✚IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

Evaluation of Mass Fluxes and Phase Parameters to Identify the Adiabatic two Phase Flow Patterns in Vertical And Horizontal Tubes

Anusha Peyyala*, Dr.N.V.V.S.Sudheer

* Department of Mechanical Engineering, P.V.P.Siddhartha Institute of Technology, Vijayawada,India.
Department of Mechanical Engineering, R.V.R & J.C College of Engineering, Guntur, India.

ABSTRACT

Two phase flows arise commonly in a variety of physical, engineering and industrial applications such as filtration, lubrication, spray process, natural gas networks and nuclear reactor cooling etc. The hydrodynamic behaviour of the two phase flows such as pressure drop, void fraction or velocity distribution varies in a systematic way with the observed flow patterns just as in case of a single phase flow, whose behaviour depends upon whether the flow is in the laminar or turbulent regime. Understanding the non linear complex dynamics underlying gas – liquid flows is a significant but challenging problem. The primary task is to characterize and quantify the various flow patterns that often appear complex. The identification of a flow regime automatically provides a picture of the phase boundaries. The location of phase boundaries in turn allows one to make various order of magnitude calculations using integrated forms of the momentum and continuity equations. Such calculations suggest what variables might be worth while investigating and what kind of behaviour is to be expected. Present study focuses on evaluation of mass fluxes and phase parameters to identify the respective flow regime in two phase flows.

Keywords: Mass Fluxes, Phase Parameters, Two Phase Flow patterns, Pattern Maps,Two phase flow heat transfer.

Introduction

The distribution of the liquid and vapour phases for two phase flows in the flow channels are an important aspect of their description. These distributions will take on some commonly observed flow structures which are defined as two phase flow patterns that have particular identifying characteristics. Heat transfer coefficients and pressure drops are closely related to the local two phase flow structure of the fluid and thus two phase flow pattern prediction is an important aspect of modelling, evaporation and condensation. In fact recent heat transfer models for predicting in tube boiling and condensation are based on the local flow pattern which require reliable flow pattern maps to identify the type of flow pattern exists at the local flow conditions predicting the transition from one type of two phase flow pattern to another. Authors [1-16] paid attention in analyzing this problem both experimentally and semi theoretically.

The possible hydrodynamic flow patterns for given system parameters can be demarcated with the aid of plots proposed by Baker [1] and Taitel and Dukler [2].At low velocities of vapour, the condensate tends to roll down the wall towards the bottom leading to stratification of heavier component. Kutateladze [3] developed analysis both for stratified and annular flow of the condensate in a horizontal tube. Lockhart and Martinelli [4] proposed a generalized correlation method for obtaining or determining the two-phase multipliers from which the frictional pressure gradient can be predicted for adiabatic gas liquid flow in a round tube. He also presented data for the simultaneous flow of air and liquids including benzene, kerosene, water, and different types of oils in pipes varying in Diameter from 0.0586 in. to 1.017 in. They correlated the pressure drop resulting from these different flow mechanisms by means of the Lockhart Martinelli parameter (X). Mandhane et al [5]: Plotted maps which show typical condensation paths for low and high flows and are suitable for steam condensing near atmospheric pressure.

Kakac [6] stated that different flow patterns can alter the heat transfer considerably, so that local heat transfer coefficients must be calculated along the length of the tube. O.Zurcher et al [7] proposed an improved two phase flow pattern map for evaporation

in horizontal tubes. This new flow pattern map includes the prediction of the onset of dry out at the top of the tube during evaporation inside horizontal tubes as a function of heat flux. Steiner [8] and Kattan et al [9] proposed the intermittent to annular flow pattern transition to occur at a fixed value of the Martinelli Parameter (X= 0.34 for both Phases turbulent and X= 0.51 for laminar liquid and turbulent vapour flows. But Taitel and Dukler [10] proposed the value of X is equal to 1.6.

Thomas HÖHNE [11] stated that Stratified two-phase flow patterns can occur in the main cooling lines of Pressurized Water Reactors, Chemical plants and Oil pipelines and using the local liquid phase volume fraction value his models distinguished between bubbles, droplets and the free surface. Christopher E. Brennen [12] defined flow pattern as a particular type of geometric distribution of the components. Zhong-Ke Gao [13] proposed a method to characterize and distinguish flow patterns in experimental two phase flows. Jacopo Buongiorno [14] stated that in up flow vertical channel, we can identify several flow patterns/patterns, whose occurrence, for a given fluid, channel geometry & pressure depends on the flow quality and flow rate. Peter A. Kew et al [15] in his paper stated that fundamental requirement of the heat exchanger designer is the ability to predict heat transfer coefficients under the conditions of interest with confidence and the selection of appropriate design correlations. John R.Thome [16] in his book stated that shell side flow patterns and flow pattern maps have received very little attention compared to intube studies and Qualitative, quantitative attempts have been made to obtain flow pattern maps ,but to date no method has been shown to be of general application.

Adiabatic two phase flows
The adiabatic two phase flow is different from the Diabatic flow. In adiabatic flow, heat transfer causes phase change and hence a change of phase distribution and flow pattern. In Diabatic Flow it causes a change in the hydrodynamics such as a pressure drop along the flow path that affects the heat transfer characteristics.

Adiabatic two phase flows
The adiabatic two phase flow is different from the Diabatic flow.
In adiabatic flow, heat transfer causes phase change and hence a change of phase distribution and flow pattern. In Diabatic Flow it causes a change in the

hydrodynamics such as a pressure drop along the flow path that affects the heat transfer characteristics.

Flow patterns in adiabatic vertical tubes
In general two types of flow patterns will occur naming flow patterns in vertical tubes and flow patterns in horizontal tubes. For co-current up flow of gas and liquid in a vertical tube, the liquid and gas phases distribute themselves into several recognizable flow structures and are referred to as flow patterns and are shown in Fig1.
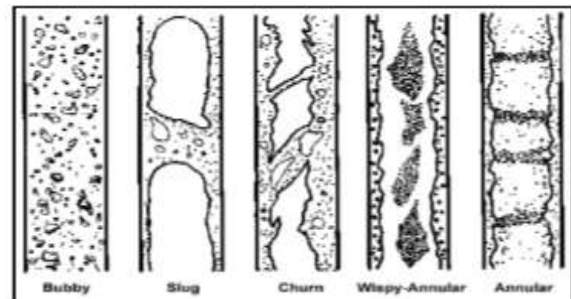

Fig 1. Flow Patterns in Vertical Tubes [16]

Flow patterns in adiabatic horizontal tubes
Two phase flow patterns in horizontal tube are similar to those in vertical flows but the distribution of the liquid is influenced by gravity that acts to stratify the liquid to the bottom of the tube and the gas to the top. Flow patterns for co-current flow of gas and liquid in a horizontal tube are shown in Fig .2 and are categorized as follows.

Perhaps the most common flow configuration in which convective condensation occurs is flow in a horizontal circular tube. This configuration is encountered in air-conditioning and refrigeration condensers as well as condensers in Rankine power cycles.

Although convective condensation is also sometimes contrived to occur in concurrent vertical downward flow, horizontal flow is often preferred because the flow can be repeatedly passed through the heat exchanger core in a serpentine fashion. Because most of the heat transfer associated with the condensation process takes place under annular flow it is obviously of primary importance to the design of condensers operating at low to moderate pressures. It is not surprising therefore that most efforts to develop methods for predicting internal convective condensation heat transfer have focused on annular flow.

Condensation during slug, plug or bubbly flow at the end of the condensation process as received much less attention. Annular flow is also somewhat easier to model analytically than the intermittent slug or plug flows. The main differences between the patterns observed for horizontal flow and vertical flow is that there is often a tendency for stratification of the flow. Regardless of the flow regime, the vapour tends to migrate towards the top of the tube while the lower portion of the channel carries more of the liquid. At very low quality bubbly flow is often observed for horizontal flow. However as indicated in Fig. 2 the bubbles because of their buoyancy, flows mainly in the upper portion of the tube.
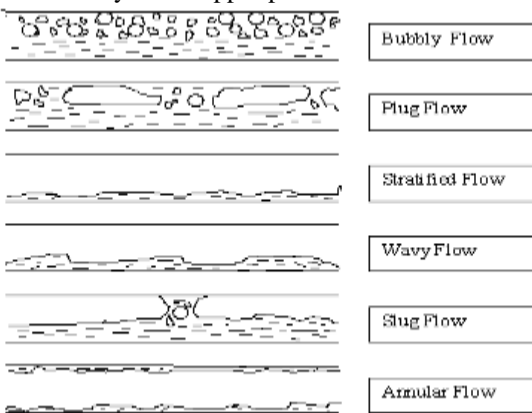

Fig .2. Schematic representations of flow patterns observed in
Horizontal co-current gas-liquid flow.

As the quality is increased in the bubbly regime, coalescence of small bubbles produces larger plug-type bubbles, which flow in the upper portion of the tube. This is referred to as the plug flow regime. At low flow rates and somewhat higher qualities, stratified flow may be observed in which liquid flowing in the bottom of the pipe is separated from vapour in the upper portion of the pipe by a relatively smooth interface. If the flow rate and/or the quality is increased in the stratified flow regime, eventually the interface becomes Helmholtz-unstable, whereupon the interface becomes wavy. This type of flow is categorized as wavy flow. The strong vapour shear on the interface for these circumstances, together with the formation and breaking of waves on the interface, may lead to significant entrainment of liquid droplets in the vapour core flow. At high liquid flow rates, the amplitude of the waves may grow so that the crests span almost the entire width of the tube, effectively forming large slug-type bubbles. Because of their buoyancy, the slugs of vapour flowing along the tube skew towards the upper

portion of the tube. In other respects it is identical to slug flow in vertical tubes, and hence it is referred to as slug flow.

At high vapour velocities and moderate liquid flow rates, annular flow is observed for horizontal gas-liquid flow. For such conditions, buoyancy effects may tend to thin the liquid film on the top portion of the tube wall and thicken it at the bottom. However at sufficiently high vapour flow rates the vapour flow is invariably turbulent, and strong lateral Reynolds stresses and the shear resulting from secondary flows may serve to distribute liquid more evenly around the tube perimeter against the tendency of gravity to stratify the flow. The strong vapour shear may also result in significant entrainment of liquid in the vapour core. Because gravitational body forces are often small compared to inertia effects and turbulent transport of momentum, the resulting flow for these circumstances is generally expected to differ little from annular flow in a vertical tube under similar flow conditions.

Adiabatic flow pattern maps
To predict the local flow pattern in a tube a flow pattern map is used. It is a diagram that displays the transition boundaries between the flow patterns and is typically plotted on log – log axes using dimensionless parameters to represent the liquid and gas velocities.

MSS flux values to identify the two phase flow patterns in vertical tubes
Fair in 1960 and Hewitt and Roberts in 1969 proposed widely quoted flow pattern maps for vertical up flow.

Fair map
First one must calculate the value of the x-axis and y-axis for the particular application at hand to utilize the Fair map which can be seen in Fig.3. The two values are then used to read vertically up and horizontally across the graph to find the point of intersection. The location of this point thus identifies where the flow is in the bubbly flow, slug flow, annular flow or mist flow regime. The dark lines show the transition thresholds between the patterns.
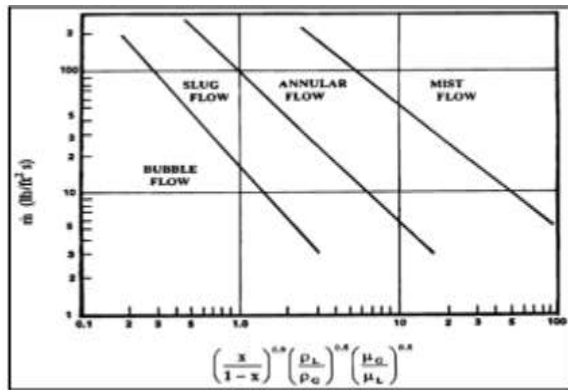
Fig3. Two Phase Flow Pattern Map of Fair for Vertical Tubes. [16]

Hewitt and roberts map

For vertical up flow, the mass velocities of the liquid m_L and gas m_G must be first calculated using the local vapour quality to use the Hewitt and Roberts 1969 map which can be seen in Fig 4.. Then the values of x and y coordinates are determined and the intersection of these two values on the map identifies the flow pattern predicted to exist at these flow conditions.
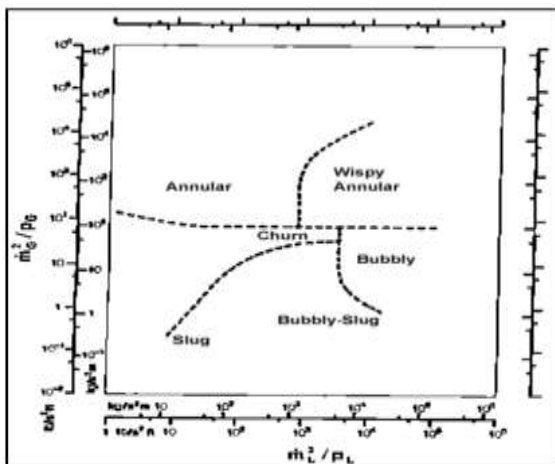

Fig4.Two Phase Flow Pattern Map of Hewitt and Roberts 1969 For Vertical Tubes [16]

Phase parameter values to identify the two phase flow patterns in horizontal tubes

The most widely quoted flow pattern maps for predicting the transition between two phase flow patterns for adiabatic flow in horizontal tubes are those of Baker in 1954 [1] and Taitel and Dukler in 1976 [2].

Baker map

To utilize the Baker map for horizontal two – phase flow in tubes first the mass velocities of the liquid and vapour must be determined which can be seen in Fig 5. Then gas phase parameter (λ) and liquid phase parameter (ψ) are to be calculated.
The gas Phase parameter λ is,

$$\lambda = [\left(\frac{\rho_G}{\rho_a}\right) \times (\frac{\rho_L}{\rho_W})] \tag{1}$$

The liquid phase parameter ψ is,

$$\Psi = \left[(\frac{\sigma_W}{\sigma}) \times \left[\left(\frac{\mu_L}{\mu_W}\right) \times (\frac{\rho_L}{\rho_W})\right]\right] \tag{2}$$

Then the values of x-axis and y-axis are then determined to identify the particular flow patterns.
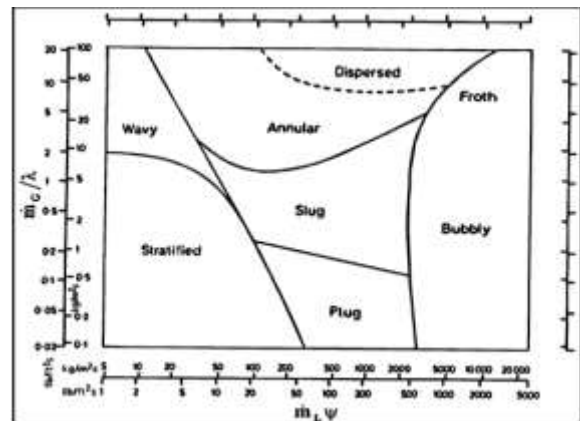

Fig 5: Two Phase Flow pattern map of Baker for Horizontal Tubes [16]

Taitel and dukler [1] map

To identify the particular flow regime using Taitel and Dukler [1] map for horizontal flow tubes there are several parameters that need to be calculated. The map uses the values of X, Fr_G ,T, K and is composed of three graphs which can be seen in Fig 6.
The Lockhart Martinelli parameter X is,

$$X = [[\frac{dp}{dz}]_L \quad [\frac{dp}{dz}]_G]^{1/2} \tag{3}$$

The gas Froude number Fr_G is,
$$Fr_G = \frac{m_G}{[\rho_G \times (\rho_L - \rho_G) \times d_i \times g]1/2} \tag{4}$$

Taitel parameter T is,
$$T = [\frac{\frac{dp}{dz_L}}{g \times (\rho_L - \rho_G)}]^{1/2} \tag{5}$$

Where g = acceleration due to gravity = 9.81 m/s^2

Dukler parameter k is,
$$K = Fr_G \, Re_L^{\ 1/2} \qquad (6)$$

Where the liquid phase and vapour phase Reynolds numbers are,

$$Re_L = \left[\frac{m_L \times d_i}{\mu_L}\right] \qquad (7)$$

$$Re_G = \left[\frac{m_G \times d_i}{\mu_G}\right] \qquad (8)$$

The Pressure Gradient of the flow for Phase K where K is either Liquid or Gas is ,

$$\left(\frac{dp}{dz}\right)_K = -\frac{2 \times f_{K} \times m_K^2}{\rho_K \times d_i} \qquad (9)$$

For $Re_K < 2000$, the laminar Flow Friction Factor Equation is,

$$f_K = \frac{16}{Re_K} \qquad (10)$$

For $Re_K > 2000$, the turbulent or transition flow the friction factor equation is,

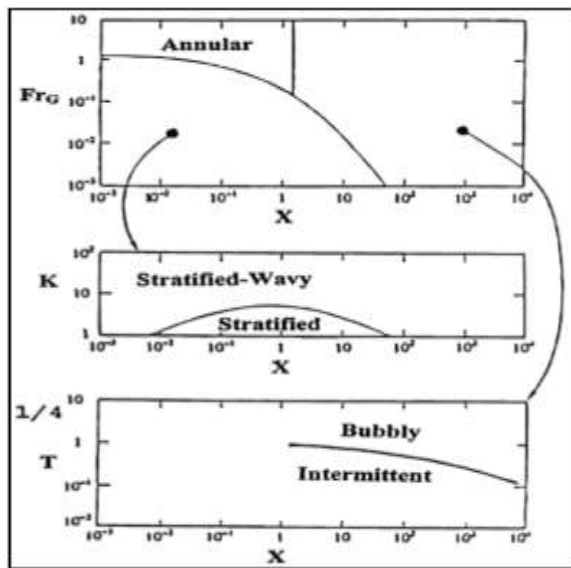$$f_K = \frac{0.079}{Re_K^{1/4}} \qquad (11)$$

Fig 6. Two Phase Flow pattern map of Taitel and Dukler [2] for Horizontal Tubes [16]

To implement the map one must first determines the Martinelli parameter X and Fr_G from eq (3) ,(4). Using these tow parameters on the top graph, if their coordinates fall in the annular flow regime, then the flow pattern is annular. If the coordinates of Fr_G and X fall in the lower left zone of the top graph, then K is calculated using eq (6). Using K and X in the

middle graph, the flow regime is identified as either stratified – wavy or as fully stratified. If the coordinates of Fr_G and X fall in the right zone on the top graph then T is calculated from eq (5). Using T and X in the bottom graph the flow regime is identified as either bubbly flow or intermittent plug or slug flow.

These flow pattern maps were all developed for adiabatic two phase flows but are often extrapolated for use with the Diabatic processes of evaporation or condensation. As with extrapolation this may or may not produce reliable results

Table 1 : Coordinate formulas of various maps for vertical and horizontal flows:

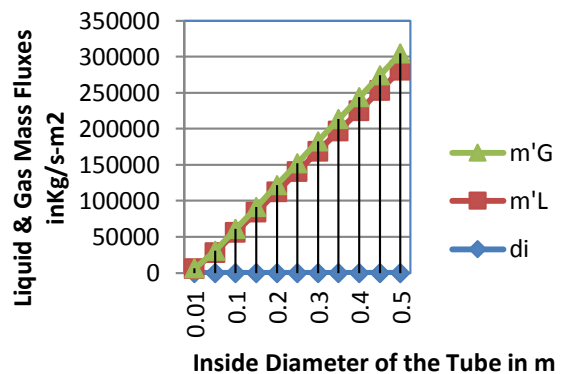| Type of flow	Type of map	x- axis	y-axis
vertical	fair map	$(\rho_G/\rho_L)^{0.5}$ $(\mu_L/\mu_G)^{0.1}$ $(1-x/x)^{0.9}$	mass Flux m in Kg/sec-m^2
	hewitt and roberts map	m_L^2/ρ_L	m_G^2/ρ_G
horizontal	baker map	$m_{L*}\Psi$	m_G/λ
	taitel and dukler map	X	Fr_G , K, T

Results

Figure 7: Effect of Inside Diameter on Liquid Mass Flux and Gas Mass Flux Values.
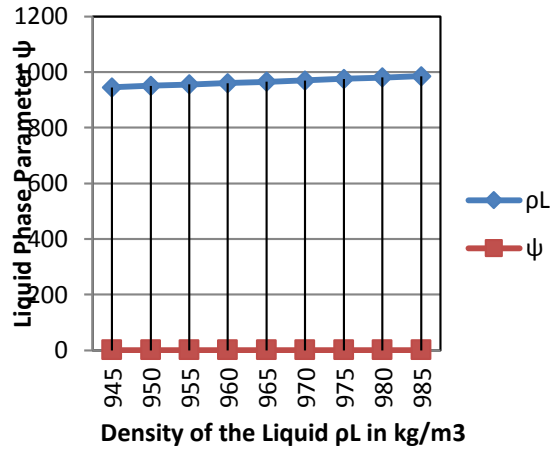

Figure 8: Variation of Liquid Phase Parameter Value by changing the Density of Liquid Value.
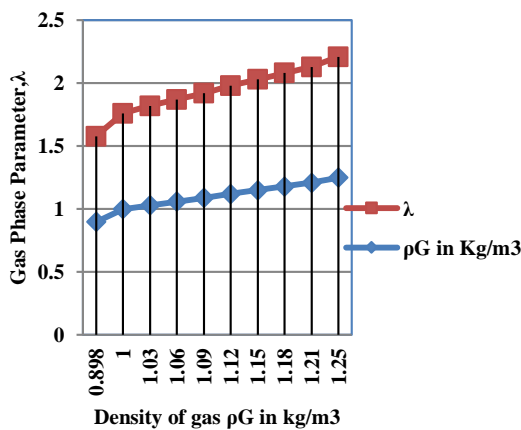

Figure 9: Variation of Gas Phase Parameter Value by changing the Density of Gas Value.
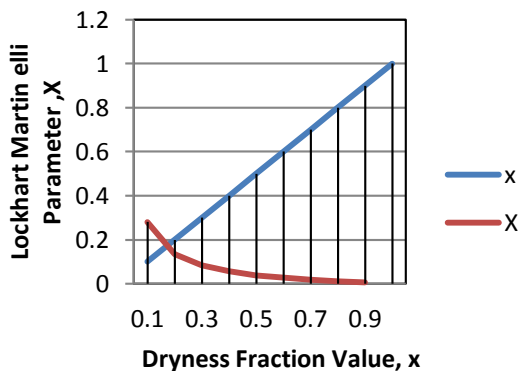

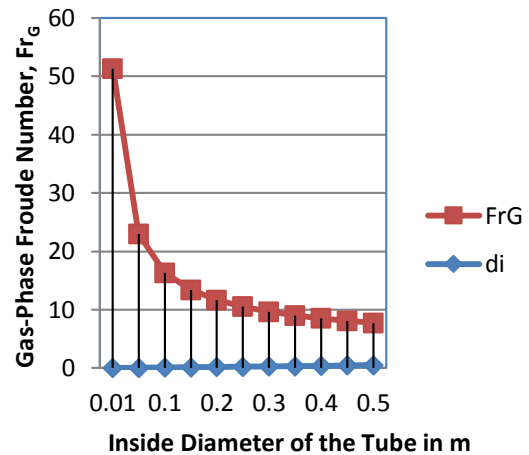*Figure 10: Lockhart Martinelli parameter variation with Dryness Fraction from 0.1 to 1*

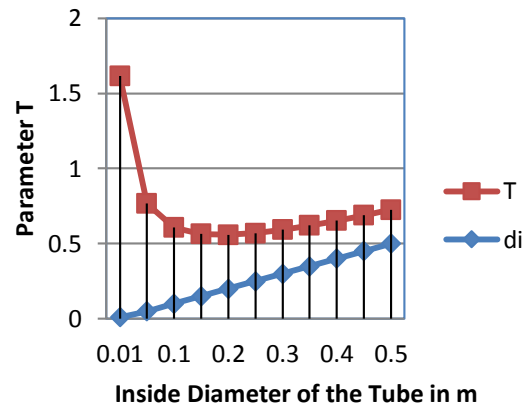*Figure 11: Variation of Fr_G Value by changing the inside diameter of the tube Value.*

Figure 12: Variation of Taitel Parameter T Value by changing the inside diameter of the tube Value.
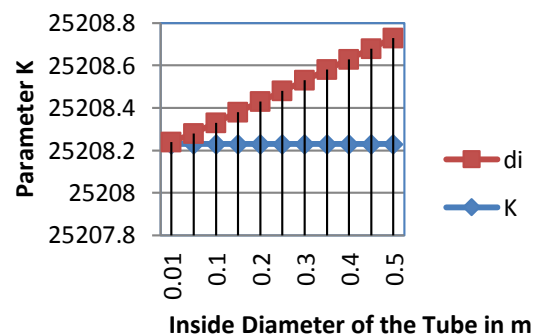

Figure 13: Variation of Dukler parameter K Value by changing the inside diameter of the tube Value.
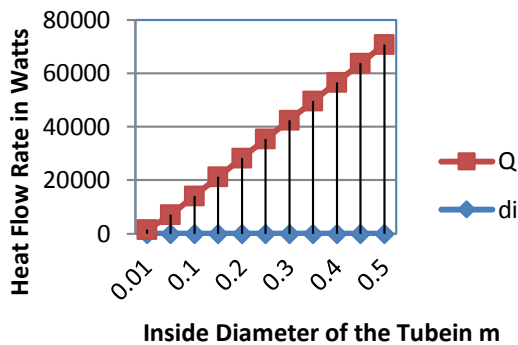
Figure 14: Effect of Inside Diameter on Heat Flow Rate Q

Discussion

By increasing the inside diameter of the tube , Liquid and Gas mass flux values are increasing which can be seen in Fig.7.Liquid phase parameter value and Gas phase parameter values are linearly varying with the changes in densities of respective liquid and gas values which can be observed in Fig.8 & Fig.9.By observing Fig.10 we can understand that the X value is decreasing by increasing the dryness fraction value from 0.1 to1.By varying the inside diameter of the tube the FrG, T, K ,Q are varying which can be seen in Figs11-14.For the obtained values we van observe that the flow patternis Bubbly. Therefore to identify the respective flow patternone must calculate the massfluxes and phase parameter values in vertical and horizontal tubes.

Conclusion

Flow pattern maps have an important influence on prediction of the Void fraction, flow boiling and convective condensation heat transfer coefficients, and two phase pressure drops. The prediction of flow pattern transitions and their integration in to a flow pattern is very important to understand the two phase flow phenomenon and designing of two –phase equipment. For vertical tubes the most widely recommended flow pattern maps are Fair 1960 and Hewitt & Roberts 1969. For horizontal tubes the methods of Taitel and Dukler 1976 [2] and Baker 1954 [1] are widely used. Evaluation of Liquid and Gas mass flux values are important to determine the type of flow pattern in vertical tubes. Whereas evaluation of Gas phase parameters and Liquid Phase parameters are useful in predicting the type of flow regime in horizontal flows. Based on these values one can identify the respective flow pattern and its effect on two phase flow heat transfer coefficients and

pressure drops which are needed while designing heat exchanger equipments.

Future scope of work

Two-phase flow patterns play an important role in micro scale processes, influencing heat transfer, void fraction, pressure drop, critical heat flux, vapour/gas separation, etc. Particular topics are,   principal flow patterns needed to have in the micro scale, usefulness and accuracy of flow pattern maps, unifying the flow pattern maps for adiabatic and Diabatic flows, critical needs in experimental and analytical techniques for smaller scales.

Nomenclature

λ	= Gas phase parameter
Ψ	= Liquid phase parameter
T	= Taitel Parameter
K	= Dukler Parameter
k	= Dukler Parameter
Fr_G	= Gas phase Froude number
ρ	= Density in kg/m^3
σ	= Surface tension in N/m
μ	= Dynamic viscosity in Ns/m^2
m	= mass flux or mass velocity in Kg/sec –m^2
g	= acceleration due to gravity, 9.81 m/s^2
Re	= Reynolds number
D	=diameter in m
X	=Lockhart Martinelli Parameter
x	= Dryness Fraction

Subscripts:

G	= gas
L	= liquid
i	= inside
a	=air
w	=water

Reference properties

ρ_{water}	= 1000 kg/m^3
ρ_{air}	= 1.23 kg/m^3
μ_{water}	= 0.001 Ns/m^2
σ_{water}	= 0.072 N/m

References

[1] O.Baker, "Simultaneous flow of oil and gas", Oil Gas J.53 (1954) 185-195.

[2] Y. Taitel, A.E. Dukler, "A model for predicting flow regime transitions in horizontal and near horizontal gas liquid flow", AICHE J.22 (1976) 47-55.

[3] S. S. Kutateledze, "Aspects of heat transfer and hydraulics of two phase medium", Energy publishing house, Moseow, 1961.

[4] Lockhart R.W., Martinelli R.C., "proposed correlation of data for isothermal two phase,

two component flow in pipes", Chem.Engrg.Progress, Vol.45, PP. 38-48, 1949.

[5] Mandhane, J.M..,Gregory,G.A..,and Aziz., "A flow pattern map for gas-liquid flow in horizontal pipes", Int.J.Multiphase flow,vol.1,no.4,pp.537-553,1974.

[6] Kakac (1991) Boilers, Evaporators and Condensers, Wiley, Newyork.

[7] O.Zurcher, D.Favrat, J.R.Thome, "Development of a Diabatic two phase pattern map for horizontal flow boiling", Department of Mechanical Engineering, Swiss Federal Institute of Technology, CH-1015 Lausanne, Switzerland, International Journal of Heat and Mass Transfer 45 (2002) 291-301.

[8] D.Steiner, Zweiphasenstromung in Apparatenelementen, Hochschulkurs Warmeubertragung II.Forschungs- Gesellschaft Verfahrenstechnik e.V.Dusseldorf, 1983.

[9] N.Kattan, J.R.Thome, D.Favarat, Flow boiling in horizontal tubes Part1: "Development of a Diabatic two phase flow pattern map", J. Heat Transfer 120 (1998)140 - 147

[10] Y.Taitel ,A.E. Dukler, "A model forpredicting flow regime transitions in horizontal and near horizontal gas-liquid flow",AIChE.J.22(1) (1976) 47-55.

[11] Thomas HÖHNE, "EXPERIMENTS AND NUMERICAL SIMULATIONS OF HORIZONTAL TWO PHASE FLOW REGIMES", Seventh International Conference on CFD in the Minerals and Process Industries CSIRO, Melbourne, Australia 9-11 December 2009.

[12] Christopher E. Brennen , "Fundamentals of Multiphase Flows", California Institute of Technology Pasadena, California, Cambridge University Press 2005 ISBN 0521 848040.

[13] Zhong-Ke GAO, "Phase Characterization of experimental gas – liquid two –phase flows", Physics Letter A374 (2010)4014-4017

[14] Jacopo Buongiorno, Associate Professor of Nuclear Science and Engineering, 22.06 Engineering of Nuclear Systems, ITS Department of Nuclear Science and Engineering, "NOTES ON TWO-PHASE FLOW, BOILING HEAT TRANSFER, AND BOILING CRISES IN PWRs AND BWRs".

[15] Peter A. Kew and Keith Cornwell, "CORRELATIONS FOR THE PREDICTION OF BOILING HEAT TRANSFER IN SMALL-DIAMETER CHANNELS", Department of Mechanical and Chemical Engineering, Herriot-Watt University, Edinburgh, EH 14 4AS. UK, Applied Thermal Engineering Vol. 17. Nos. 8-10. pp. 705-715. 1997.

[16] Wolverine Engineering Data Book III , by Professor John R.Thome, Director, Laboratory of Heat and Mass Transfer (LTCM), Faculty of Engineering Science and Technology ,Swiss Federal Institute of Technology Lausanne(EPFL), Chapter 12.

Author biblography

	AnushaPeyyala Assistant Professor, Department of Mechanical Engineering, P.V.P.Siddhartha Institute of Technology,Vijayawada,India
	Dr.N.V.V.S.Sudheer Associate Professor, Department of Mechanical Engineering, R.V.R & J.C College of Engineering, Guntur, India.