



## Experimental investigation of the influence of column scale, gas density and liquid properties on gas holdup in bubble columns



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### ABSTRACT

Measurements of gas holdups in bubble columns of 0.16, 0.30 and 0.33 m diameter were carried out. These columns were operated in co-current flow of gas and liquid phases and in semibatch mode. The column of 0.33 m diameter was operated at elevated pressures of up to 3.6 MPa. Nitrogen was employed as the gas phase and deionized water, aqueous solutions of ethanol and acetone and pure acetone and cumene as the liquid phase. The effects of differing liquid properties, gas density (due to elevated pressure), temperature, column diameter and superficial liquid velocity on gas holdup were studied. The gas holdup measurements were utilized by differential pressure measurements at different positions along the height of the bubble columns which allowed for the identification of axial gas holdup profiles. A decrease of gas holdup with increasing column diameter and an increase of gas holdup with increasing pressure was observed. The effect of a slightly decreasing gas holdup with increasing liquid velocity was found to exist at smaller column diameters. The use of organic solvents as the liquid phase resulted in a significant increase in gas holdup compared to deionized water. It is found that published gas holdup models are mostly unable to predict the results obtained in this study.

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### Introduction

Within the chemical and petrochemical industry bubble columns are present as multiphase reactors and contactors in a variety of processes. Bubble columns are thereby utilized in various modes of operation, ranging from semibatch to co- and countercurrent operation with two or three phases involved. The basic construction of bubble columns is relatively simple, unless no internals are present, as they are mainly cylinders in which gas and liquid are brought in contact. The main features of bubble columns have been summarized by e.g. Deckwer (1985) and Kantarci et al. (2005).

Despite the simple construction, precise prediction of the governing hydrodynamic parameters and the overall flow field is still not possible which has been pointed out by Jakobsen et al. (2005) recently. This can also be seen from the fact that decades of researchers tried to develop models based on empirical and

semi-empirical approaches to calculate gas holdups only. Unfortunately the predictions of available models tend to fail if they are used for scale-up purposes or to predict holdups for systems with physical properties other than they are derived from. But even if the commonly investigated air/water system is examined with different available correlations immense variations of the results are observed. The reasons for this can be found in several factors. A first point to be stated is that the experimental facilities differ in terms of column diameter, height to diameter  $H/D$  ratio and mode of gas distribution. There are several recommendations summarized by e.g. Shah et al. (1982) concerning the minimum diameter (at least 0.15 m) and  $H/D$  ratio (greater than 5) which should be used in order to measure gas holdups independently from undesired side effects. A second point concerns the qualities of the liquids used. Even if deionized water or tap water is used as the liquid phase different water qualities and accidental impurities cause differences in the experimental data. This is due to a bubble coalescence inhibiting or promoting effect of the specific impurity. A third point accounts for the availability of experimental data especially for scale-up and gas density studies. Only

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a few studies, e.g. by Forret et al. (2003), Krishna et al. (2001), Krishna and Ellenberger (1996) and Wilkinson et al. (1992), with varying column diameters are present up to this date and their results are contradictory. Therefore even fewer gas holdup models exist which account for the influence of column diameter.

It is the purpose of this paper to present and discuss gas holdup results obtained in three gas–liquid bubble columns of different sizes but comparable gas distributors and liquids employed. In addition the influence of impurities is simulated by adding small amounts of ethanol and acetone to the liquid phase. To discuss the effect of gas density due to elevated pressure on gas holdup experimental studies at pressures of up to 3.6 MPa were carried out. Some other influencing parameters which are important for production scale bubble columns like temperature and liquid superficial velocity are also examined within the studies presented.

## Experimental facilities and procedures

### Experimental facilities

To perform the experimental studies three bubble columns of different diameters and heights were set up. Table 1 summarizes the column dimensions together with their  $H/D$  ratio based on liquid height.

As can be seen from Table 1 all columns are above the minimum  $H/D$  ratio of 5 and the minimum diameter of 0.15 m mentioned by Shah et al. (1982) to avoid any wall effects on gas holdup during the measurements. The columns of 0.16 and 0.3 m diameter are used to study the effect of column dimensions, superficial liquid velocity and liquid properties on gas holdup. A third column of 0.33 m diameter is primarily used to examine the effect of a higher gas density due to elevated pressures and the effect of temperature on gas holdup. As the difference in diameter to the 0.30 m diameter column is small, no remarkable effects of scale are expected. Nitrogen was always used as the gas phase (see Table 2 for nitrogen densities at investigated pressure levels) and deionized water, acetone, cumene and aqueous solutions of organic solvents as liquid phase (properties related to investigated temperature levels listed in Table 3).

All columns were operated in co-current flow of gas and liquid phase. The gas was distributed by a perforated plate sparger with holes of 1 mm diameter. The spargers were designed according to the methods proposed by Ruff et al. (1976) and its dimensions are listed in Table 4. All spargers match flow characteristics in each column which results in a different number of openings due to the varying column diameters and the associated flow rates.

Simplified schematics of all three facilities are given in Figs. 1–3. Note that nearly all safety devices, valves and outlets are not shown here to enhance clarity of the depicted experimental setups. Safety devices include for example pressure relief valves, concentration sensors, groundings, buffer vessel level indication and automatic shut-down mechanisms. Fig. 1 shows the 0.16 m diameter column which is made of glass.

Liquid is circulated via a pump from bottom to top of the column. At the top the liquid leaves the column through an overflow and flows into a buffer vessel. The liquid flow rate is measured by a Coriolis flow meter (Endress + Hauser, promass63a, 0.1%

**Table 1**  
Column dimensions and  $H/D$  ratio.

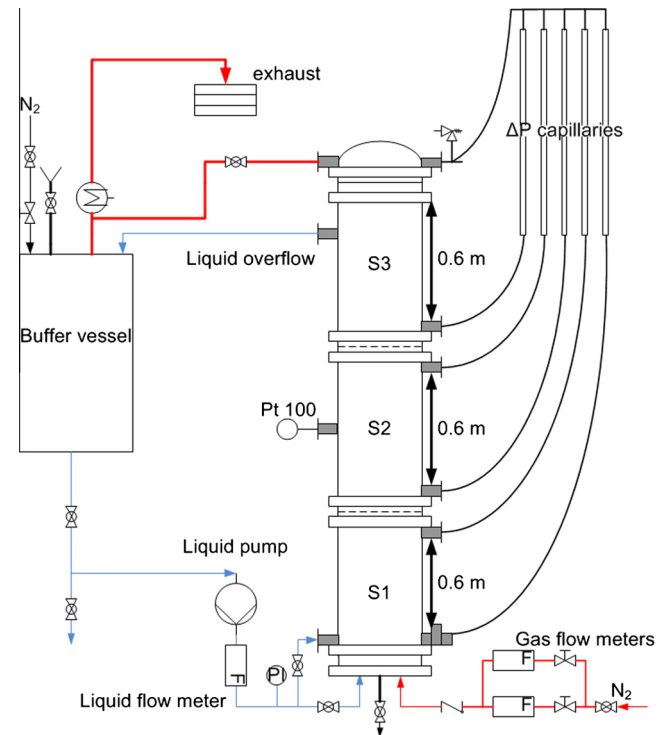
Column diameter $D$ (m)	Liquid height $H$ (m)	$H/D$ ratio (-)
0.16	1.8	11.25
0.30	2.63	8.75
0.33	3.88	11.75

**Table 2**  
Density of nitrogen at various pressures.

$p$ (MPa)	0.1	1	1.85	3.6
Nitrogen Density (kg/m <sup>3</sup> )	1.15	11.50	21.28	41.38

**Table 3**  
Liquid properties at different temperatures.

$T$ (°C)	20	50	75
<i>Deionized H<sub>2</sub>O</i>			
Density (kg/m <sup>3</sup> )	998	988	975
Viscosity (mPa s)	1	0.55	0.38
Surface tension (N/m)	0.074	0.068	0.063
<i>Acetone</i>			
Density (kg/m <sup>3</sup> )	767	–	–
Viscosity (mPa s)	0.32	–	–
Surface tension (N/m)	0.024	–	–
<i>Cumene</i>			
Density (kg/m <sup>3</sup> )	867	844	823
Viscosity (mPa s)	0.79	0.54	0.42
Surface tension (N/m)	0.028	0.025	0.022



**Fig. 1.** Simplified schematic of 0.16 m diameter glass column.

measurement error). Liquids employed were deionized water, aqueous solutions of ethanol, acetone and cumene. Nitrogen as the gas phase also enters the column at the bottom and is distributed by a perforated plate sparger. It leaves the column at the top from where it enters the buffer vessel to separate entrained liquid from the gas. Afterward nitrogen passes through a condenser, again to separate liquid and gas, before it enters the exhaust system. The amount of gas flowing through the column is measured by two gas flow meters (Krohne, H250, 1.6% measurement error), one for low and one for higher gas throughputs, to ensure a better accuracy of the measurement. Gas and liquid superficial velocities were varied up to 0.1 m/s and 0.01 m/s respectively. Gas holdups are measured by glass capillaries which are connected with the

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