frac{\rho_L(u_{SL})^2}{2}}{\frac{4C_G}{D}\left(\frac{u_{SG}D}{\upsilon_G}\right)^{-m}\frac{\rho_G(u_{SG})^2}{2}} \quad (15)$$

X is recognized as the parameter introduced by Lockhart and Martinelli [1] and can be calculated unambiguously with the knowledge of the flow rate, fluid properties and tube diameter. Liquid hold up can be calculated from h_L/D which is in the form of $\tilde{A}_G, \tilde{A}_L$.

All dimensionless variables with the superscript can be seen from

$$\begin{aligned}
\tilde{A} &= \pi/4, \\
\tilde{A}_L &= A_L/D^2, \\
\tilde{S}_L &= S_L/D, \\
\tilde{A}_G &= A_G/D^2, \\
\tilde{S}_G &= S_G/D, \quad (13) \\
\tilde{S}_i &= S_i/D, \\
\tilde{D}_L &= D_L/D, \\
\tilde{D}_G &= D_G/D, \\
\tilde{h}_L &= h_L/D
\end{aligned}$$

$$\begin{aligned}
\tilde{S}_L &= \pi - \cos^{-1}(2\tilde{h}_L - 1), \\
\tilde{S}_G &= \cos^{-1}(2\tilde{h}_L - 1), \\
\tilde{S}_i &= \sqrt{1-(2\tilde{h}_L - 1)^2}, \\
\tilde{U}_G &= \frac{\tilde{A}}{\tilde{A}_G}, \\
\tilde{U}_L &= \frac{\tilde{A}}{\tilde{A}_L}
\end{aligned}$$

$$\tilde{A}_L = 0.25\left[\pi - \cos^{-1}(2\tilde{h}_L - 1)\right] + 0.25\left[(2\tilde{h}_L - 1)\sqrt{1-(2\tilde{h}_L - 1)^2}\right]$$

$$A_G = 0.25\left[\cos^{-1}(2\tilde{h}_L - 1)\right] - 0.25\left[(2\tilde{h}_L - 1)\sqrt{1-(2\tilde{h}_L - 1)^2}\right]$$

In order to solve Eq.(14) for liquid hold up, gas hold up and pressure drop, an iterative computer program is required. A flow chart of this program is shown in Fig 3.

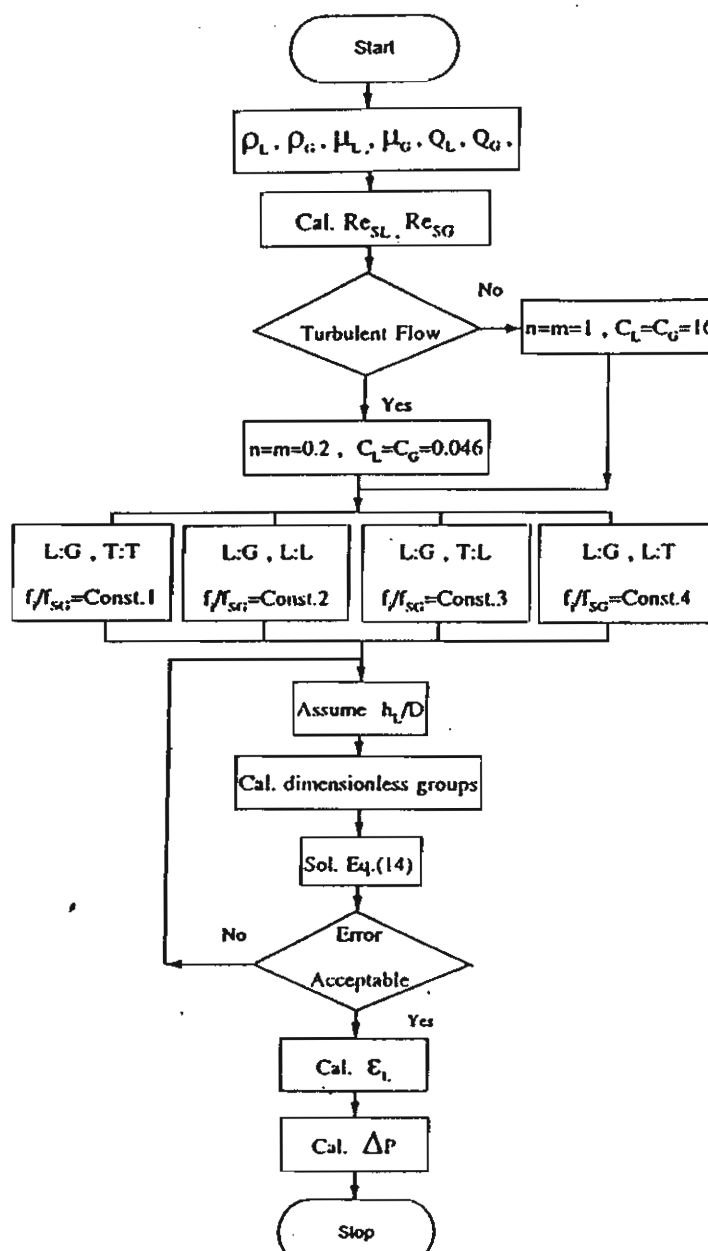


Figure 3. Flow chart for calculation of liquid hold-up and pressure drop

4. Results and Discussion

To handle practical problems, it is necessary to gain a better understanding of flow characteristics. Visual observation shows that different flow patterns may occur with gas-liquid cocurrent flow in horizontal pipes. In accordance with results obtained from this experiment, the following flow patterns were obtained :

a) Stratified flow: The water flows in the lower part of the pipe and the air over it with a smooth interface between the two phases.

b) Two-dimensional wavy flow: Similar to stratified flow except for a wavy interface, due to a velocity difference between the two phases and two-dimensional steady waves travel with a relatively regular pitch.

c) Three-dimensional wavy flow: At a higher air flow rate, the water surface is disturbed and three-dimensional waves occur, which have small irregular ripples on the fundamental waves.

d) Violent wavy flow: The interface is violently disturbed by the air stream. This flow pattern occurs at a relatively high air flow rate.

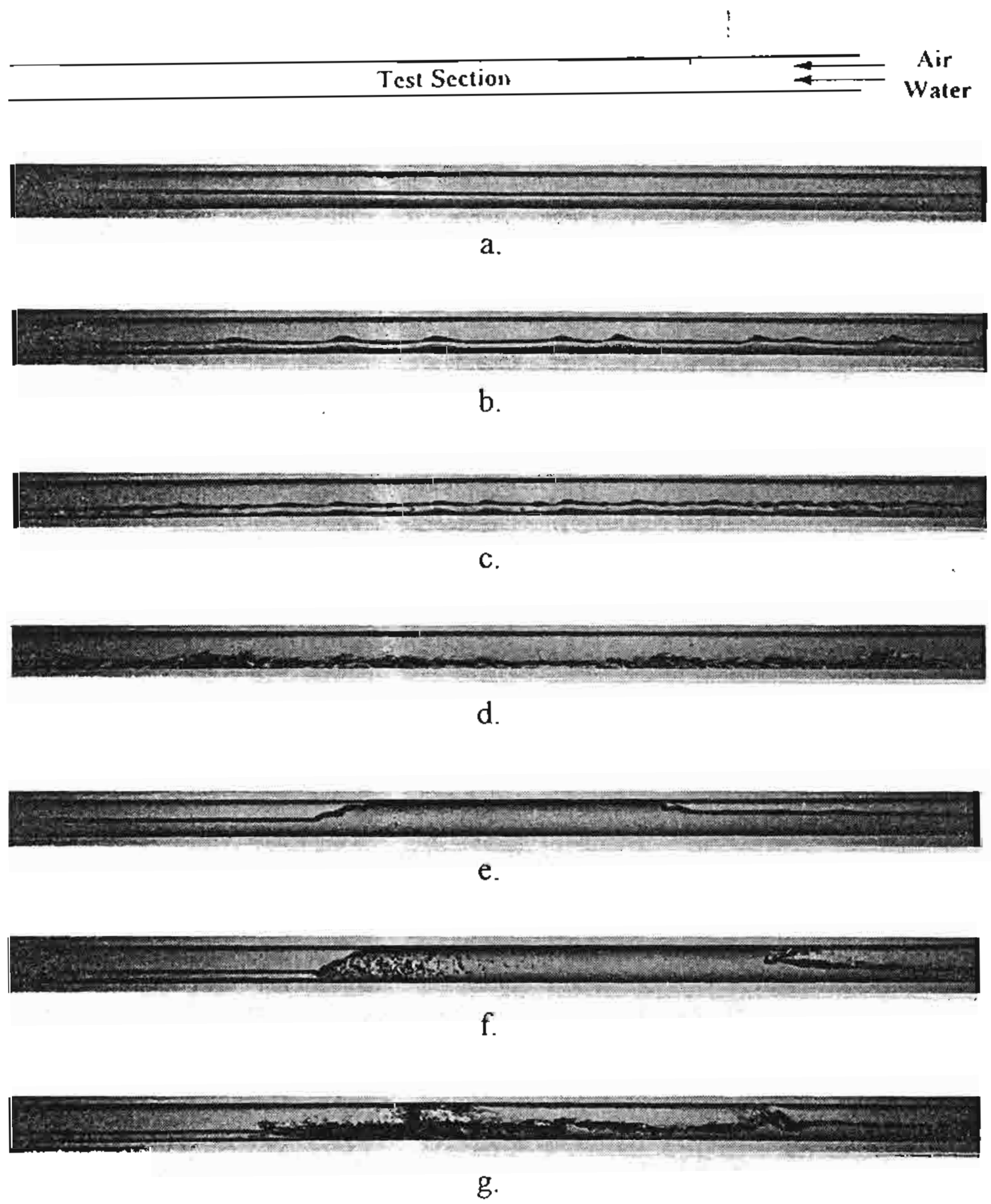
e) Plug flow: Air moves along the upperside of the pipe. This flow pattern occurs at a relatively low air flow rate. The interface is smooth and no bubbles are contained in a water plug.

f) Slug flow: Splashes or slugs of water occasionally pass through the pipe with a higher velocity than the bulk of the water. The tail of water slug is relatively smooth and sometimes contains some small bubbles. The upstream portion of the water slug is similar to the wavy flow, and the downstream portion to the stratified flow or wavy flow.

g) Pseudo slug flow: The semi-slug is defined as a highly agitated long wave which contains many bubbles. Its upstream and downstream portions are similar to the wavy flow.

The typical photographs of flow patterns are shown in Figure 4. The focus of the study was on the stratified and small wavy flow. Figures 5 and 6 show the relation between the liquid holdup, ε_L against the Lockhart-Martinelli parameter, X for a laminar liquid-turbulent gas flow in the 0.054 m. diameter pipe and Q_L = 1.67×10^{-5}, 6.67×10^{-5} m^3/s respectively. The values $C_G=C_L=0.046$, $n=m=0.2$ for turbulent flow and $C_G=C_L=16, n=m=1.0$ for laminar flow are used. The figures show a comparison of the experimental data with the present model where the ratio, f_i/f_{SG} is assumed. It is found that an agreement of the present model with the experimental data is obtained by using f_i/f_{SG} = 0.30-1.0. The data obtained by Spedding et al. [11] who tested the model against wavy and stratified flow data from 93.5 and 45.5 mm diameter pipes are compared with the predictions from the present model. Their data points were taken from log scale, thus were a cause of some uncertainties. Their data can be accurately predicted with f_i/f_{SG} = 0.6 for laminar liquid-turbulent gas flow. Their predicted f_i/f_{SG} are in the recommended range in this work. The scatter of Spedding et al. data for the smaller diameter pipe is much greater than the large diameter.

Figures 7 and 8 show also the relation between ε_L against X for a turbulent liquid-turbulent gas flow for $Q_L = 8.3 \times 10^{-5}$ and 1.67×10^{-4} m^3/s respectively. They show that the liquid holdup can be accurately predicted by assuming f_i/f_{SG} = 2.0-4.0. The data shows that the assumption of f_i/f_{SG} = 1.0 overpredicted liquid holdup for the stratified flows. The results correspond to those from Kawaji [10] who predicted holdup successfully by substituting f_i/f_{SG} = 3.0 and also from Spedding et.al.[11] by substituting f_i/f_{SG} = 4 for turbulent liquid-turbulent gas flow into the Taitel and Dukler [8] momemtum balance. Their predicted f_i/f_{SG} are also in the recommended range in this work. However, for Spedding et al. results, a discrepancy is found between the present recommended ratio of f_i/f_{SG} and the experimental data at greater Lockhart Martinelli Parameter. This is because of a change of interfacial phenomena. The amplitude of the water layer fluctuation increases slightly with



a. Stratified flow
b. Two-dimensional wavy flow
c. Three-dimensional wavy flow
d. Violent wavy flow
e. Plug flow
f. Slug Flow
g. Pseudo slug flow

Figure 4. Photographs of flow Patterns

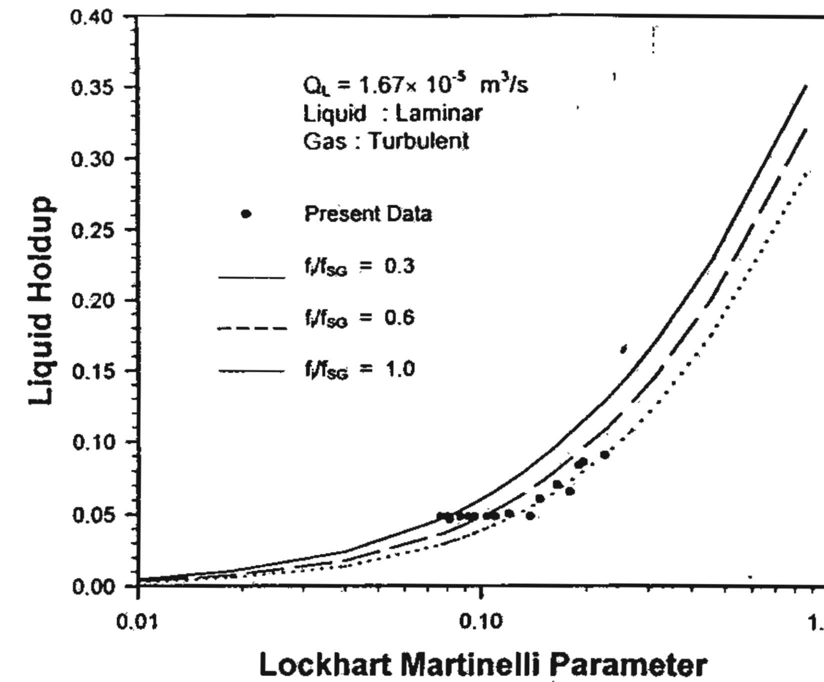


Figure 5. ε_L against log (X) for $Q_L = 1.67\times10^{-5}$ m^3/s ; Liquid-Laminar and Gas-Turbulent

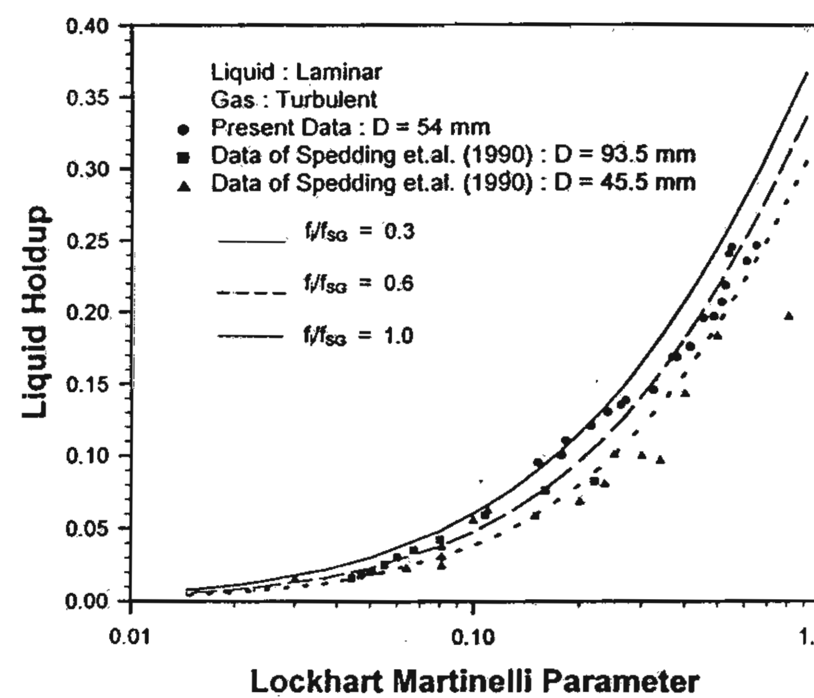


Figure 6. ε_L against log (X) for $Q_L = 6.67\times10^{-5}$ m^3/s ; Liquid-Laminar and Gas-Turbulent

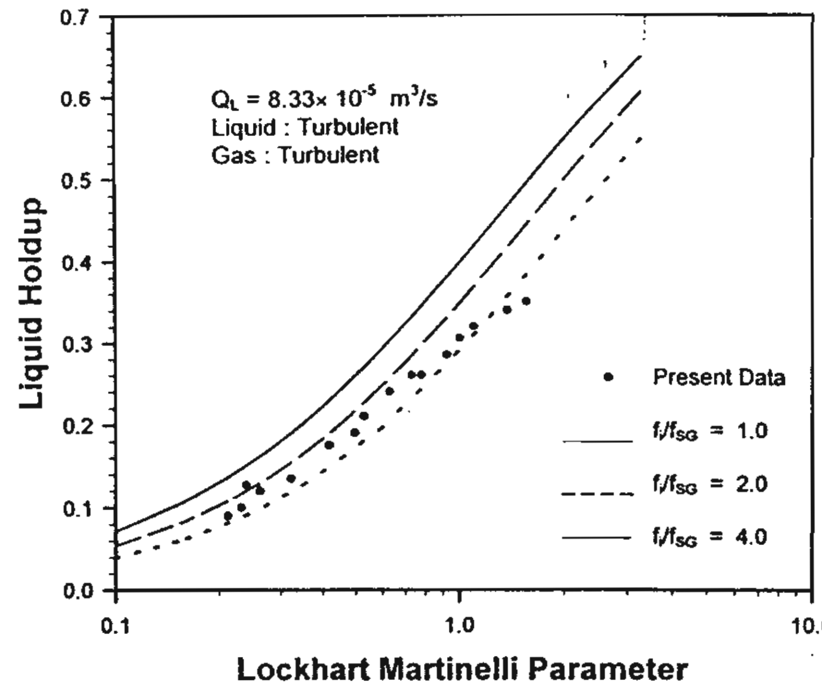


Figure 7. ε_L against log (X) for Q_L= 8.33×10^{-5} m^3/s ; Liquid-Turbulent and Gas-Turbulent

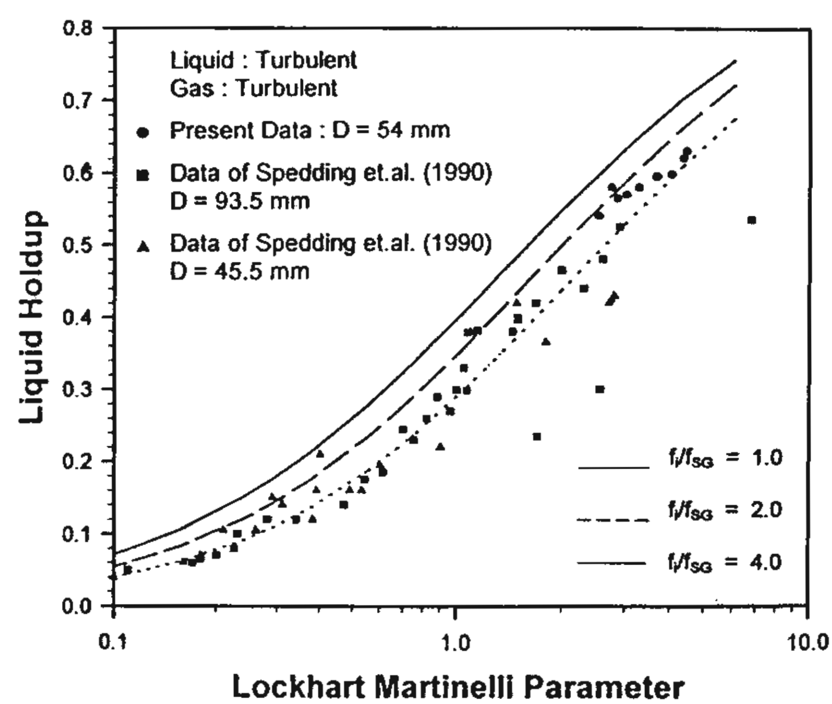


Figure 8. ε_L against log (X) for Q_L= 1.67×10^{-4} m^3/s ; Liquid- Turbulent and Gas-Turbulent

air flow. Two-phase pressure drop can be determined further by substituting h_L/D into Eq. (1) or (2). In this work, the situation when gas flow was laminar, was not considered.

5. Conclusion

This paper presents new data to predict the liquid holdup in horizontal concurrent stratified flow in a circular pipe. It has been demonstrated that the liquid holdup can be predicted by using Taitel and Dukler momemtum balance between both phases. The ratio of the friction factor of the gas at the interface and the gas at the pipe wall, f_i/f_{SG} is assumed to be constant. The constant depends on the phase being either turbulent or laminar. With this method a model of interfacial friction factor is not necessary. For turbulent liquid-turbulent gas flows, the former assumption that $f_i = f_{SG}$ is shown to give a result which does not agree with the experimental data.Future work should examine the effect of pipe diameter. It may be also worthwhile to study in countercurrent flow for comparison with concurrent flow data.

Nomenclature

A	Crossectional area of pipe, m^2
A_G, A_L	Crossectional area of gas and liquid phase, m^2
C_G, C_L	Constant in Eq.(7) and (8)
D	Pipe diameter,m
D_G, D_L	Hydraulic diameter of gas and liquid phase, m
f_G, f_L	Gas-wall and liquid-wall friction factor
f_i	Interfacial friction factor
f_{SG}	Superficial gas-wall friction factor
g	Gravitational acceleration, m/s^2
h	Liquid height, m
n,m	Constant in Eq.(7) and (8)
P	Pressure, N/m^2
dP/dx	Two phase pressure gradient, N/m^3
$(dP/dx)_{SG}$	Pressure gradient of single gas phase, N/m^3
$(dP/dx)_{SL}$	Pressure gradient of single liquid phase, N/m^3
Q_G	Volume flow rate of gas,m^3/s
Q_L	Volume flow rate of liquid,m^3/s
Re_G	Gas phase Reynolds number
Re_L	Liquid phase Reynolds number
Re_{SG}	Superficial gas phase Reynolds number
Re_{SL}	Superficial liquid phase Reynolds number
S_G	Gas phase perimeter,m
S_L	Liquid phase perimeter,m
S_i	Interfacial width,m
U_G	Average velocity of gas, m/s
U_L	Average velocity of liquid, m/s
U_{SG}	Superficial velocity of gas, m/s
U_{SL}	Superficial velocity of liquid, m/s
X	Lockhart-Martinelli parameter

Greek Symbols

ρ	Density, kg/m^3
υ	Kinematic viscosity, m^2/s
τ	Shear stress, N/m^2
ε	Liquid hold up

Subscripts

G	Gas phase
L	Liquid phase
i	Interface
WL	Liquid-wall
WG	Gas-wall
SG	Superficial gas
SL	Superficial liquid

Superscripts

~	dimensionless term

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This work was given financial support by the Thailand Research Fund (TRF), whose guidance and assistance are gratefully acknowledged. The authors also wish to thank students and staff of the Department of Mechanical Engineering, King Mongkut's University of Technology Thonburi for tremendous assistance given during their work.

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29 September 1998

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Dear Dr. Wongwises,

This is to inform you that your paper entitled, "Flow regime maps for the developing steady gas-liquid two-phase flow in a horizontal pipe" has been accepted for publication in the ASEAN Journal of Science and Technology for Development (AJSTD). Your paper is included in the second issue of Volume 15 which is scheduled for release this coming December 1998.

Thank you and best regards.

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Issue: AJSTD vol. 15, no. 2

Article: Flow Regime Maps for the Developing Steady Gas-Liquid Two-Phase Flow in a Horizontal Pipe

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FLOW REGIME MAPS FOR THE DEVELOPING STEADY GAS-LIQUID TWO-PHASE FLOW IN A HORIZONTAL PIPE

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ABSTRACT

Visual observations of flow patterns for the developing steady air-water two phase flow were obtained in a 54 mm diameter test section with 10 m. long. A flow regime map for the developing two phase flow was developed in the form of two dimensional graph which was separated into area corresponding to various flow patterns. The present flow regime map was compared with those of other researchers. The map will be useful for predicting the flow patterns at given conditions and will be a basis to derive the flow regime maps for the transient conditions.

INTRODUCTION

Two-phase gas-liquid flow in horizontal pipe lines has become of greater concern in a wide variety of engineering equipment and process. This type of flow has been encountered extensively in an increasing number of important situations for example in gas-oil pipelines, boiler, chemical and nuclear reactors etc. It is not possible to understand the two-phase flow phenomena without a clear understanding of the flow patterns encountered. It is to be expected that two-phase pressure drop, holdup, system stability, exchange rates of momentum , heat and mass will be influenced by the flow pattern which exists. The ability to predict the type of flow accurately is necessary before the relevant calculation techniques will be developed.

The steady two phase flow can be divided into a fully developed flow and a developing flow. A fully developed flow results when the velocity profile ceases to change in the flow direction. Many studies have been carried out to perform the flow regime maps in horizontal pipes, mostly for fully developed flow. Alves[1] suggested a map based on data for air-water and air-oil mixtures utilizing the superficial liquid and gas velocities as the coordinates. The test section used in his investigation consisted of four 18-foot passes of 1.042 inch pipe connected by upward flow return bends. The flow patterns were observed through 18-inch lengths of glass pipe located at the beginning of the first and second passes and at the end of the first and fourth passes. Baker[2] proposed a flow pattern map based on the data of several researchers. Most of these data are for the air-water system. Baker plotted G/l versus Lly/G, which is equivalent to gas mass velocity, G, versus ratio of liquid to gas velocity, L/G. Here, l and y are fluid property correction factors and are defined as:

$$\lambda = \left[\left(\frac{\rho_G}{\rho_A}\right)\left(\frac{\rho_L}{\rho_W}\right)\right]^{1/2}$$

and

$$\psi = \frac{\sigma_W}{\sigma}\left[\left(\frac{\mu_L}{\mu_W}\right)\left(\frac{\rho_W}{\rho_L}\right)^2\right]^{1/3}$$

which r, s and m represent density, surface tension and viscosity respectively. The subscripts G and L represent the gas and liquid phases, and the subscripts A and W represent the values for air and water at atmospheric conditions (typical 20 °C and atmospheric pressure). The Baker map is still widely used and is presented for reference purposes.

Hoogendorn[3] investigated flow patterns in smooth 25 meter long test sections which had diameters of 15, 24, 50, 91 and 140 mm. The liquids used were water, spindle oil, gas-oil, and freon-11. Air and freon vapors were the gases used. Gas pressure ranged between 1 and 3 atm and operating temperature was 28 °C. He used the mixture velocity and the input gas volume fraction as coordinates.

More data on flow patterns in horizontal flow have shown that the original map is deficient in representing the effects of various system parameters. These subjects have led to the development of a number of alternative flow maps; for example those produced by Mandhane et al.[4] which is probably the most successful. It is, however, impossible to represent all the appropriate transitions in terms of a single set of parameter. This has been recognized by a number of authors and developed later by Taitel[5] and Dukler[5], Weisman et al.[6], Barnea[7], Lin et al.[8], Spedding et al.[9] have proved successful in predicting a fairly wide range of system conditions.

Flow regime maps for developing steady flows have received comparatively very little attention in the literature. The earliest work was performed by Sakaguchi et al.[10,11] who investigated the developing steady-state and transient behavior of air-water two-phase flow in horizontal tubes. The experiment was carried out in the different test sections. It was found that the flow pattern transitions occur at lower flow rates (both liquid and gas flow rates) in transient condition than in steady condition. Wong et. al.[12] studied the flow patterns transition in two-phase gas liquid flow and proposed a set of standardised flow pattern terminology through experimental observation.

In the present study, the main concern is to clarify the characteristics of the flow patterns and perform the flow regime maps for the developing steady flow.

EXPERIMENTAL APPARATUS AND METHOD

A schematic diagram of the test facility is given in Fig 1. Air and water were used as the working fluids. The main components of the system consisted of the test

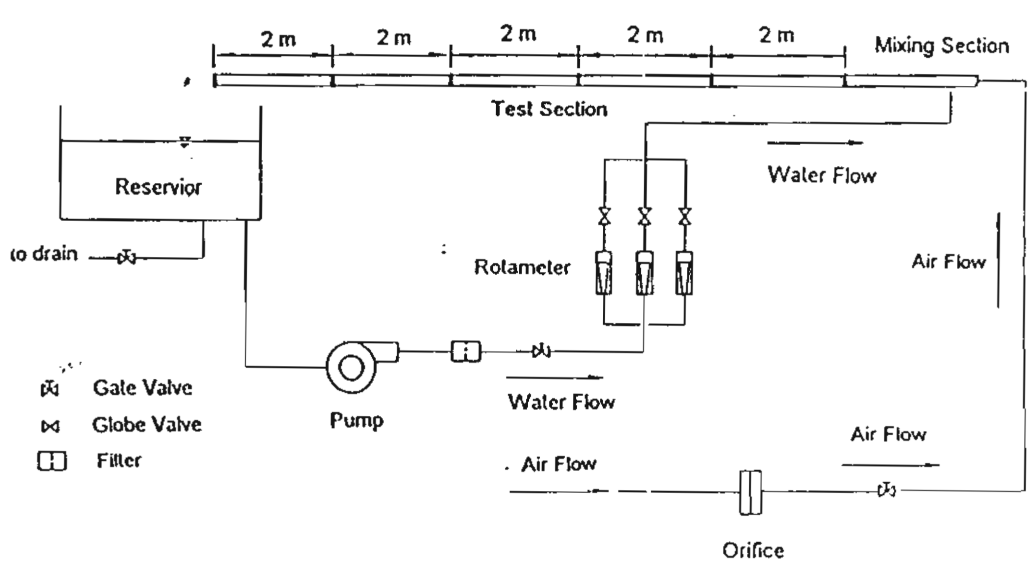


Figure 1. Schematic diagram of experimental apparatus

section, air supply, water supply. A horizontal test section, with an inside diameter of 54 mm and length of 10 m were made of transparent acrylic glass to permit visual observation of the flow patterns. The connections of the piping system were designed such that parts could be changed very easily. Water was pumped from the storage tank through the rotameter to the water inlet section. Air was supplied to the test section through an air inlet section which was constructed of a lot of small diameter tubes with 4 mm. inside diameter (Fig. 2) to maintain a uniform flow. Both the air and water streams were brought together in a mixer and then passed through the test section cocurrently.The inlet flow rate of air was measured by means of a round-type orifice and that of water was measured by three sets of rotameters. Experiments were conducted with various flow rates of air and water to perform the flow regime maps for the developing steady flows.The air flow rate was increased by small increments while the water flow rate was kept constant at preselected value. After each change in inlet air flow rate, both the air and water flow rates were recorded. The process of each flow pattern formations were detected in detail by visual observation, video recorder and high speed camera.

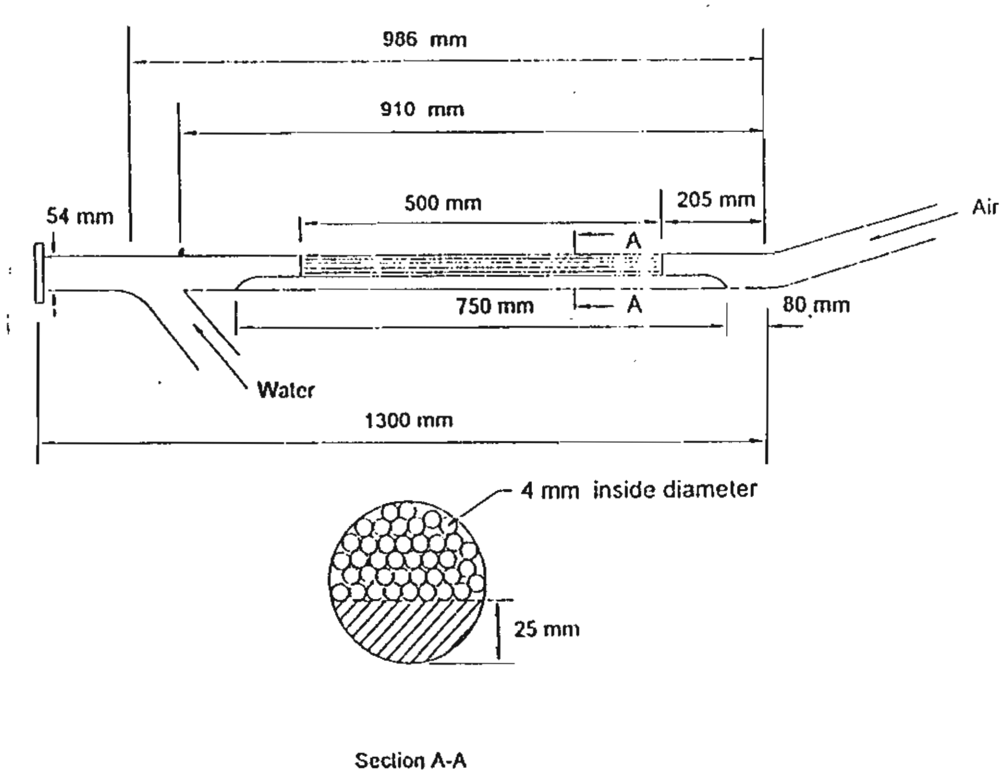


Figure 2. Schematic diagram of mixing section

RESULTS AND DISCUSSION

Visual observation shows that different flow patterns may occur with gas-liquid cocurrent flow in horizontal pipes. The typical photographs of flow patterns in accordance with results obtained between 2 to 4 m. from the outlet of the test section are shown in Fig.3 . Description of each flow patterns are defined as follow:

a. Stratified flow:

The water flows in the lower part of the pipe and the air flows over it with a smooth interface between both phases (Fig. 3a).

b. Two-dimensional wavy flow:

Similar to stratified flow except for a wavy interface. Due to a velocity difference between the two phases, two-dimensional steady waves occur and move with a relatively regular pitch (Fig. 3b).

c. Three-dimensional wavy flow:

In a higher air flow rate, water surface are stronger disturbed and three-dimensional waves which have small irregular ripples on the fundamental waves occur. There is still no bubbles in the water phase (Fig. 3c).

d. Violent wavy flow:

The interface is violently disturbed by the air stream. This flow pattern occurs at a relatively very high air flow rate (Fig. 3d.).

e. Plug flow:

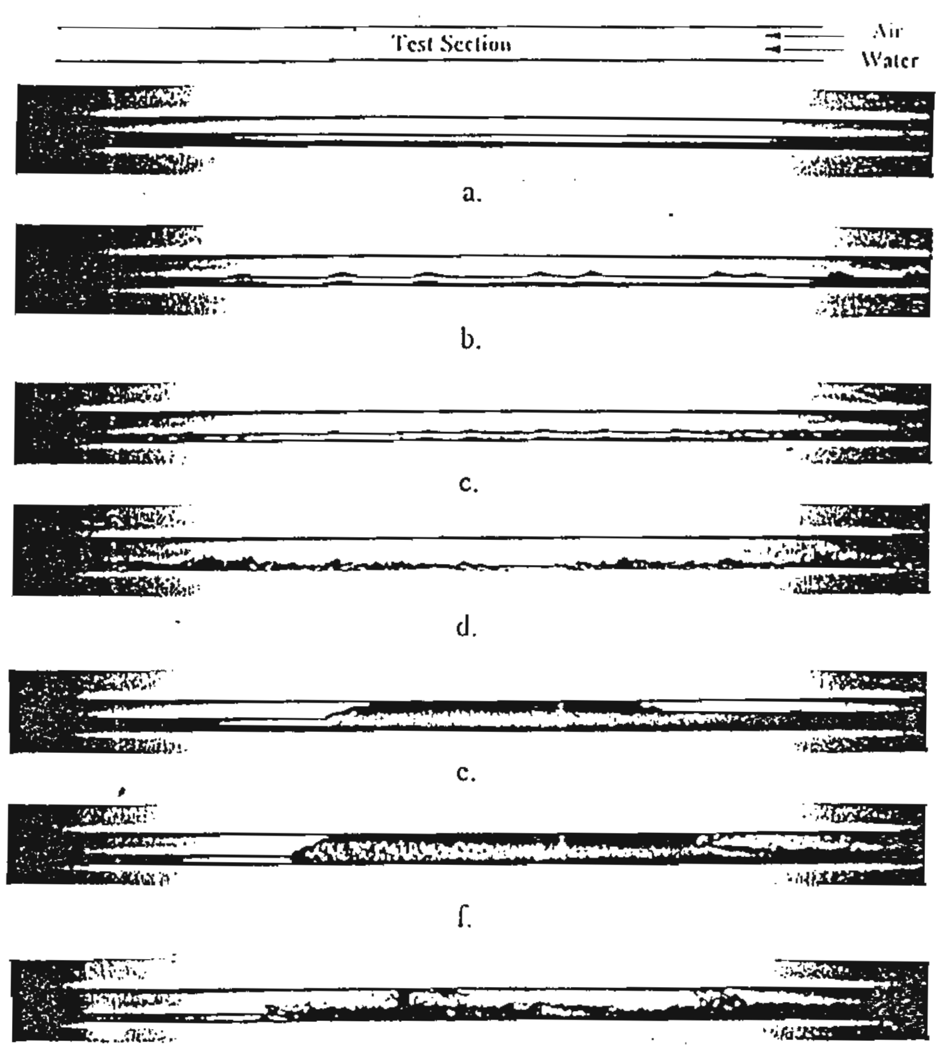
This flow pattern occurs at a relatively lower air flow rate but higher water flow rate. Air moves along the upperside of the pipe, without any shearing of water from wave crest. The interface is smooth and no bubbles are contained in a water plug (Fig. 3e).

f. Slug flow:

At a certain air flow rate, the air-water interface become more wavy and unstable. Wave with higher amplitude grow up and blocks the whole pipe section and is then pushed strongly by the air with very high velocity. Water slugs contain some small bubbles and occasionally pass through the pipe with a higher velocity than the bulk of the water (Fig. 3f).

g. Pseudo slug flow:

An initial formation of pseudo slug is similar to that of slug flow. Higher



a.

b.

c.

d.

e.

f.

g.

Figure 3. Typical photographs of flow patterns

a. Stratified flow:
b. Two-dimensional wavy flow:
c. Three-dimensional wavy flow:
d. Violent wavy flow:
e. Plug flow:
f. Slug flow:
g. Pseudo slug flow

amplitudes of waves decrease the flow path. Air with higher velocities near the crest wave lead to the blowing up of the wave crests, which later break up into droplets and splash up (Fig. 3g).

h. Pseudo slug + annular flow:

An information of the pseudo slug + annular flow is similar to that of the pseudo slug flow, except some water appears on the inner pipe wall as a thin film.

It is quite difficult to see the thin film of water in the pseudo slug + annular flow from the photograph. It is, therefore, not shown in the figure. The definitions of two and three dimensional wavy flows and the violent wavy flow have been also proposed by Sakaguchi et. al.[10,11].

The usual method in the presentation of flow pattern data is to classify the flow pattern by visual observation and plot the data as a flow regime map in terms of system parameters. Parameters that are commonly used are the phase superficial velocities. A flow regime map obtained in the present study for pipe diameter 54 mm is presented in Fig. 4. The subscripts L and G refer to the water and air respectively, the subscript o designates "superficial" or the situation where the designated phase flows alone in the pipe. Both superficial velocities, V_{GO} and V_{LO}, refer to average ambient conditions (1.013 bar, 30°C). The flow regime map is valid in the range of 0.5 to 7 m/s for V_{GO} and 0.02 to 0.26 m/s for V_{LO}. The cross hatched area represent the regions in which the transition from one flow to another occurs. The present flow regime map is also compared with that of Sakaguchi et. al.[10] for pipe diameter 30 mm.(Fig. 5). Some experimental results agree qualitatively. Some part of the transition lines between the stratified and the wavy flow, and the wavy and the slug flow, and the plug and the slug flow agree with Sakaguchi's boundary. The plug flow region is larger while the slug flow region is smaller than those from Sakaguchi's map. In the present map, the region of the pseudo slug flow is largest. The present regime map is also compared with that of Wong et al. [12] for pipe diameter 25.4 mm. and shown in Fig. 6. The data points from Wong et. al.[12] are taken from a log-log flow regime map, thus cause of some uncertainties. The transition line between plug and slug flows patterns agree very good with that between plug and plug-slug flows in Wong's map. The cause of shift of boundary is due to Wong et. al.[12] demarcated the region between plug and slug flows in three regions; plug, plug-slug, and slug flow. The stratified flow and region of pseudo slug flow is smaller than that of Wong et. al.[12]. The region of pseudo slug from both are very good agree qualitatively. Violent wavy flow region cover the region of roll wave in Wong's map. The discrepancies from comparisons with other investigations depend mainly on the identification of flow pattern according to their definitions.

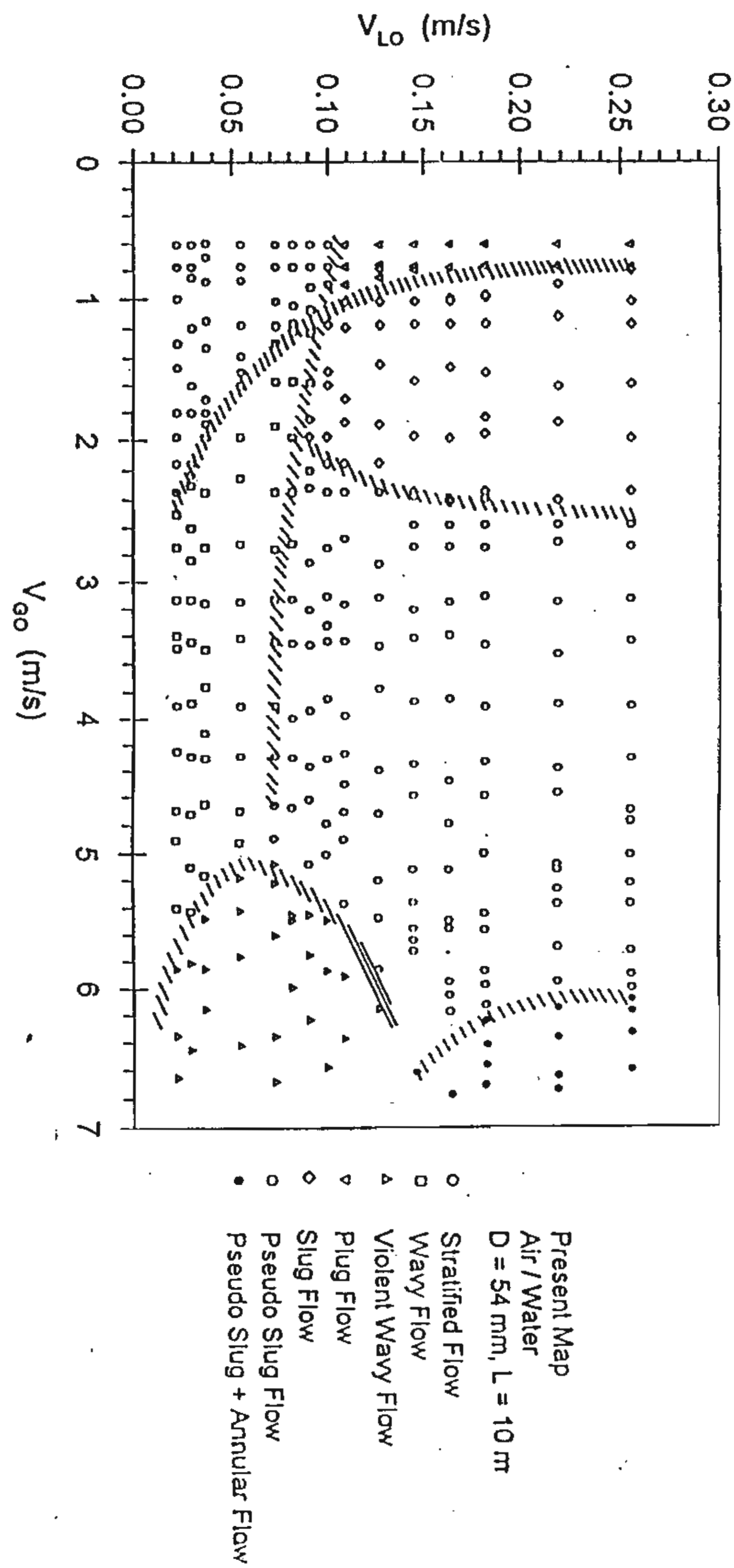


Figure 4. Typical flow regime map for the steady flow conditions

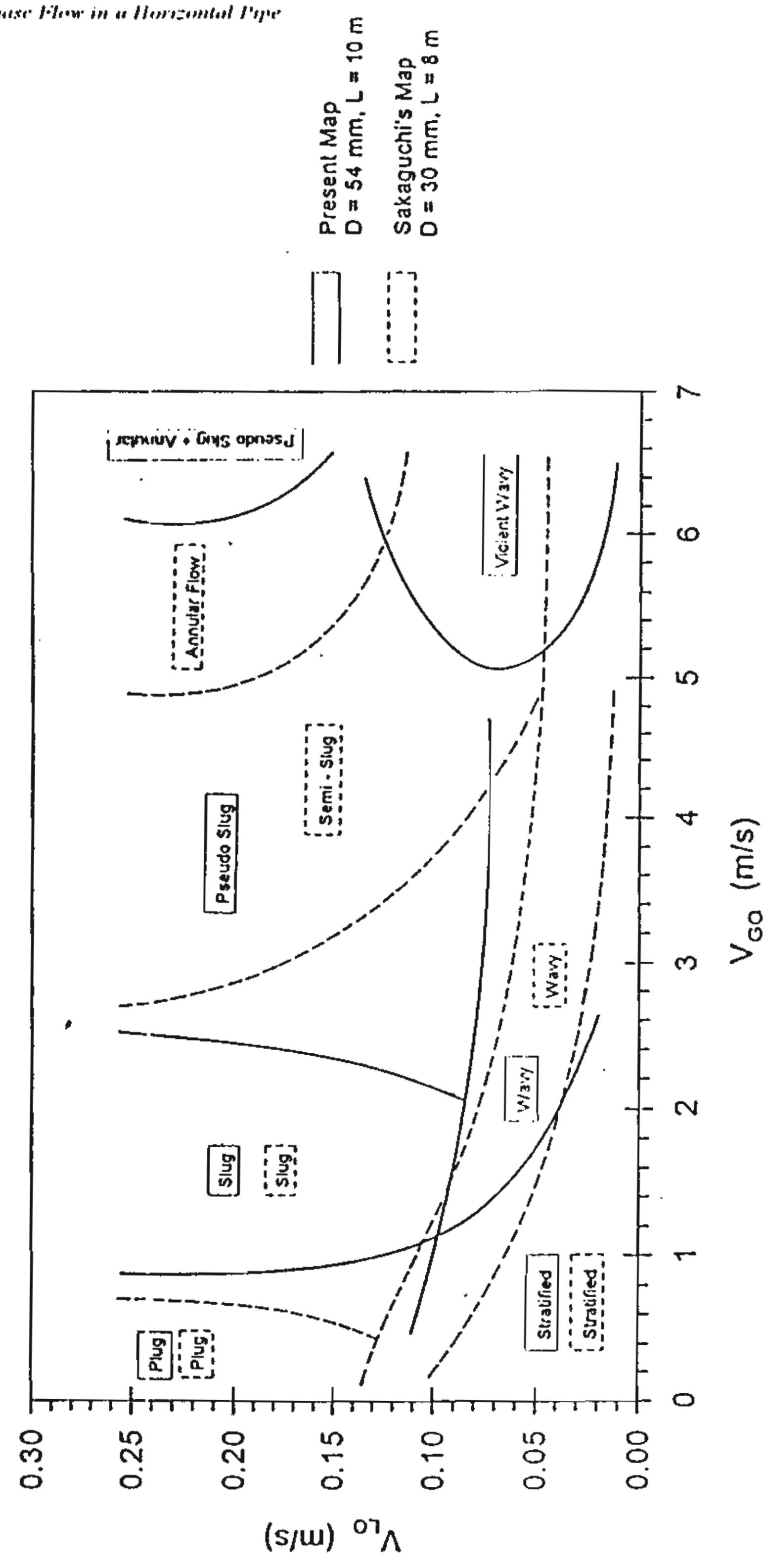


Figure 5. Comparison of the present map with the Sakaguchi's map

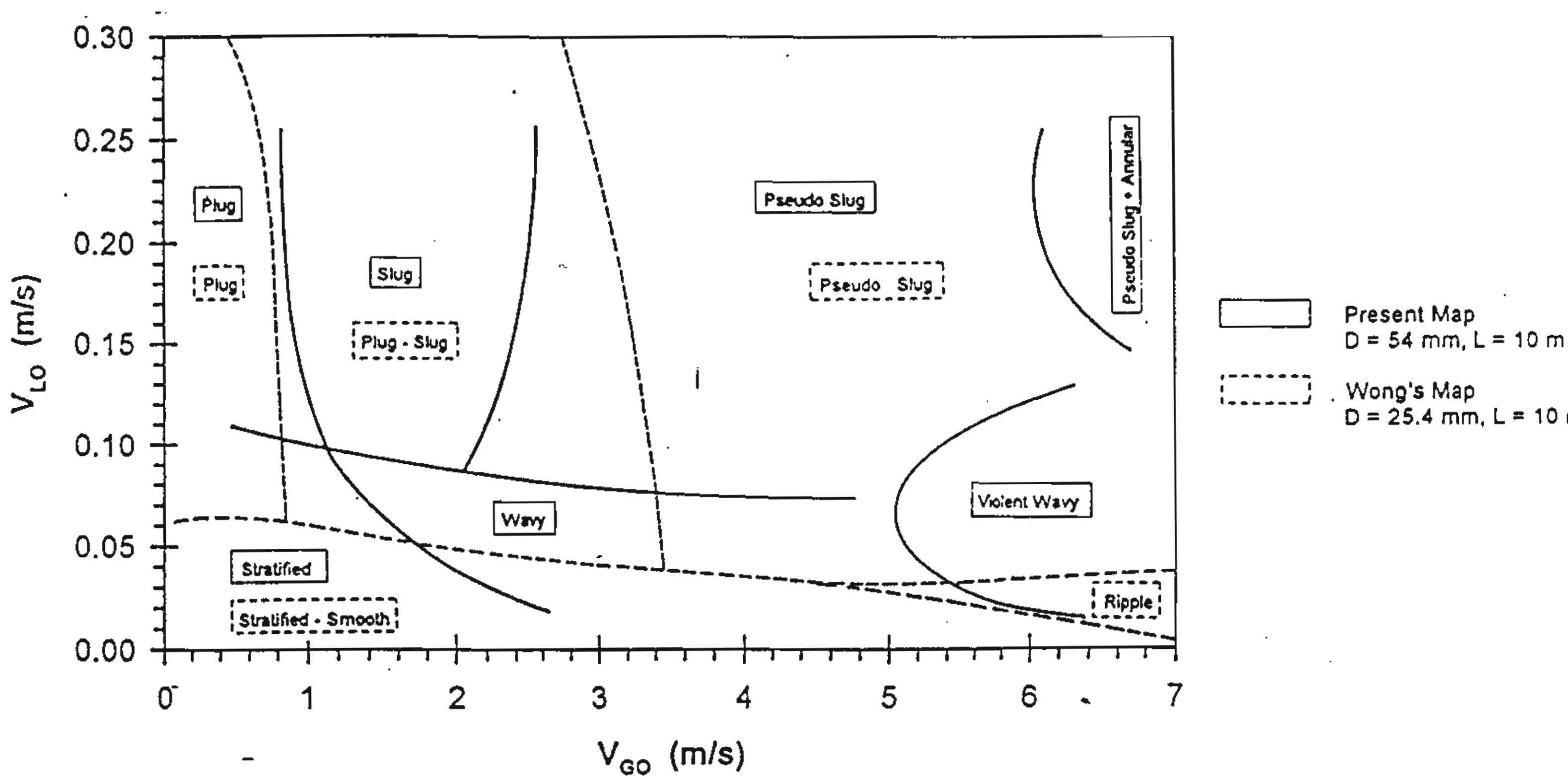


Figure 6. Comparison of the present map with the Wong's map

geometries of pipe and the conditions of inlet and outlet sections (see Bendiksen et. al.[13]). However, the results agree qualitatively, in general.

CONCLUSION

This paper presents new data to clarify the flow patterns of developing steady flow. Air flow is slowly increased while the water flow is fixed. The flow phenomena which are stratified, two-dimensional wavy, three-dimensional wavy, violent wavy , plug, slug, pseudo slug and pseudo slug + annular flows are observed and recorded by high speed camera. The flow regime maps have been presented as functions of the superficial velocity of both phases and are compared with other flow regime maps. These maps are useful to predict the flow pattern for developing flow at steady conditions in various flow systems and can be used as the basis information to perform the transient flow regime maps. The results will be very important for the further development to analyse the behavior of flow instability in a two phase flow system for example the burnout phenomena in oscillating flow , initiation of water hammer in horizontal pipes due to increasing condensation heat transfer and steam velocity caused by a local change of heat transfer to the system.

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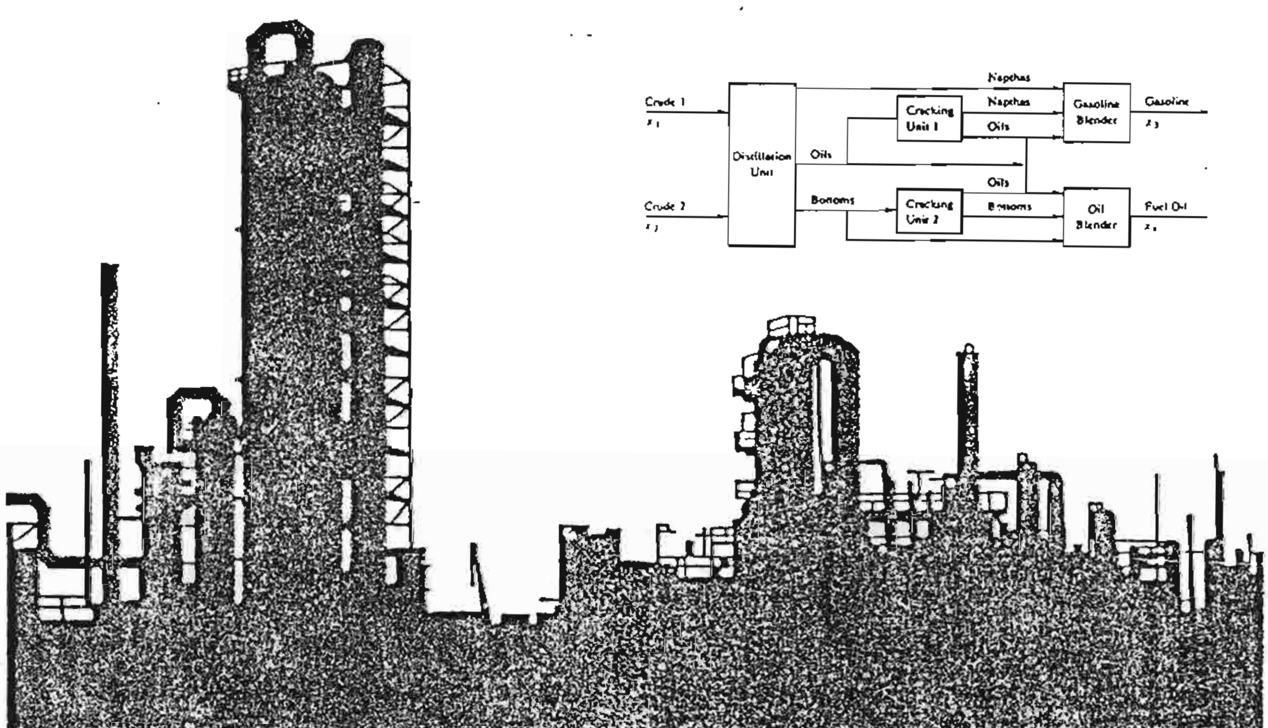
14. APPENDIX

(see next pages)

การออกแบบและการหาสภาพที่เหมาะสมที่สุดทางความร้อน

THERMAL DESIGN AND OPTIMIZATION

ดร. สมชาย วงศ์วิเศษ



หนังสือในโครงการส่งเสริมการสร้างตำรา
มหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี

ISBN 974-621-865-4

คำนำพิมพ์ครั้งที่ 2

(ฉบับแก้ไขและปรับปรุง)

ผู้เขียนได้เขียนหนังสือเล่มนี้โดยมีจุดประสงค์เพื่อใช้ประกอบการสอนในวิชา MEE 531 การออกแบบระบบทางความร้อน (Thermal System Design) สำหรับนักศึกษาระดับปริญญาตรี ชั้นปีที่ 4 และนักศึกษาระดับบัณฑิตศึกษาภาควิชาวิศวกรรมเครื่องกล คณะวิศวกรรมศาสตร์ มหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี โดยผู้เขียนได้ปรับปรุงแก้ไขเพิ่มเติมจากชุดที่พิมพ์ในครั้งแรก เนื่องจากหนังสือเล่มนี้ไม่ใช่หนังสือที่แปลโดยตรงจากเล่มใดเล่มหนึ่งแต่เป็นหนังสือที่ได้จากการผสมผสานกันจากตำราหลายๆเล่มดังนั้นจึงช่วยทุ่นเวลาและสะดวกสำหรับนักศึกษาในการทำความเข้าใจกับเนื้อหา

หนังสือเล่มนี้แบ่งอย่างกว้างๆได้เป็นสองส่วนคือ ส่วนที่ว่าด้วยการออกแบบ (Design) และส่วนที่ว่าด้วยการหาสภาพที่เหมาะสมที่สุด (Optimization) โดยจะมีทั้งหมด 12 บท ตั้งแต่บทที่ 1 ถึงบทที่ 6 จะเป็นการปูพื้นความรู้ด้านต่าง ๆ ไม่ว่าจะเป็นหลักการในการออกแบบซึ่งจะเน้นเฉพาะการออกแบบระบบทางความร้อน และ การกล่าวถึง เศรษฐศาสตร์ ซึ่งถือเป็นปัจจัยที่สำคัญที่สุดในความเป็นจริงทางธุรกิจ รวมไปถึงการศึกษาระบบอุปกรณ์พื้นฐานในทางความร้อนที่ต้องพบเสมอในอุตสาหกรรม อาทิเช่น อุปกรณ์แลกเปลี่ยนความร้อน (Heat Exchanger) เครื่องจักรกลเทอร์โบ (Turbomachinery) เนื้อหาในบทที่ 7 ถึงบทที่ 12 จะเป็นการนำความรู้พื้นฐานทางวิศวกรรมเครื่องกล โดยเฉพาะอย่างยิ่ง เทอร์โมไดนามิก กลศาสตร์ของไหล และการถ่ายเทความร้อนและมวล เข้ามาประกอบกันแล้วใช้เทคนิคต่าง ๆ ในการหาสภาพที่เหมาะสมที่สุด มาช่วยในการออกแบบโดยมีเกณฑ์ซึ่งโดยทั่วไปคือ เงื่อนไขทางเศรษฐศาสตร์เป็นตัวตัดสิน

เนื่องจากเป็นการประยุกต์วิชาการต่าง ๆ เข้าด้วยกันและมีตัวอย่างตลอดจนแบบฝึกหัดของการนำไปใช้งานจริง จึงหวังเป็นอย่างยิ่งว่า หนังสือเล่มนี้คงจะสร้างภาพให้นักศึกษาซึ่งกำลังจะจบเป็นวิศวกรได้เห็นแนวทางในการนำวิชาการความรู้ต่าง ๆ มาผสมผสานกันอย่างมีเหตุมีผลแล้วนำไปออกแบบสร้างระบบได้อย่างมีประสิทธิภาพ และ เนื่องจากปัญหาในการหาสภาพที่เหมาะสมที่สุดในสถานการณ์จริงอาจเป็นปัญหาที่ซับซ้อนประกอบไปด้วยสมการและตัวแปรต่างๆมากมาย การคำนวณธรรมดาเพื่อหาคำตอบในเวลาอันสั้นดังเช่นในห้องเรียนย่อมเป็นไปไม่ได้ ผู้เขียนจึงได้รวบรวมโปรแกรมคอมพิวเตอร์สำหรับในการคำนวณบางวิธีไว้ในภาคผนวกโปรแกรมดังกล่าวได้รับการตรวจสอบว่าใช้งานได้ ดังนั้นจึงเหมาะสำหรับวิศวกรหรือผู้ที่เกี่ยวข้องสามารถนำไปประยุกต์ใช้กับงานที่กำลังแก้ปัญหาอยู่ และเนื่องจากการจำกัดด้วยจำนวนหน้าผู้เขียนไม่สามารถรวบรวมโปรแกรมคอมพิวเตอร์สำหรับการหาสภาพที่เหมาะสมที่สุดทุกวิธีไว้ในหนังสือเล่มนี้ดังที่ตั้งใจไว้แต่แรกแต่ก็ได้แสดงแผนภูมิสายงาน (Flow Chart) แสดงขั้นตอนการคำนวณของเกือบทุกวิธีไว้ซึ่งง่ายในการทำความเข้าใจ ผู้สนใจสามารถเขียนโปรแกรมคำนวณได้เองตามแผนภูมิสายงานที่ให้ไว้

ผู้เขียนขอพระคุณ ศ.ดร.นักสิทธิ์ คูวัฒนชัย และ ศ.ดร. ปิยะวัฒน์ บุญหลง ที่ได้ให้คำแนะนำสิ่งที่เป็นประโยชน์และสิ่งที่ควรแก้ไขจากเล่มที่พิมพ์ในครั้งแรก

ผู้เขียนขอขอบคุณสำนักงานกองทุนสนับสนุนการวิจัย (สกว) เนื่องจากในขณะเขียนหนังสือนี้เป็นช่วงเวลาเดียวกับที่ผู้เขียนได้รับทุนพัฒนานักวิจัย “เมธีวิจัย สกว.” ผู้เขียนสามารถนำเนื้อหาและหลักการในหนังสือเล่มนี้ไปใช้ประโยชน์ในงานวิจัยในขณะเดียวกันก็สามารถก็เอาประสบการณ์จากงานวิจัยมาสอดแทรกลงในหนังสือเล่มนี้

ผู้เขียนขอขอบคุณเพื่อนร่วมงานทุกระดับชั้นที่ให้ความช่วยเหลือด้วยดีเสมอมา

คุณความดีของหนังสือเล่มนี้ ผู้เขียนขอมอบแด่ คุณพ่อและคุณแม่ ซึ่งเป็นผู้ที่มีพระคุณอย่างหาที่เปรียบมิได้ ครูอาจารย์ผู้ประสิทธิ์ประสาทวิชาความรู้แขนงต่างๆ คุณ วีณา วงศ์วิเศษ ซึ่งเป็นภรรยาของผู้เขียนที่เข้าใจในวิชาชีพตลอดจนให้ความช่วยเหลือ เป็นกำลังใจ และรับผิดชอบครอบครัวและลูกๆได้ดีอย่างไม่มีที่ติ ตลอดช่วงเวลาที่เราได้ใช้ชีวิตร่วมกัน ส่วนความผิดพลาดใด ๆ ที่เกิดจากหนังสือเล่มนี้ ผู้เขียนขอน้อมรับไว้แต่เพียงผู้เดียว

(รศ.ดร.สมชาย วงศ์วิเศษ)
ภาควิชาวิศวกรรมเครื่องกล
คณะวิศวกรรมศาสตร์
มหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี

25 กันยายน 2541

Nuclear Engineering and Design

Prof. T.G. Theofanous
University of California, Santa Barbara
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Center for Risk Studies and Safety
6740 Cortona Drive
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January 3, 1997

Dr. Somchai Wongwises
Department of Mechanical Engineering
King Mongkut's Institute of Technology Thonburi
91 Suksawas 48
Bangmod, Radburana
Bangkok 10140, Thailand

Re: NED-96-496 "Study of PWR reflux condensation flow characteristics," by Y. Luwei, C. Tingkuan. X. Jinliang and H. Zhihong

Dear Dr. Wongwises:

I would like to thank you very much for your important contribution toward judging the suitability of the above-referenced manuscript for publication in *Nuclear Engineering and Design.*

Sincerely,

T.G. Theofanous, Editor
Thermal-Hydraulics & Safety

TGT/h

ASEAN Journal on Science & Technology for Development
c/o National Institute of Geological Sciences
College of Science, University of the Philippines, Diliman, Quezon City 1101, PHILIPPINES
Fax (632) 9291266; (632) 9205301 loc. 7118

December 13, 1997

DR. SOMCHAI WONGWISES
Head of Fluid Mechanics Division
Department of Mechanics Division
Department of Mechanical Engineering
King Monkut Inst. Tech. Tnonburi
Suksawad 48, Radburana
Bangkok 10140 Thailand

Dear Dr. Wongwises,

This is to acknowledge receipt of your comments on the paper by entitled"Measurement of radon in Mandakini Valley of Garhwal Himalaya". Your comments will truly of great help to the authors in revising their paper.

Thank you.

Very truly yours,
kqueano
KARLO L. QUEANO
Managing Editor

ajstd97/acknow48

Contact Persons:

Dr. Linda S. Posadas
Department of Science and Technology
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Fax (632) 837-3168

Dr. Graciano P. Yumul, Jr.
National Institute of Geological Sciences
College of Science, University of the Philippines, Diliman, Quezon City 1101, Philippines
Fax (632) 929-1266; (632) 9205301 loc. 7118

15. <u>รายงานการเงิน</u>

<u>รายจ่ายประจำงวดปัจจุบัน</u> (1 มีนาคม 2541 - 31 สิงหาคม 2541)

หมวด (ตามเอกสารโครงการ)	รายจ่ายจากรายงานครั้งก่อน	รายจ่ายคราวนี้	รวมสะสม
1.ค่าจ้าง *	113500	-------	113500
2.ค่าตอบแทนเมธีวิจัย	450000	90000	540000
3.ค่าตอบแทนอื่นๆ	41000	--------	41000
4.ค่าใช้สอย (เอกสารต่างๆ)	98126	--------	98126
5.ค่าวัสดุ	183224	--------	183224
6.ค่าครุภัณฑ์	37000	--------	37000
7.ไปต่างประเทศ	10000	--------	10000
8. -----------------	---------	--------	----------
รวม	932850	90000	1022850

* เนื่องจากหัวหน้าโครงการร่วมลงมือภาคปฏิบัติด้วยจึงลดค่าใช้จ่ายในส่วนนี้ลงไปได้

<u>**จำนวนเงินที่ได้รับและเงินคงเหลือ**</u>

<u>งวดที่ 1</u>	ได้รับจาก สกว	360000	บาท
	ได้จากมหาวิทยาลัย	100000	บาท
	อื่นๆ(เช่นดอกเบี้ย)	....	บาท
	รวม	460000	บาท
	รายจ่าย	367850	บาท
	เหลือ	92150	บาท
<u>งวดที่ 2</u>	ได้รับจาก สกว	360000	บาท
	ได้จากมหาวิทยาลัย	100000	บาท
	อื่นๆ	92150	บาท
	(เช่น ยกมาจากงวดก่อน หรือ ดอกเบี้ย)		
	รวม	552150	บาท
	รายจ่าย	347000	บาท
	เหลือ	205150	บาท
<u>งวดที่ 3</u>	ได้รับจาก สกว	270000	บาท
	ได้จากมหาวิทยาลัย	100000	บาท
	อื่นๆ	205150	บาท
	(เช่น ยกมาจากงวดก่อน หรือ ดอกเบี้ย)		
	รวม	575150	บาท
	รายจ่าย	308000	บาท
	เหลือ	267150	บาท

สาขาย่อย ถนนประชาอุทิศ

ธนาคารกรุงศรีอยุธยา จำกัด (มหาชน)

สำนักงาน 427-1041,1324

ชื่อบัญชี
NAME OF ACCOUNT

~~เมธีวิจัย สกว.~~ -
นายสมชาย วงศ์วิเศษ

บัญชีเลขที่
ACCOUNT NO. 330 1 01633 5

สมุดคู่ฝากเลขที่
SERIAL NO. 0634233

ผู้รับมอบอำนาจ

	วันที่ DATE	รายการ TRANS.	ถอน WITHDRAWAL	ฝาก DEPOSIT	คงเหลือ BALANCE	หมายเลข TLR.ID.
1	29/08/95	CDB		******1,000.00	******1,000.00	7544A
2	04/10/95	CLN		****360,000.00	****361,000.00	5834A
3	27/10/95	CWB	****180,000.00		****181,000.00	7549J
4	13/11/95	CWB	****100,000.00		*****81,000.00	7546J
5	15/11/95	CLB		****100,000.00	****181,000.00	7544
6						
7	28/12/95	INT		******2,651.80	****183,651.80	0003A
8	02/04/96	CWB	******7,000.00		****176,651.80	7546J
9	27/06/96	INT		******4,486.34	****181,138.14	0003A
10	08/08/96	CWB	******4,000.00		****177,138.14	7545
11						
12						
13						
14	23/08/96	CWB	*****20,000.00		****157,138.14	754
	23/08/96	ERR		*****20,000.00	****177,138.14	7547J
15	23/08/96	CWB	*****20,000.00		****157,138.14	7547
16	26/08/96	CWB	*****20,000.00		****137,138.14	7546J
17	28/08/96	CWB	*****30,000.00		****107,138.14	7546J
18	09/09/96	CWB	*****45,000.00		*****62,138.14	7546
19	17/09/96	CWB	*****20,000.00		*****42,138.14	7545
20	30/10/96	CLB		*****15,000.00	*****57,138.14	7545A
	06/11/96	CWB	*****57,000.00		********138.14	7547
21	13/11/96	CLB		****360,000.00	****360,138.14	7542
22						

CDB, CDN ฝากเงินสด
CWB, CWN, CWA ถอนเงินสด
TDB, TDN ฝากโดยการโอน
TWB, TWN ถอนโดยการโอน

ธนาคารกรุงศรีอยุธยา จำกัด (มหาชน)
ปีกแผ่นเป็นแก่นสาร บริการเป็นกันเอง

วันที่ DATE	รายการ TRANS.	ถอน WITHDRAWAL	ฝาก DEPOSIT	คงเหลือ BALANCE	หมายเลข TLR.ID.	ลายเซ็น AUTH.
5/11/96	CWB	******5,000.00		****355,138.14	7547J	
02/12/96	CWB	*****20,000.00		****335,138.14	7541A	
11/12/96	CLN		****100,000.00	****435,138.14	7542A	
12/12/96	TWB	****305,509.00		****129,629.14	7548J	
3/12/96	CWB	*****15,000.00		****114,629.14	7547J	
27/12/96	INT		******3,711.67	****118,340.81	0003A	
03/01/97	CLB		*****10,000.00	****128,340.81	7542A	
03/01/97	CWB	*****20,000.00		****108,340.81	7542A	
14/01/97	CWB	******7,000.00		****101,340.81	7542A	
04/03/97	CWB	*****50,000.00		*****51,340.81	7546	

2

23/05/97	CWB	******5,000.00		*****46,340.81	7547J	
27/06/97	INT		******1,741.26	*****48,082.07	0003A	
6/08/97	CLB		******1,000.00	*****49,082.07	7544A	
0/09/97	CLN		****270,000.00	****319,082.07	7542A	
06/10/97	CWB	*****50,000.00		****269,082.07	7549J	
7/10/97	CWB	*****10,000.00		****259,082.07	7548J	
30/12/97	INT		******3,933.87	****263,015.94	0003A	
09/04/98	TWB	****198,500.00		*****64,515.94	7549J	
9/05/98	CDB		****200,000.00	****264,515.94	0260J	
29/06/98	INT		******5,469.50	****269,985.44	0003A	

2

CLB } ฝากด้วยเช็คเคลียริ่ง
CLN }

TTR โอนทางโทรเลข

BCC เช็คต่างจังหวัด

INT ดอกเบี้ย

ธนาคารกรุงศรีอยุธยา จำกัด (มหาชน)

ปึกแผ่นเป็นแก่นสาร บริการเป็นกันเอง

วันที่ DATE	รายการ TRANS.	ถอน WITHDRAWAL	ฝาก DEPOSIT	คงเหลือ BALANCE	หมายเลข TLR.ID.	ลายเซ็น AUTH.
11/09/98	CDB		******2,800.00	****272,785.44	7541A	

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