IOSR Journal Of Applied Physics (IOSR-JAP)
e-ISSN: 2278-4861.Volume 12, Issue 2 Ser. I (Mar. – Apr. 2020), PP 42-53
www.Iosrjournals.Org

A Simplified Liquid Holdup Model for Annular Flow in Horizontal Pipes.

Osokogwu, U and Salam, K. K.
Oil and Gas Engineering Centre
School of Water, Energy and Environment
Cranfield University, Bedfordshire, MK 43 0AL, UK

Abstract
Accurate determination of liquid holdup in annular flow is important not only to the oil and gas industry but also to the nuclear power plant industries, chemical and refining industries where reactors, heat exchangers, evaporators, etc are used.In this study, a simplified liquid holdup for annular flow was developed from volumetric flow rate and pipe diameter which could be easily obtained in the field. The volumetric flow rate could be obtained from the separators in the field while the pipe is known by the field engineers or personnel. The essence was to present a simple model void of complexity to the industries in need. The proposed model was validated using measured liquid holdup from the experiments conducted in 2-inch (0.0504m) flow loop where annular flow conditions were presented. Again, the results from the proposed model were compared with different liquid holdup models, but among them,Beggsand Brill (1973) matched preferably with both the proposed and the measured liquid holdup. Based on this, comparison plots between the proposed model,Beggs and Brill (1973) and measured liquid holdup were extended. In all, the proposed model presented good match at all flow conditions with the measured liquid holdup while Beggs and Brill (1973) over predicted liquid holdup at low superficial liquid velocity.

Keywords: *Gas-liquid flow, holdup, annular flow, model, high velocity*

Date of Submission: 09-03-2020 Date of Acceptance: 23-03-2020

I. Introduction

Gas-liquid annular flow, is a complex flow often encountered in petroleum production systems, where reservoir fluids are conveyed to the surface via the vertical tubular pipes and flowlines, likewise in the nuclear power plants, the chemical and refining processes (e.g. reactors, heat exchangers). In annular flow, the gas, together with the entrained liquid droplets, flow within the core of the pipe at high velocitywhile the liquid flows as film along the walls of the pipe under the influence of gravity, Sergey *et al.,* (2014), Kesana*et al.,* (2012).

Annular flow is predominantly gas induced stream, flowing at high velocity at the core centre of the pipe with the entrained liquid droplets,while the liquid phase which is greatly impacted upon by the dominant effects of the gas phase, flows circumferentially across the walls of the pipe in a non-uniform manner. The large difference between the density of gas phase and the liquid phase, creates the liquid holdup in the pipe.

Liquid holdup is the volumetric fraction of liquid phase occupied in a pipe with respect to the cross-sectional area of that pipe. Liquid hold up has been extensively investigated in annular flow in horizontal pipes, but despite the experimental investigations and modelling, there is still no universalliquid holdup model on annular flow in the industries. The choice of a model, is often based on the experience and expertise of the field engineers or the users. Among the existing models are:Beggs and Brill (1973), Chen and Spedding (1981), Kadambi (1985), Tandon*et al.,* (1985), Xiao *et al.,* (1990), Abdul-Majeed (1996) and Spedding*et al*., (1998). Again, the models as presented in Table 1, are all unique in their respective ways, even though, Beggs and Brill (1973) ispreferably used in horizontal pipes in petroleum industry.

Beggs and Brill (1973)liquid holdup model, was developed using Froude number with mixture velocity and a non-slip liquid conditions. The non-slip, could be obtained from volumetric liquid flow rate divided by the sum of the volumetric liquid and gas flow rates.The model is specifically for segregated flow conditions (stratified-smooth, stratified-wavy and annular flow) in horizontal pipes.

Chen and Spedding (1981) considered stratified and annular flow conditions, using Lockhart-Martinelli (1949) parameter and correlation factors obtained from the experiments conducted for liquid holdup. The correlation factors were to account for the different pipe diameters with respect to annular flow in pipes.

Kadambi (1985) in his study concentrated on pressure drop and void fraction in annular flow, using polynomial velocity profile of Pai (1953). Pai (1953) studied turbulent flow in a single-phase, while Kadambi improved on it on two-phase annular flow. In Kadambi (1985) model, Hutchinson and Whalley (1973) empirical correlations for liquid entrainment were considered. In conclusion, Kadambi (1985) presented a void fraction model, where liquid hold could be obtained.

Xiao *et al.*,(1990) also in their study, developed a liquid holdup model from a fully developed steady-state annular flow in pipes. They further noted, that it is the geometric relationships of flow that differs in the analysis of annular flow from stratified flow. In their model, liquid holdup in the gas core and the liquid entrainment were considered. While the geometric parameters as a function of non-dimensional mean film thickness were also evaluated and presented in the model. The liquid entrainment was defined based on Oliemans*et al.,* (1986) correlations.

Abdul-Majeed (1996) studied Taitel and Dukler (1976) mechanistic model for liquid holdupand simplified it by replacing the implicit model with explicit model. This was achieved by introducing empirical modification using regression analysis with liquid holdup and dimensionless value as dependent variable, while Lockhart-Martinelli(1949) parameter was presented as independent variables.

Spedding*et al.,* (1998) carried out experimental investigations of air-water flow on horizontal and nearly horizontal pipes with inclination angles of (+5^o, -5^o) with a pipe internal diameter of 58mm. Spedding*et al.,* (1998) presented a liquid holdup correlation with the concept of pipe diameter and volumetric flow rates.

Tandon*et al.,* (1985)investigated void fraction in two-phase annular flow, (Garcial*et al.*, 2005). The void fraction equations were analytically developed and based on Lockhart-Martinelli (1949) parameter, (Garcial*et al.,* 2005).

Having reviewed the above liquid holdup models, a simplified liquid holdup model is presented in this study. The essence, is to progress the work of the field engineers who are directly involved in such operations by facilitating the optimum delivery of results, without the encumbrances of using rigorous software to present liquid holdup in the time of need. The proposed simplified model was developed based on volumetric liquid and gas flow rates with respect to the pipe diameter and its radius as considered necessary for annular flow in horizontal pipes. From the volumetric flow rates from their separators and the pipe diameters already known, the liquid holdup could be obtained, likewise the gas holdupand the film thickness by extension, using Tso & Sugawara, (1990) model in equation 1.

$$\delta = \tfrac{1}{2} D\left[1-\left(1-H_L\right)^{0.5}\right] \qquad (1)$$

In Table 1, is the summary of the liquid holdup models with the variables and the specific flow conditions.

Table 1: Liquid Holdup Models used in Annular Flow in Horizontal pipes.

Authors	*Model*	*Variables*	*Flow*
Begss& Brill (1973)	$H_L(0) = \frac{0.98\lambda^{0.4846}}{(N_{FR})^{0.0868}}$	$\lambda = \frac{q_L}{(q_L + q_g)}$ $N_{FR} = \frac{v_m{}^2}{gd}$	***Segregated [Stratified, wavy, Annular Flow]***
Chen &Spedding (1981)	$H_L = \frac{X^{\frac{2}{3}}}{k_i + X^{\frac{2}{3}}}$	*K_i=2.5 [pipe D≥0.2m]K_i=6 [D≤0.045m]* *K_i=1 [0.045-0.2m]* $X = \left[\frac{V_{sg}\rho_g\mu_L}{V_{sL}\rho_L\mu_g}\right]^m \frac{\rho_L V_{sl}^2}{\rho_g V_{sg}^2}$	***Annular Flow***
Kadambi (1985)	$\alpha = \eta_i{}^2$ *Based on (Pai,1953)*	$u_L = u_{mL}\left[1+\frac{s_L - n}{n-1}\eta^2 + \frac{1-s_L}{n-1}\eta^{2n}\right]$	***Annular Flow***
Tandon et al, (1985)	$H_G = 1-1.928R_{eL}{}^a\left[F(X_{TT})\right]^b + 0.9293R_{eL}{}^c\left[F(X_{TT})\right]^d$ $H_G = 1-0.38R_{eL}{}^e\left[F(X_{TT})\right]^b + 0.0361R_{eL}{}^g\left[F(X_{TT})\right]^d$	$50 < R_{eL} < 1125$ *[a=-0.315,b=-1c=-0.63, d=-2, e=-0.088, g=-0.176]* $F(X_{TT}) = 0.15\left[X_{TT}^{\,b} + 2.85X_{TT}^{-0.476}\right]$ $X_{TT} = \left(\frac{\mu_L}{\mu_G}\right)^{0.1}\left(\frac{1-x}{x}\right)^{0.9}\left(\frac{\rho_G}{\rho_L}\right)$	***Annular Flow, [Gas holdup model] H_L=1-H_g***
Xiao et al. (1990),	$H_L = 1-\left(1-2\frac{\delta}{D}\right)^2 E_c$	$E_C = \frac{V_{SL}FE}{V_{SG} + V_{SL}FE}$	***Annular Flow***
Abdul-Majeed (1996)	$E_1 = \exp\left(A + BR - CR^2 + DR^4\right)$	*A = -0.9304919, B = 0.5285852, C = -9.219634x10^{-2}, D = 9.02418x10^{-4} ,* *R = In(X)*	***Turbulent Flow*** ***Annular Flow***

		$X = \left[\dfrac{V_{sg}\rho_g\mu_L}{V_{sL}\rho_L\mu_g}\right]^m \dfrac{\rho_L V_{sl}^2}{\rho_g V_{sg}^2}$	
***Spedding et al.* (1998)**	$H_L = (3.5 + D)\left(\dfrac{Q_L}{Q_T}\right)^{0.7}$	$V_{sg} \geq 6m/s$	***Annular Flow***
This Study (Proposed)	$H_L = \left(\dfrac{q_L}{q_g}\right)\left(\dfrac{d_1}{d_2}\right)$	d_1= full pipe diameter, d_2= pipe radius	***Annular Flow***

II. Experiments Setup

In this study, experiments were conducted using a 2-inch (0.0504m) horizontal pipe. The pipeline was a 28.68m closed-loop system with water inlet pipe connected to a water storage tank and the outlet pipe connected back to the same water storage tank. The plastic fibre water storage tank with a capacityof 4.4m^3, was designed with double chambers: suction chamber that acts as water source to the experimental test flow loop and returning chamber that retains the returning water. The flow loop had 2-pairs of pressure transducers installed at 2.13m apart, light emission diode infrared sensors (LED), two double pairs of conductivity rings sensors installed at 0.07m apart, pairs of conductance probes installed at 0.20m apart and the temperature sensors. The gas (air) was delivered using a 2-inch (0.0504m) air pipe from a compressorwith a capacity of 400m^3/h and a maximum discharge pressure of 10bar. The air was metered using a gas flowmeter (vortex) with temperature and pressure sensors installed on the air flow line as presented in Figure 1.

On the sketch of the experimental 2-inch flow loop facility in Figure 1, the red flow line represents the air supply pipe, green line is for sand/water slurry pipe, the blue shows the water pipe flow and the pink represents multiphase flow to the delivery water tank.

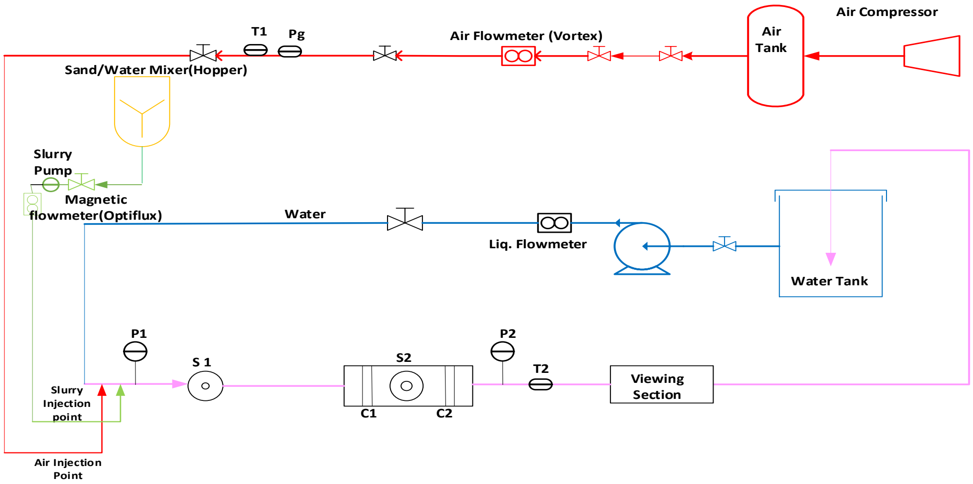

Figure 1.A Sketch of Experimental 2-inch Flow Loop Facility used

2.2 Calibration Setup and Procedures

Liquid holdup in annular flow from the experiments were obtained using conductivity ring sensors which measuredthe resistance based on the liquid volume fraction in the horizontal pipe and presents an output voltage as its readings in the LabVIEW. The process involved a bench calibration with different cylindrical plastic blocks of 49mm, 48mm, 46mm, 42.34mm and 33.40mm with a length of 169mm which were inserted into the calibration tool in Figure 2,with internal diameter of 50mm (0.050m) and length of 170mm.

Figure 2. Bench Calibration Instruments for the Experiment

To replicate the experimental test conditions, the annular bench calibrations wereconducted using a horizontal pipe as presented in Figure 2. Results obtained were analysed and plotted to obtain a reference equation which was used on the experimental data to present the liquid holdup in Figure 4. Table 2, is the test flow properties, their range and units in the experiments conducted in this study.

Table 2: Experimental Properties and Ranges Used.

Properties	Range	Units
Temperature	*16.5-19.3*	^0C
Pipe internal diameter (flow loop)	*0.0504*	*m*
Air flow line internal diameter	*0.0504*	*m*
Superficial liquid velocity	*0.0501-0.2001*	*m/s*
Superficial gas velocity	*8.0774-23.7260*	*m/s*

III. Mathematical Development

The simplified phenomenological liquid holdup model was developed with the concept ofannular flow in horizontal pipes. In the development, the following assumptions were made: that liquid hold up occupies half or less than the entire diameter of the pipe, length is less significant in developing the equation, viscosity is less important and will assume mass liquid or gas mass flow rate. Density was considered important in the concept of the liquid hold up model as shown in Figure 3.

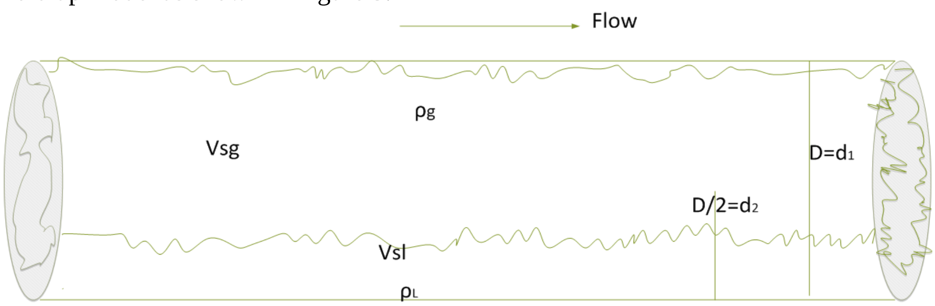

Figure. 3: A Sketch of Model Development Concept for Annular Flow in Horizontal Pipe.

To model it, the density of gas and the density of the liquid will be of priority as follows:
Density = Mass divided by volume.

$$\rho = \frac{M}{V} \quad (2)$$

For two-phase flow, density will be classified as liquid or gas density as below:

$$\rho_L = \frac{M_L}{V} \quad (3)$$

$$\rho_g = \frac{Mg}{V} \quad (4)$$

Therefore, for the liquid phase:

$$\rho_L = \frac{M_L}{V}$$

Above equation 2 could also be expanded as:

$$\rho_L V = M_L \quad (5)$$

The interest is on V, hence we make V the subject of the formula by dividing through by liquid density as:

$$\frac{\rho_L V}{\rho_L} = \frac{M_L}{\rho_L} \quad (6)$$

$$V = \frac{M_L}{\rho_L} \quad (7)$$

However, mass liquid flow rate is a function of liquid density, superficial gas velocity and cross-section area of the pipe.

Thus, the above equation 6 becomes;

$$V = \frac{\rho_L V_{SL} A}{\rho_L} \qquad (8)$$

As density concealed out, equation 8 reduces to:

$$V = V_{SL} A \qquad (9)$$

But volume is a function of area and height. Height, which in annular flow conditions, mostly horizontal pipes is thickness,

$$V = A \times h \qquad (10)$$

By substituting equations 9 into equation 10, yields:

$$Ah = V_{SL} A \qquad (11)$$

Without losing focus, our interest in on height, so dividing through by Area, the above equation 11, becomes:

$$\frac{A.h}{A} = \frac{V_{SL} A}{A} \qquad (12)$$

$$h_L = V_{SL} \qquad (13)$$

Following the same procedures by using density of gas, will alsoyield this:

$$h_g = V_{Sg} \qquad (14)$$

For annular flow in pipes, the gas velocity is always higher than the liquid velocity. Also, the gas occupies more space in term of height in the pipe than the liquid phase. Therefore, the liquid height is divided by the gas height to obtain liquid hold as follows:

$$\frac{h_L}{h_g} = H_L = \frac{V_{SL}}{V_{Sg}} \qquad (15)$$

Again, note that,

$$V_{SL} = \frac{q_L}{A}, V_{Sg} = \frac{q_g}{A} \qquad (16)$$

Thus, equation 16 when substituted into equation 15, becomes:

$$H_L = \frac{V_{SL}}{V_{Sg}} = \frac{\frac{q_L}{A}}{\frac{q_g}{A}} \qquad (17)$$

$$K = \frac{d_1}{d_2} \qquad (18)$$

K, which is part of the concept is then multiplied with the obtained result of equation 17, to as equation 18. Therefore, liquid hold-up in annular becomes;

$$H_L = \left(\frac{q_L}{q_g}\right)\left(\frac{d_1}{d_2}\right) \qquad (20)$$

IV. Results and Discussion

The liquid holdup obtained from the experiments is plotted as the graph of liquid holdup against the superficial gas velocity shown in Figure 4. The graph shows that liquid holdup increases with increase in superficial liquid velocity as Vsl=0.1851m/s has the highest liquid holdup as presented in Figure 4. While liquid holdup decreases with increase in superficial gas velocity in horizontal pipes. The plot of Vsl=0.1355m/s with a hump from Vsg=16m/s was an upward fluctuation from superficial liquid velocity which was detected from the conductivity ring sensors. The error bar on the plot of Vsl=0.1851m/s, was the error propagation of 0.0067m/s which was presented to justify the level of accuracy of the measured liquid holdup.

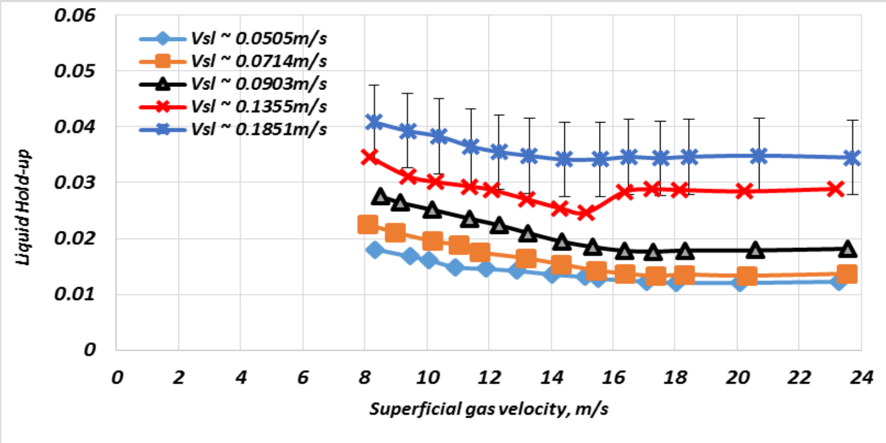

Figure 4: Liquid Holdup against Superficial gas velocity.

4.2. Model Validation

The developed liquid holdup model was validated using the measured liquid holdup results of Figure 4, from the experiments with others like Beggs& Brill (1973), Chen &Spedding (1981), Abdul-Majeed (1996) and Spedding et al (1998). The developed model matched preferably with the measured liquid holdup and Beggs& Brill (1973) in all the flow conditions in the results presented, (seeFigures 5 to 9).

The graph of Figure 5, withan average superficial liquid velocity of 0.0505m/s shows that the proposed liquid holdup model matched preferably with the measured liquid holdup and Beggs& Brill (1973) model. The model of Chen and Spedding (1981) over predicted the measured liquid holdup while Spedding et al (1981), Abdul-Majeed (1996) slightly over predicted the measured liquid holdup as Presented in Figures 5-9. As superficial liquid velocity increases, the margin between the measured liquid holdup and the predictive models increases except Beggs& Brill (1973). To further validate the proposed model in this study, performance plots with ±20% margin, were presented using with Beggs& Brill (1973) and the proposed model against the measured liquid holdup from the experiments. Beggs& Brill (1973) model, was chosen because of the model's proximity to the measured liquid holdup results and that of the proposed as presented in Figures 5 to 9.

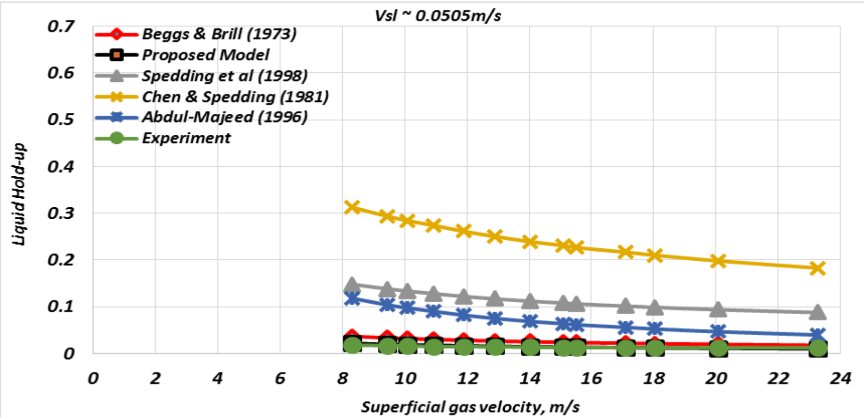

Figure 5: Liquid holdup against Superficial gas velocity for Vsl=0.0505m/s

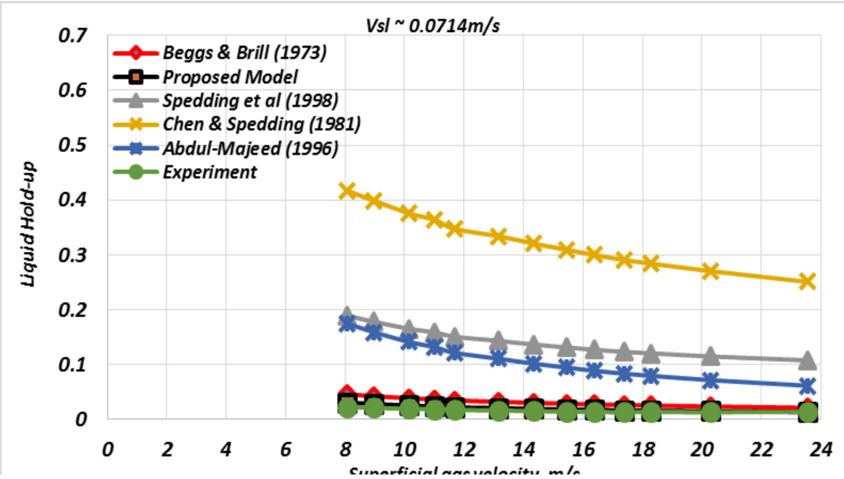

Figure 6: Liquid holdup against Superficial gas velocity for Vsl=0.0505m/s

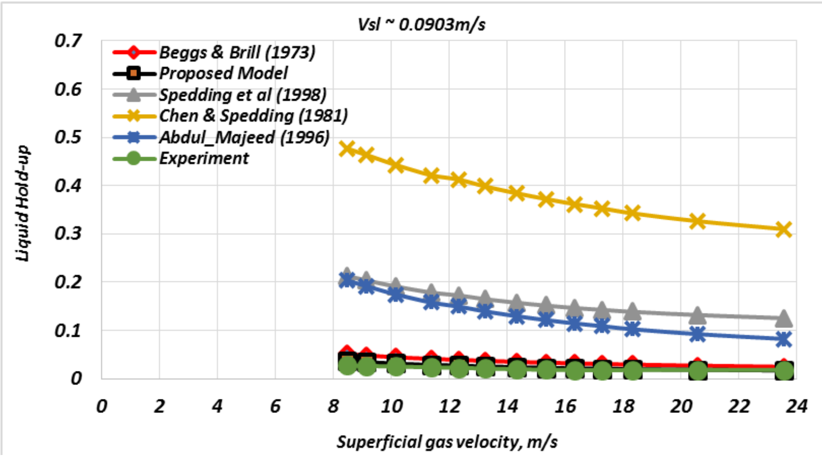

Figure 7: Liquid holdup against Superficial gas velocity for Vsl=0.0505m/s

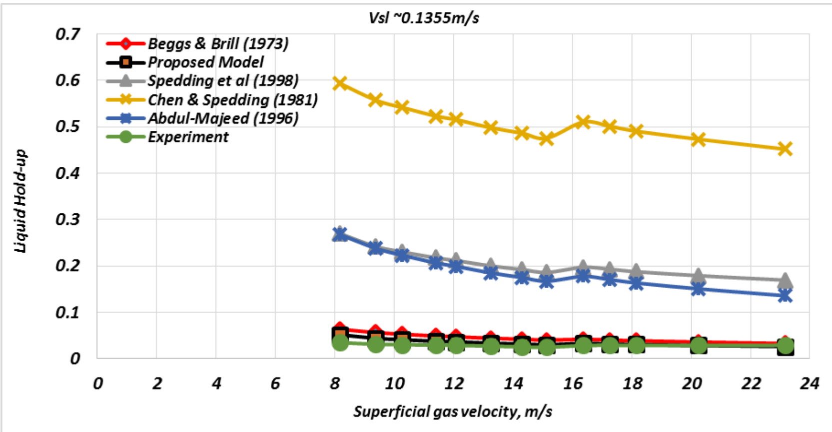

Figure 8: Liquid holdup against Superficial gas velocity for Vsl=0.0505m/s

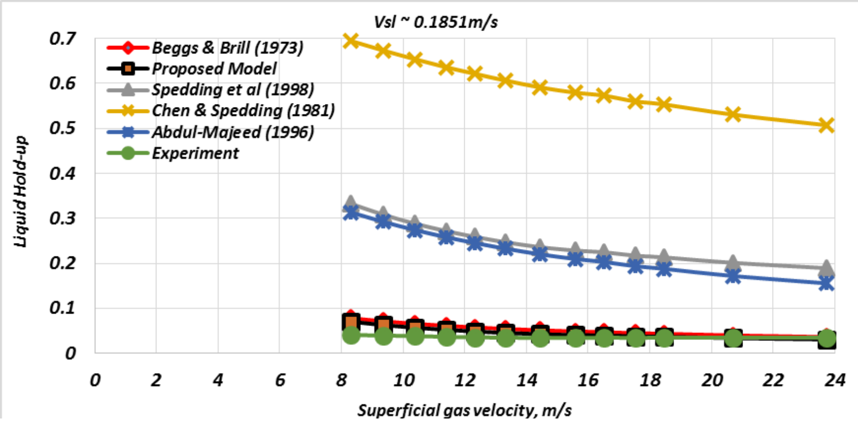

Figure 9: Liquid holdup against Superficial gas velocity for Vsl=0.0505m/s

4.3. Comparing Results with Measured Liquid Holdup

The measured liquid holdup results and the developed model were compared to determine the variance from the predictive model. Interestingly, Beggs and Brill (1973) was considered for comparison. This is simply because Beggs and Brill (1973) was the only liquid holdup model that preferably matched the measured liquid holdup and the proposed model in all the flow conditions presented (see Figures 5-9).Therefore,it's pertinent to verify how preferably,they were matched using the performance plot with a margin of ±20% as a yardstick.

As presented in Figure 10, the proposed model matched perfectly with the measured liquid holdup from the experiment while Beggs and Brill (1973) over predicted. This has further proven that the proposed model will account for liquid holdup better at low volumetric flow rate in the pipe than Beggs and Brill (1973).

Figures 11and 12also illustrated that the proposed model could predict liquid holdup closely with the obtained measured liquid holdup from the experiments. The proposed matched preferably better than Beggs and Brill (1973) for superficial liquid velocities of 0.0714m/s. and 0.0903m/s, despite the matched data points being at the boundary but was still within the margin of +20%. Therefore, the proposed model could be used with superficial liquid velocities of 0.0505m/s, 0.0714m/s and 0.0903m/s with respect to such volumetric flow rate in the field. Importantly, as the superficial liquid velocity increases, Beggs and Brill (1973), proposed model and the measured liquid holdup matched closely.

For Figures 13 and 14 which were the highest superficial liquid velocities in this study, shows a perfect match between the proposed model and the Beggs and Brill (1973) liquid holdup model. This depicts that Beggs and Brill (1973) liquid holdup model could account better in high superficial liquid velocity or better still at high volumetric flow rate but will give over predictive liquid holdup results when the volumetric flow rate is low. However, the proposed model in this study could account for both high and low volumetric liquid flow rate as seen from Figures 10 -14.

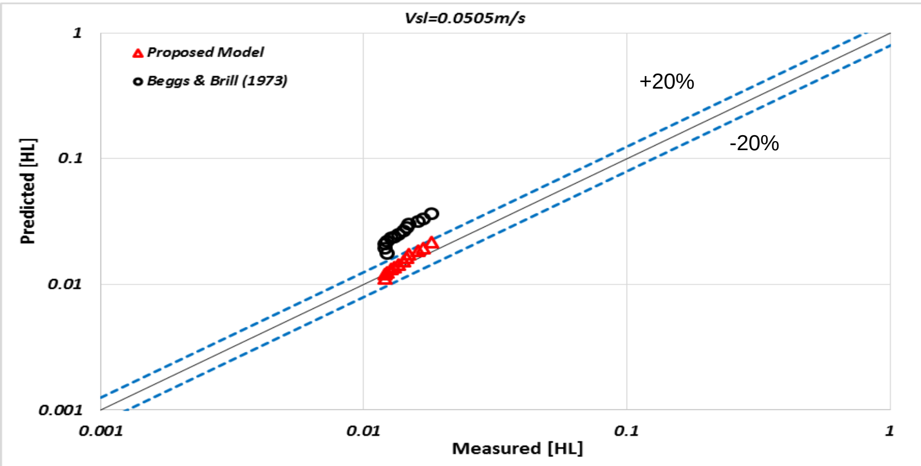

Figure 10: Predicted against Measured Liquid Holdup for Vsl=0.0505m/s

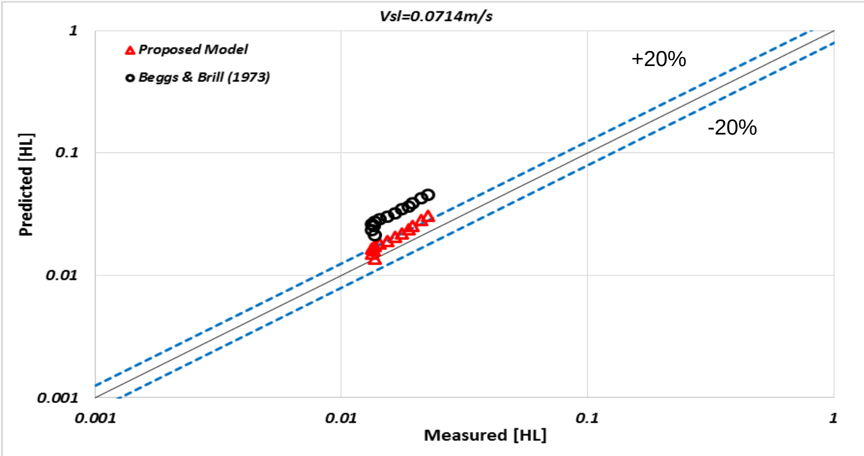

Figure 11: Predicted against Measured Liquid Holdup for Vsl=0.0714m/s

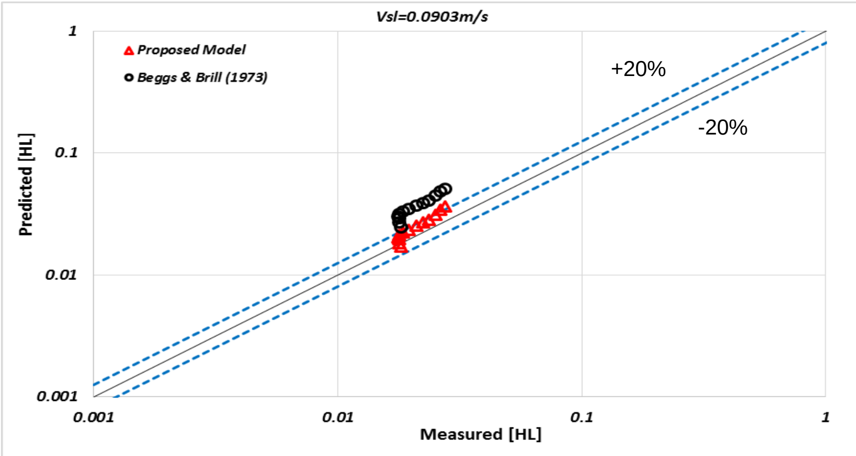

Figure 12: Predicted against Measured Liquid Holdup for Vsl=0.0903m/s

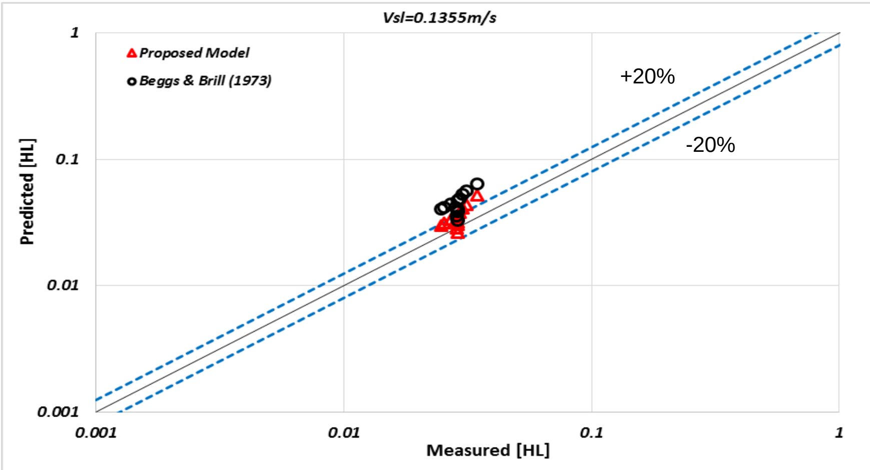

Figure 13: Predicted against Measured Liquid Holdup for Vsl=0.1355m/s

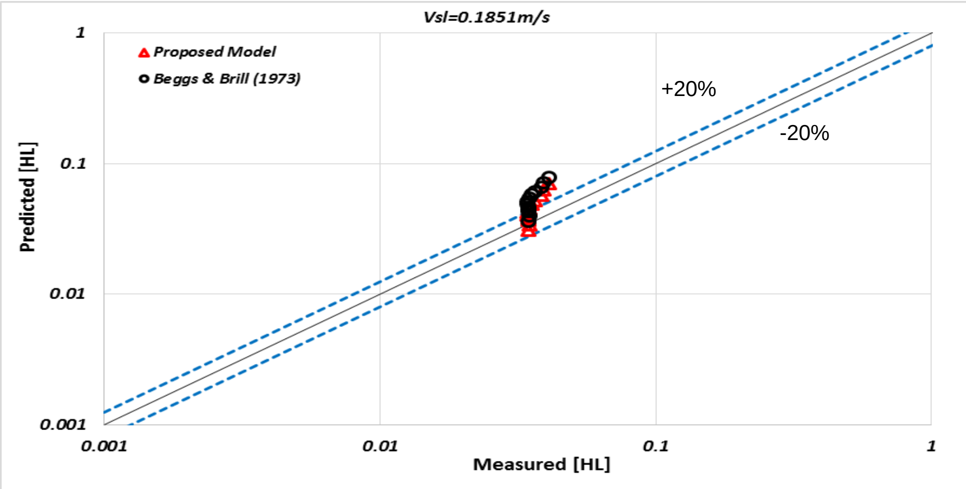

Figure 14: Predicted against Measured Liquid Holdup for Vsl=0.1851m/s

V. Statistical Analysis

The standard deviation of the proposed liquid holdup model, Chen and Spedding (1981), Beggs and Brill (1973), Spedding et al (1998) and Abdul-Majeed (1996) from the measured liquid holdup is presented in Table 3.

Table 3: Standard Deviation of the Models from the Measured Liquid Holdup.

Vsl (m/s)	*Proposed Model*	*Chen &Spedding (1981)*	*Beggs& Brill (1973)*	*Spedding et al (1998)*	*Abdul-Majeed (1996)*
0.0505	2.55	40.50	9.17	26.78	20.30
0.0714	4.90	43.75	9.64	27.73	23.52
0.0903	4.21	42.02	8.42	25.99	23.19
0.1355	4.56	40.88	7.44	24.77	23.54
0.1851	5.17	39.56	6.95	24.19	23.01

In evaluating the models from statistical analysis using standard deviation approach in Table 3, the proposed model predicted better, hence it predictedclose tothe measured liquid holdup in all the flow conditions in this study. Beggs and Brill (1973) was close on high superficial liquid velocity of 0.1851m/s. For the proposed model, the standard deviation increasedwith respect tothe measured liquid holdup as the superficial liquid velocity increases, whereas, Beggs and Brill (1973) model decreases as the superficial liquid velocity increases.

Therefore, the proposed model could give a better result from low to high superficial liquid velocity, whileBeggs and Brill (1973) could give a better result at high superficial liquid velocity.

VI. Conclusion

The proposed liquid holdup model is result-oriented and will aid in determining liquid holdup with information available to the field users without difficulties. The proposed model is a simplified model that justified all the complex variables in other models to more available data within the users’ reach. It has been proven from the comparison results of Figures 10-14 that the proposed model could be used both in low and high volumetric flow rate conditions and as well, applicable to low and high superficial velocities in horizontal pipes. Although, it has been validated on annular flow conditions but could be further tested with other flow regimes within the segregated flow (e.g. stratified-smooth and stratified-wavy flow).

Acknowledgement

The authors would like to express their gratitude to TETFUND for the scholarships and the Oil and Gas Engineering Centre, Cranfield University, Bedfordshire, UK for their support and for making the required instruments available for this work. Also, to the PSE Lab Manager, Mr Stan Collins and Shaun, the Technician for their support.

Nomenclature

A = Cross-Sectional Area of Pipe, m^2

C_1 = Conductivity Ring Sensor (Upstream)

C_2 = Conductivity Ring Sensor (Downstream)

D, d_1, d_2 = Inside Pipe Diameter, m
FE = Liquid Entrainment Fraction
g = Acceleration due to Gravity, $m.s^{-2}$
H_L = Liquid Holdup
H_G = Gas Holdup
h_L= Liquid Height in pipe (thickness), m
h_g= Gas Height in pipe (thickness), m
M = Mass, kg
M_L = Mass liquid Flow Rate, kg/s
M_G = Mass Gas Flow Rate, kg/s
m = Constant
P_1 = Pressure Sensor (Upstream)
P_2 = Pressure Sensor (Downstream)
q_L = Liquid Flow Rate, m^3/s
q_g = Liquid Flow Rate, m^3/s
R_{eL}= Reynold's Number
V_m = Mixture Velocity, m/s
Vsl = Superficial Liquid Velocity, m/s
Vsg = Superficial Gas Velocity, m/s
S_1 = Sand Probe (Upstream)
S_2 = Sand Probe (Downstream)
T_1 = Temperature Sensor (Upstream)
T_2 = Temperature Sensor (Downstream)
X = Lockhart-Martinelli Parameter

Greek Symbols
ρ_g = Gas Density of Fluid, kg/m^3
ρ_L = Liquid Density of Fluid, kg/m^3
μ_L = Liquid Viscosity, kg/m.s
μ_G = Gas Viscosity, kg/m.s
λ = No-Slip

Reference

[1]. Abdul-Majeed, G. H. (1996) "Liquid Holdup in Horizontal Two-Phase Gas-Liquid Flow" Journal of Petroleum Science and Engineering, Vol. 15, pp. 271-280.
[2]. Beggs, H. D and Brill, J.P (1973) "A Study of Two-Phase Flow in Inclined Pipes" *Journal of Petroleum Technology*, Vol. 25, (5), pp. 607-617.
[3]. Chen, J. J and Spedding, P. C (1981) "An Extension of the Lockhart-Martinelli Theory of Two-Phase Pressure Drop and Holdup" Int. J. Multiphase Flow, 6, pp. 659-675.
[4]. Garcia, F., Garcia, R. and Joseph, D. D. (2005) "Composite Power Law Holdup Correlations in Horizontal Pipes" International Journal of Multiphase Flow, Vol. 31, pp. 1276-1303.
[5]. Hutchinson, P. and Whalley, P. B. (1973) "A Possible Characterization of Entrainment in Annular Flow" Chemical Engineering Science, Vol. 28, pp. 974-975.
[6]. Kadambi, V (1982) "Stability of Annular Flow in Horizontal Tubes" Int. J. Multiphase Flow Vol.8, No. 4, pp 311-328.
[7]. Kadambi, V (1985) "Prediction of Pressure Drop and Void-Fraction in Annular Two-Phase Flows" The Canadian Journal of Chemical Engineering, Volume 63, ISSN: 0008-4034, pp. 728-734.
[8]. Kesana, N.R., Throneberry, J.M., Mclaury, B.S., Shirazi, S.A and Rybicki, E.F,(2012) "Effect of Particle Size and Viscosity on Erosion in Annular and Slug Flow" Proceedings of the ASME 2012 International Mechanical Engineering Congress & Exposition IMECE2012, November 9-15, 2012, Houston, Texas, USA.
[9]. Lockhart-Martinelli, R. (1949) "Proposed Correlation of Data for Isothermal Two-Phase Component Flow in pipes" Chemical Engineering, Prog. Vol. 45, pp. 39-48.
[10]. Oliemans, R. V, Pots, B. F. M and Trompe, N (1986) "Modelling of Annular Dispersed Two-Phase Flow in Vertical Pipes" Int. J. Multiphase Flow, Vol. 12, No.5, pp. 711-732.
[11]. Pai, S.I. (1953) "On Turbulent Flow in a Circular Pipe" J. Franklin Inst. 256(4), pp. 337-352.
[12]. Sergey, V. Alekseenko, Andrey, V. Cherdantsev, Mikhail, V. Cherdantsev, Sergey, V. Isaenkov, Sergey, M. Kharlamov and Dmitriy, M. Markovich (2014) "Formation of Disturbance Waves in Annular Gas-Liquid Flow" Kutateladze Institute of Thermophysics, Novosibirsk, Russia, Novosibirsk State University, Novosibirsk, Russia, 17th International Symposium on Applications of Laser Techniques to Fluid Mechanics, Lisbon, Portugal, 07-10 July, 2014.
[13]. Spedding, P., Watterson, J., Raghunathan, S. and Fergusonn, M. (1998) "Two-Phase Co-Current Flow in Inclined Pipe. International Journal of Heat Mass Transfer, Vol. 41, pp. 4205-4225.
[14]. Taitel, Y and Dukler, A. E., (1976) "A Model for Predicting Flow Regime Transitions in Horizontal and Near Horizontal Gas-Liquid Flow" *AICHE J.*, Vol. 22, pp. 47-55.
[15]. Tandon, T., Varma, H. and Gupta, C. (1985) "A void Fraction Model for Annular Two-Phase Flow" International Journal of Heat Mass Transfer, Vol. 28, pp. 191-198.
[16]. Tso, C. P. and Sugawara, S. (1990) "Film Thickness Prediction in a Horizontal Annular Two-Phase Flow" Int. J. Multiphase Flow, Vol. 16, No. 5, pp. 867-884.

[17]. Wicks, M (1971) "Transport of Solids at Low Concentration in Horizontal Pipes" Shell Pipeline Corporation, R & D Laboratory, Houston, Texas, Publisher: Oxford; Pergamon, pp.101-123.

[18]. Wicks, M. and Dukler, A. E., (1960) "Entrainment and Pressure Drop in Concurrent Gas-Liquid Flow: Air-Water in Horizontal Flow" *AIChE. J,* 6, 463.

[19]. Wilkes, N. S., Azzopardi, B. J and Thompson, C. P. (1983) "Wave Coalescence and Entrainment in Vertical Annular Two-Phase Flow" International Journal of Multiphase Flow, 9 (4), pp. 383-398.

[20]. Xiao, J. J., Shoham, O. and Brill, J.P. (1990) "A Comprehensive Mechanistic Model for Two-Phase Flow in Pipelines" 65th Annual Technical Conference, Society of Petroleum Engineers, New Orleans, L.A.

Osokogwu. "A Simplified Liquid Holdup Model for Annular Flow in Horizontal Pipes." *IOSR Journal of Applied Physics (IOSR-JAP)*, 12(2), 2020, pp. 42-53.