Void fraction calculations from experimental data

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1 Introduction

The purpose of this homework is to propose a straightforward application of the basic void fraction models discussed during the class and to utilize them on selected experimental data. These models are described in detail by Delhaye (2008, pp. 232-240).

2 Description of the experiment

The Spinflow experiment is dedicated to the characterization of air-water two-phase flow at the atmospheric pressure by using the nuclear magnetic resonance (NMR). Without going too deeply into the details of the measurement, it sufficient to know that the NMR signal is proportional to the liquid content in the measuring volume. This volume may be approximated by a cylinder of height $H = 65$ mm and diameter $D = 49$ mm, which is also the pipe internal diameter. If one assumes the flow is fully developed, then the averaged space fraction of the liquid is uniform in the flow direction and it can be shown that the NMR signal is proportional to $\overline{R_{L2}}$.

It can be shown that by using an appropriate NMR sequence, the probability distribution of the liquid velocity in the measuring volume can also be obtained. Furthermore, it can be shown that the first moment of this distribution is the true mean liquid velocity of the 1D-time-averaged model,

$$v_{L1D} \triangleq \frac{\langle\!\langle \alpha_L \overline{v}^{X_L} \rangle\!\rangle_2}{\langle\!\langle \alpha_L \rangle\!\rangle_2} \tag{1}$$

The centered variance of the distribution (vp3) is related to both the spatial distribution of the mean velocity and the mean turbulence in the flow. This later quantity is also related to the longitudinal dispersion coefficient D.

The control parameters of the experiment are as follows.

- The liquid flow rate: Q_L in l/min.
- The gas mass rate: M_G in Nl/min.
- The mean temperature of the two phases: T.

The liquid flow rate is measured by an electromagnetic flowmeter, while the gas rate is measured by a thermal mass meter. The temperature is measured in the liquid in a tank located upstream of the test section by a plain alcohol thermometer. The measured parameters are the following,

- The cross sectional-averaged void fraction, $\overline{R_{G2}}$ and the mean liquid velocity (1) by NMR.
- The pressure at location 1 (bottom) and 2 (top), see figure 1.

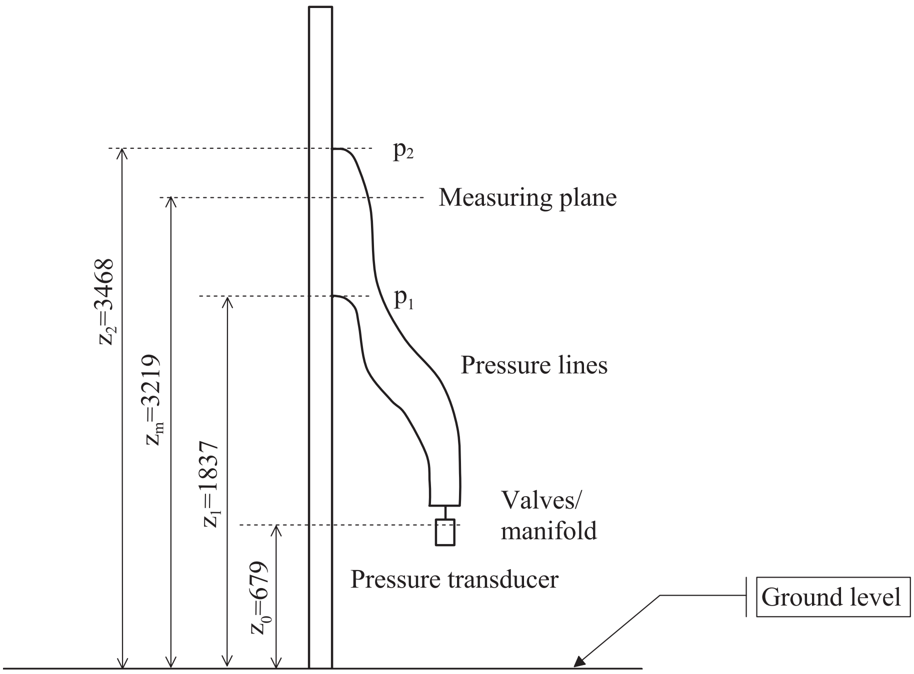

Figure 1: Schematic of the test section showing the location of the pressure taps, the pressure transducer and measuring section. All length are in mmm.

	Control parameters								NMR data				
Run	QL300	VL300	MG200	VG200	MG50	TL	Pb(1)	Ph(2)	v3	M0/N	vp3	D	Remarques
	l/min	V	Nl/min	V	%FS	Cel.	bar	bar	cm/s		cm/s	cm2/s	
J668	39.60	1.534	0.	.004	1.2	20.5	1.446	1.446	35.56	14177.	8.57	.1112	S 08 D7 sM0= 27,31:47
0669	39.60	1.534	2.	.055	5.2	20.3	1.438	1.441	37.00	13659.	9.25	.1653	B 08 D7 sM0= 29,31:52
0670	39.60	1.534	4.	.101	8.6	20.3	1.430	1.437	37.91	13121.	10.58	.2103	B 08 D6 sM0= 27,31:50
0671	39.60	1.534	6.	.152	12.9	20.3	1.420	1.431	39.22	12500.	11.65	.2875	B 08 D6 sM0= 29,31:51
0672	39.60	1.534	8.	.200	16.7	20.3	1.410	1.426	40.49	11957.	12.19	.3078	B 08 D5 sM0= 34,31:48
0674	39.60	1.534	10.	.254	21.0	20.3	1.401	1.421	41.92	11379.	13.26	.3825	B 16 D5 sM0= 19,31:49
0675	39.60	1.534	12.	.302	25.0	20.3	1.394	1.418	43.61	10880.	14.16	.4618	B 16 D5 sM0= 24,31:50
0676	39.60	1.533	14.	.350	29.0	20.3	1.386	1.414	44.57	10422.	15.36	.5502	B 16 D5 sM0= 32,31:52
0677	39.60	1.532	16.	.401	32.8	20.8	1.381	1.411	45.32	10005.	16.32	.5459	BA32 D4 sM0= 21,30:48
0678	39.60	1.535	18.	.452	37.0	20.8	1.376	1.410	46.66	9700.	21.53	.8990	BA32 D4 sM0= 41,28:52
0679	39.60	1.531	20.	.501	41.2	20.8	1.372	1.407	45.52	9650.	30.14	1.8860	A 32 D4 sM0=127,28:52
0680	39.60	1.531	22.	.549	45.3	20.8	1.370	1.404	46.15	9540.	33.68	1.9660	P 32 D3 sM0=169,24:50

Table 1: Control parameters of the experiments. %FS mean percent of full scale.

The pressure measurement system is shown in figure 1. The following physical properties are given,

- Density of water 1bar, 20°C, $\rho_L = 998$ kg/m^3.
- Density of the gas at 1 atm, 0°C, $\rho_{G0} = 1.2928$ kg/m^3.
- Superficial tension, σ=72 mN/m.

A set of experiments have been performed in single and two-phase flows. They are shown in Table 1.

3 Flowmetering

The liquid flow rate is set by using the indication of the electromagnetic flow meter digital display. However, the calibration of the sensor has been performed by using the analog output in V (VL300). The relation between this voltage and liquid flow rate is the following,

$$QL[\mathrm{l/min}] = 75.525 \times (\mathrm{VL300[V]} - 1) \tag{2}$$

The gas rate is set by using the digital display of a mass flow controller (200 Nl/min range) and another mass meter placed in series with it (50 Nl/min range). The first mass meter reading in V can be converted to Nl/min, by using the following calibration information,

$$MG[\mathrm{Nl/min}] = 40\mathrm{VG200[V]} \tag{3}$$

The digital display of the 50 Nl/min mass meter can be converted into mass rate according,

$$MG[\mathrm{Nl/min}] = 0.5\mathrm{VG50[\%FS]} \tag{4}$$

To convert to mass flow rate units use the reference value of the air density given above.

4 Data processing

For all the data of Table 1, calculate the liquid flow rate by using (2) and the gas mass rate by using both sensors readings (3) and (4). What do you observe? According to you, what is the most reliable data for the gas.

For all the data, computes the following quantities,

- The superficial velocity of the gas and the liquid
- The mean void fraction between section 1 and 2 from the pressure measurements. Discuss the effect of wall friction on the measurement. If necessary, use the homogeneous model to evaluate the frictional pressure drop.
- The void fraction by the homogenous model, the Bankoff model, the Wallis model and the Zuber-Findlay model. Please check the appropriate flow regime.

Compare the mean liquid velocity calculated from the knowledge of the liquid flow rate and the void fraction determined by NMR. In addition calculates the liquid superficial velocity from NMR measurements only. Comment your results and plot the Wallis and the Zuber-Findlay diagrams for these experiments.

5 Additional information

All the void fraction models were described during lecture 2. However, no closure relation was given for the Wallis model. We will consider that given by Dukler & Taitel (1986, p. 48-49) for the modeling of the bubble to slug flow regime transition,

$$\overline{w}_G^X - \overline{w}_L^X = u_0, \quad u_0 = u_\infty (1 - R_G)^{0.5}, \quad u_\infty = 1.53 \left(\frac{\sigma g (\rho_L - \rho_G)}{\rho_L^2} \right)^{0.25} \tag{5}$$

References

Delhaye, J.-M. 2008. *Thermohydraulique des réacteurs nucléaires*. Collection génie atomique. EDP Sciences.

Dukler, A. E., & Taitel, Y. 1986. *Multiphase Science and Technolgy*. Vol. 2. Hemisphere. Chap. 1-Flow pattern transitions in gas-liquid systems: measurement and modelling, pages 1–94.