Chemical Engineering Journal 326 (2017) 308–317

Contents lists available at ScienceDirect

Chemical Engineering Journal

journal homepage: www.elsevier.com/locate/cej

Experimental analysis of Taylor bubble behavior and mass transfer during lateral oscillation of a vertical milli-channel

Mohammadreza Haghnegahdar [a,*], Stephan Boden [a,b], Uwe Hampel [a,b]

[a] *Institute of Fluid Dynamics, Helmholtz-Zentrum Dresden – Rossendorf, Bautzner Landstr. 400, 01328 Dresden, Germany*
[b] *AREVA Endowed Chair of Imaging Techniques in Energy and Process Engineering, Technische Universität Dresden, 01062 Dresden, Germany*

HIGHLIGHTS

- X-ray imaging was used to study the effect of channel vibration on the mass transfer of bubbles.
- The mass transfer rate positively correlates with frequency and amplitude of channel vibration.
- Channel oscillation causes an enlargement of free rise velocity of bubbles.
- Channel oscillation intensifies the surface wave motion of bubbles and causes enhancement of mass transfer.

ARTICLE INFO

Article history:
Received 7 April 2017
Received in revised form 14 May 2017
Accepted 22 May 2017
Available online 23 May 2017

Keywords:
Vibration
Milli-channels
Mass transfer
Taylor bubble
Carbon dioxide

ABSTRACT

In this paper, we report on an experimental study on the influence of low-frequency horizontal vibration of a vertical millimeter-size channel with Taylor bubbles. We investigated the motion, shape and dissolution rate of individual elongated Taylor bubbles of air and CO_2, which were freely rising in stationary water. Bubble size and dissolution rate were determined from microfocus X-ray radiographs. From the shrinking rate we calculated the liquid-side mass transfer coefficient. The rise velocity of bubbles and surface wave motion were analyzed using a videometric technique. The comparison of the results for the stationary and the oscillating channel showed that mechanical vibration of the channel is able to enhance the mass transfer coefficient from gas to the liquid phase by 80%–186%, depending on the frequency and amplitude of vibration. It was found that channel oscillation causes the increase of free rise velocity of bubbles which is mainly attributed to the development of propelling interfacial waves and increase of liquid film flow rate. Furthermore, analyzing the surface wave motion of bubbles revealed that the enlargement of contact area between the phases and the increased mixing enhances the mass transfer additionally up to 30% compared to non-agitated bubbles of similar Peclet number.

© 2017 Elsevier B.V. All rights reserved.

1. Introduction

Multi-phase chemical reactors with micro- and millimeter-size channel structures are considered as a promising alternative to conventional multiphase reactors, such as bubble columns and fixed bed reactors which are widely used for gas absorption, catalytic hydrogenation, biochemical conversions, direct fluorination and others. The main advantages of small channel multiphase reactors are creation of a large volumetric interfacial area, low-pressure drop, and ease of scale-up. However, because the governing flow regime in such reactors is laminar, the liquid-side mass transfer coefficient (k_L) between the phases is lower than for turbulent flow in e.g. bubble columns or stirred tank reactors [1]. To enhance the individual mass transfer coefficient, one of the most recently considered methods is applying structural vibration or sound fields to agitate the fluidic phases. Such approaches were demonstrated for many conventional multi-phase contactors and proved their ability to intensify the mass transport processes [1,2]. In the following, the most relevant studies on the application of ultrasound and vibration in gas-liquid contacting systems will be shortly reviewed.

One of the first investigations on the effect of axial vibration on bubble-bed gas absorbers has been carried out by Harbaum and Houghton [3]. They demonstrated a noticeable enhancement in mass transfer performance in the frequency range 20 Hz–200 Hz. Jaeger and Kurzweg [4] investigated the longitudinal dispersion in oscillatory pipe flow of binary gas mixtures at high axial oscillation frequencies. It was shown that the magnitude of the dispersion coefficient is directly related to the product of the frequency

---

* Corresponding author.
E-mail addresses: m.haghnegahdar@hzdr.de (M. Haghnegahdar), s.boden@hzdr.de (S. Boden).

http://dx.doi.org/10.1016/j.cej.2017.05.138
1385-8947/© 2017 Elsevier B.V. All rights reserved.

Notation

A_b	bubble surface area based on the bubble sphere-volume equivalent diameter (d_{eq})
a	specific interfacial area
C^*	concentration of gas at interface
C	concentration of gas at the liquid bulk
C_L	water concentration
d	bubble diameter
d_{eq}	sphere-volume equivalent bubble diameter
D	channel hydraulic diameter
D_c	gas molecular diffusion coefficient
E	radiographic extinction image
f	channel vibration frequency
g	acceleration due to gravity
h	distance from the liquid surface
H	Henry's constant
I	X-ray intensity
k_L	liquid-side mass transfer coefficient
k_v	calibration function
L_b	bubble length
n	total moles of gas inside the bubble
P	pressure inside of the bubble
P_{atm}	atmospheric pressure
Pe	Peclet number
R	universal gas constant
Sh	Sherwood number
t	time
T	bubble temperature
U_b	bubble free rise velocity
V_b	bubble volume
y	mole fraction of CO_2 inside of gas phase
z	axial direction
ρ	liquid density

and the square of oscillation amplitude. For elongated Taylor bubbles, Brannock and Kubie [5] were the first to investigate the influence of vibration on the free rise velocity of bubbles [6]. They measured the rise velocity of long bubbles while exposing the vertical pipes to an axial sinusoidal motion. It was found that an acceleration of up to 10 m/s^2 had no considerable influence on the bubble shapes while for acceleration up to 15 m/s^2 the bubbles started to distort. The bubble nose became more elongated and its curvature increased. The results indicate that the bubble rise velocity increases as the acceleration decreases. For a horizontal motion of vertical channels, Kubie [7] performed a similar study and investigated the rise velocity of elongated bubbles. It was shown that the mean bubble velocity is a function of the pipe diameter, the relative acceleration and the amplitude of the sinusoidal motion and increases as the relative acceleration increases. He also compared the increasing trend of the bubble rise velocity in horizontal direction with the decreasing rise velocity for vertical channel vibration and showed that the reason for this difference is the direction and magnitude of resulting acceleration acting on the bubbles.

Ellenberger and Krishna [8,9] discussed the application of low-frequency vertical vibrations to the liquid phase of an air–water bubble column. They mounted a vibration exciter at the bottom of the bubble column which transfers the vibration to the liquid phase by means of a piston. They showed that vibration causes to produce considerably smaller bubbles at the nozzle. Also, it was shown that application of vibrations causes enhancement of mass transfer coefficient and gas hold up by a factor of two or more [10]. Furthermore, the results showed that application of vertical oscillation has the potential of enhancing the contacting of phases in fluid-fluid dispersions [11,12]. Dillon et al. [13] investigated the pressure drop of two-phase flow in a narrow horizontal annular test section with an inner diameter of 7.93 mm. The influence of lateral mechanical oscillation of the test section on two-phase pressure drop was investigated, with vibration amplitudes up to 0.2 mm and frequencies in the range 5 Hz–400 Hz. The results showed a negligible influence of the vibration, which was within the experimental uncertainty limits. The impact of low-frequency vertical vibrations on the hydrodynamics and mass transfer characteristics of monolith loop reactors was studied by Vandu et al. [14] and compared with conventional internal airlift reactor and bubble column configurations. The results showed that imposing oscillation has the effect of significantly improving the ratio of volumetric mass transfer coefficient to the gas hold up for all considered reactor configurations. For monoliths, it was moreover found that vibrations additionally improve the gas–liquid distribution across the channels.

Hashmi et al. [15] reviewed current knowledge about the underlying physics of oscillating bubbles in micro-sized contactors. They critically discussed state of the art on the application of oscillation in microfluidic devices. They also highlighted the benefits and the challenges of using vibrating bubbles and argued that these investigations would be revolutionary to the progress of next-generation Lab-on-Chip systems. Madani et al. [6] considered the rise of a Taylor bubble in a vertical vibrating channel. The experiments were done for two different pipe diameters and with fluids of different viscosities and restricted to high Reynolds numbers to study the inertial effects. The results showed that for low acceleration the average velocity decreases with the relative acceleration of oscillation. Also, it was shown that, beyond a critical relative acceleration, the mean bubble velocity rises and the increase of fluctuating velocity slow down. Fernandez Rivas et al. [16] reviewed concepts of micro-sono-reactors and discussed the latest progress and future directions. They discussed that micro-sono-reactors are capable of handling small reaction volumes in a reproducible and efficient system, which the main parameters of the system such as frequency, amplitude, acoustic power, and sonication times can be accurately adjusted. Moreover, it was argued that processes including the micro-sono-reactors are easily scalable and enable flow recirculation.

Polezhaev et al. [17] found a significant increasing evaporation rate in a tube in which the gas/liquid interface axially oscillates and reported a tenfold increase of the apparent diffusive coefficient. The dependency of the enhancing effect on the tube diameter, the frequency and the amplitude of the liquid oscillations was investigated and the parametric dependence of the apparent diffusive coefficient was correlated via the associated dimensionless Péclet number. Yao [2] gave an overview over the recent investigations on the application of power ultrasound to adsorbent regeneration, food drying, air dehumidification, water treatment and others. They concluded that although the ultrasonic treatment may cause degradation of especially biological process constituents, it can significantly help to decrease the food processing time and reduce the drying temperature. Recently, Dong et al. [18] used ultrasonic oscillation to intensify the gas-liquid mass transfer in micro-reactors. They applied severe surface wave vibration on the bubbles and found that for slug bubbles confined in a smaller microchannel, surface wave oscillations require more ultrasound energy to excite due to the confinement effect. It was proven that the volumetric mass transfer coefficient increased by

Download English Version:

https://daneshyari.com/en/article/6465575

Download Persian Version:

https://daneshyari.com/article/6465575

Daneshyari.com