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Local void fraction and bubble size distributions in cold-gassed and hot-sparged stirred reactors

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ABSTRACT

Vertical distributions of local void fraction, bubble size and gas–liquid interfacial area in air–water dispersions at 24 and 81 °C have been measured with a dual electric conductivity probe in a fully baffled dished base stirred vessel of 0.48 m diameter holding 0.145 m^3 liquid. The agitator was a hollow blade dispersing turbine below two up-pumping hydrofoils. The vertical distribution of the void fraction in the hot conditions is similar to that at ambient temperature though the void fraction is significantly lower in the hot system. The vertical distributions of bubble size show maxima with large bubbles above the bottom impeller, near the top impeller and close to the free surface. With given operating conditions, the overall Sauter means bubble size in the hot systems appears to be about 21% greater than when cold. Estimates of the local interfacial area show a maximum just above the level of the top impeller.

1. Introduction

Gas–liquid stirred reactors are widely used in the chemical, mineral and biochemical industries and for wastewater treatment. In the past 20 years, many researchers have studied gas dispersion in two-phase systems operated at ambient temperature (i.e. "cold"). Extensive research has established empirical relationships for industrial design and scale-up. During the past decade, further research has been carried out with hot systems in which the vapor pressure should be taken into account (Gao et al., 2001a, 2001b; Zhao et al., 2001). This has shown that hot and cold systems are radically different; indeed it is certain that many industrial reactors have been designed on the basis of incorrect assumptions or insufficient information about the physical conditions. Agitator power draw is greater at higher temperatures, and while bulk and micro-mixing times are essentially unaltered, the retained gas fractions are substantially reduced. Gao et al. (2001a) have reported vertical void fraction distributions in cold gassed and hot sparged systems agitated by various agitators. They found that hot sparged systems had a similar vertical void fraction distribution to that in cold gassed conditions, with maxima in similar locations though with lower overall void fractions. Recently, Bao et al. (2008a, 2008b) have investigated the influence of volumetric fractions of settling particles on the power demand and gas dispersion in a three-phase gas–liquid–solid system operating at different temperatures. The research has consistently found that the total gas holdup in a hot system is only about one-half to two-thirds of that at room temperature. They also suggested correlations relating the total gas holdup to the operating conditions including the temperature, gas rate, power input and solid concentration. The final goal of all investigations related to the multiphase stirred reactors is to present consistent models which are accurate and relevant to industrial design and scale-up. However, the complex interaction among gas, liquids and solids leads to a difficulty in presenting this consistent model, especially in a hot-sparged or boiling ungassed system. Most previous investigations have focused on the global measurements and have presented empirical correlations related to a specific industrial design. Such global measurements are insufficient for understanding and quantitative interpretation of the dynamic processes in agitated systems (Barigou and Greaves, 1992). On the other hand, developments in computer technology and CFD software have encouraged more and more researchers to focus on numerical simulations of gas dispersion in stirred tanks (Min et al., 2008). The validation of CFD investigations requires detailed information, such as the distribution of voids and any solid particles, together with bubble sizes, all of which demand more investigation than simply the measurement of global properties.

Abbreviations: HEDT, Half elliptical hollow blade disk turbine; WH$_U$, Wide blade up-pumping hydrofoil; PDF, Possibility distribution function; CDF, Cumulative distribution function

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For reactor selection, design and diagnosis, the local gas-dispersion characteristics need to be understood at both low and high temperatures since these are closely related to hydrodynamics and the mass transfer performance.

The lack of local information in multi-phase systems can be attributed to limitations in measurement techniques. In recent decades, most measurements of the local gas-phase characteristics in stirred tanks have been carried out using optical techniques, capillary probes, conical hot-film probes or conductivity probes. Among these, optical techniques, such as traditional photography (Bouaifi and Roustan, 1998) and multiphase particle image velocimetry (Montante et al., 2008) are non-invasive, and can only be used in absolutely transparent vessels with very little gas, conditions which are quite different from the reality of industrial applications. Capillary probe techniques (Barigou and Greaves, 1992; Alves et al., 2002) are more general than optical methods since they can be used in opaque and dense dispersions. However, they cannot usually detect bubbles smaller than the capillary diameter, and the maximum detectable bubble size is also limited because long slugs are prone to detection errors. Moreover there are problems arising from the non-isokinetic sampling of bubbles, the coalescence of bubbles before analysis and the disturbances to the flow field caused by the sampling tube which may also introduce bias errors to the results. Hot-film probe techniques (Lu and Ju, 1987) are sensitive to temperature changes in the system, so precise temperature control is required. Conductivity probe techniques (Figueiredo, 1978) like the capillary and hot-film probes, are also invasive, but they will not disturb the flow field seriously if the volume of the probe is kept small compared to the scale of the whole flow field. A conductivity probe is suitable for both opaque and dense dispersions, although the minimum detectable bubble size is limited by the size of the probe tip.

Many industrial vessels have aspect ratios significantly >1, and multiple impeller agitators are required in such tall vessels. In our previous work on the global gas-dispersion and solid-suspension performance Bao et al. (2006) have recommended an agitator configuration of a hollow half elliptical blade dispersing turbine below two up-pumping wide blade hydrofoils, (identified as HEDT+2WH$_U$) as the optimal combination for these three-phase systems. However, the specific distributions of the void fraction and solids and the distributions of bubble size are still open to further investigation. Few workers (Bouaifi and Roustan, 1998; Alves et al., 2002) have investigated bubble size distributions in these industrially important aerated vessels with multiple impeller agitators. In the present work, the local void fraction, bubble size distributions and interfacial areas in both cold and hot systems have measured with a fine dual electric conductivity probe providing detailed information about the gas dispersion and a better understanding of the differences between the hot and cold gassed systems, which have been identified in our previous work (Bao et al., 2008b).

2. Experimental

2.1. Equipment

All the present experiments were carried out in a fully baffled, stainless steel dished-bottom cylindrical tank with internal

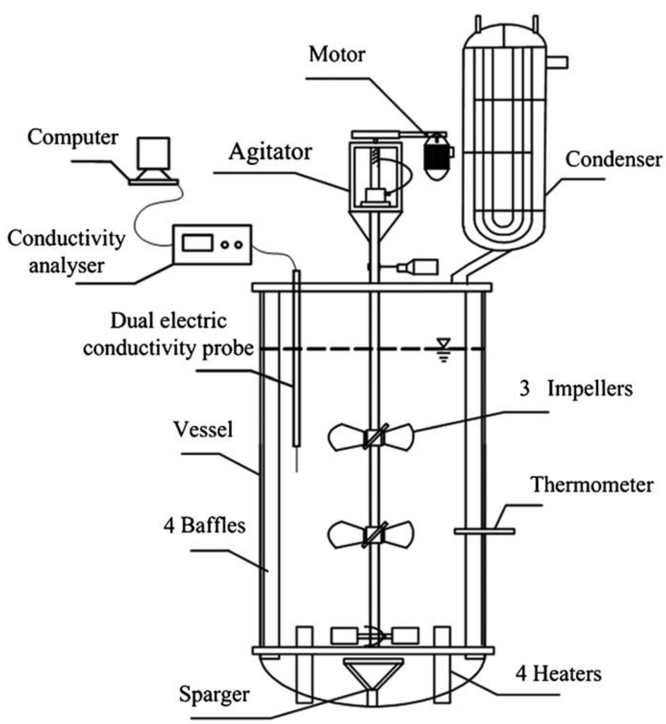

Fig. 1. Schematic of the experimental setup.

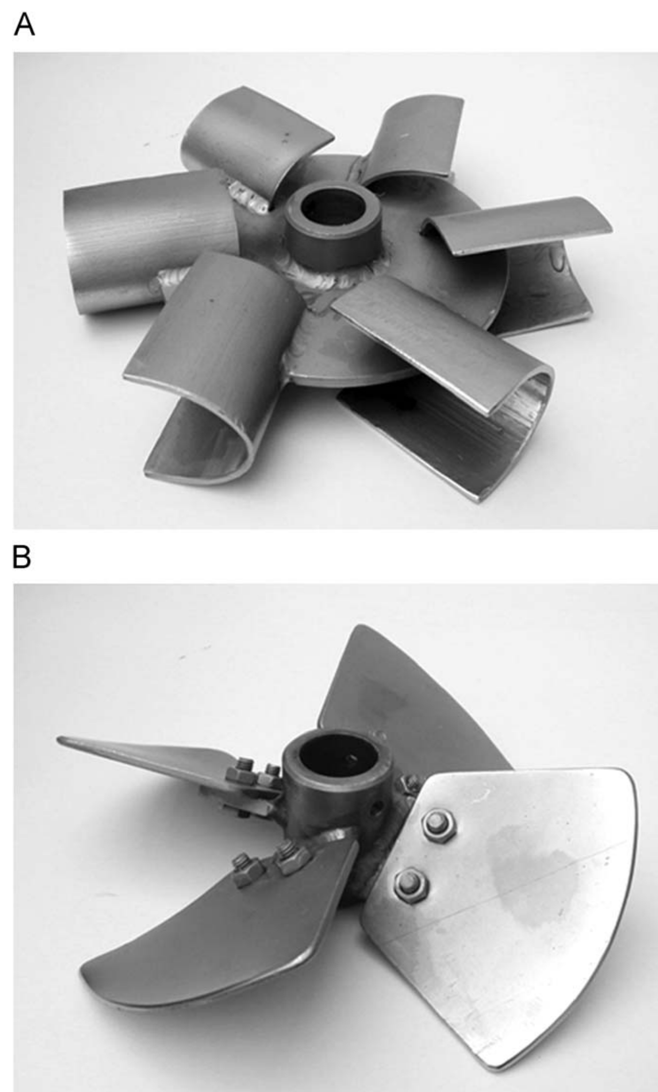

Fig. 2. (A) Six-half-elliptical-blade disk turbine (HEDT). (B) Four-wide-blade hydrofoil impeller (WH).