Journal of Materials Processing Technology 236 (2016) 1–8

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

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

Impeller design assisted by physical modeling and pilot plant trials

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ARTICLE INFO

Article history:
Received 20 January 2016
Received in revised form 28 April 2016
Accepted 30 April 2016
Available online 2 May 2016

Keywords:
Physical model
Degassing
Aluminum
Impeller design

ABSTRACT

A physical model of a batch aluminum degassing reactor equipped with the rotor-injector technique was used to measure deoxidation kinetics of water, assuming that this kinetics is similar to dehydrogenization of aluminum. Performances of three different impeller designs were tested with the model, two of them available commercially, while the third one is a design proposed in this work, which shows a better performance than the two commercial designs reducing the degassing time between 14% and 34%, the gas consumption between 14% and 32%, and an increment in gas efficiency between 22% and 49% compared with the commercial designs. Performance of the impellers in aluminum was tested in a pilot degassing unit, and again, the impeller design proposed showed a better performance by reducing the amount of hydrogen in liquid aluminum after 10 min of degassing 1/2 respect to the commercial design A and 2/3 respect to the design B.

1. Introduction

The quality of aluminum castings highly depends on the refining processes where non-metallic inclusions, alkali metals and hydrogen are removed from the melt. Removal of these impurities is achieved effectively by fluxing gases through a rotating impeller that breaks-down gas into fine bubbles with a big interfacial area, high residence time and preferentially evenly distributed in the entire ladle. Although this technology is mature, there is still room for optimizing the process based on a deep knowledge of the phenomena governing the process and by improving the technology of degassing. Specifically in the case of aluminum degassing, according to Engh (1992), lots of fundamental work was done three decades ago by establishing the thermodynamics of the process through expressions of the solubility of hydrogen in aluminum as a function of temperature and the role of most of the common alloying elements on its solubility. Also Engh (1992) establishes that kinetics of the degasification has also being studied through mathematical and physical models since under the aggressive conditions prevailing in industry, plant trials are difficult to achieve.

Regarding mathematical models, Zhang et al. (2012) published a review that accounts four types of models that predict hydrogen removal evolution in time during gas fluxing based on simple mass balances of hydrogen for both batch and continuous reactors. All of these models assume that degassing is controlled by mass transfer of hydrogen in the liquid side of the liquid-bubble interphase, where the key parameters are the interfacial area and the global mass transport coefficient that depends in turn on the stirring conditions in the melt (stirring power, flow patterns and turbulence). However, the models still require the total surface area of bubbles and the mass transport coefficient as key kinetic data as is pointed out by Zhang et al. (2011).

Actually, both parameters, i.e. total interfacial area and the mass transfer coefficient, have been subject of many studies since the removal kinetics depend on the values of these two quantities. Regarding size of bubbles, Mazumdar and Evans (2004) revealed in their review that a great amount of work has been done in the steelmaking industry. Johansen et al. (1996) performed visual observations in transparent models, while Mazumdar and Guthrie (1995) carried out conductivity or ultrasound measurements in physical models to determine the size of bubbles. Fu et al. (1998) reported acoustic measurements to measure residence times of bubbles. Water physical models are used for measuring bubbles sizes although it is known that liquid Al has greater surface tension than water and therefore bigger bubbles are present in aluminum. Sigworth (1999) pointed out that only a few correlations of the bub-

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http://dx.doi.org/10.1016/j.jmatprotec.2016.04.031
0924-0136/

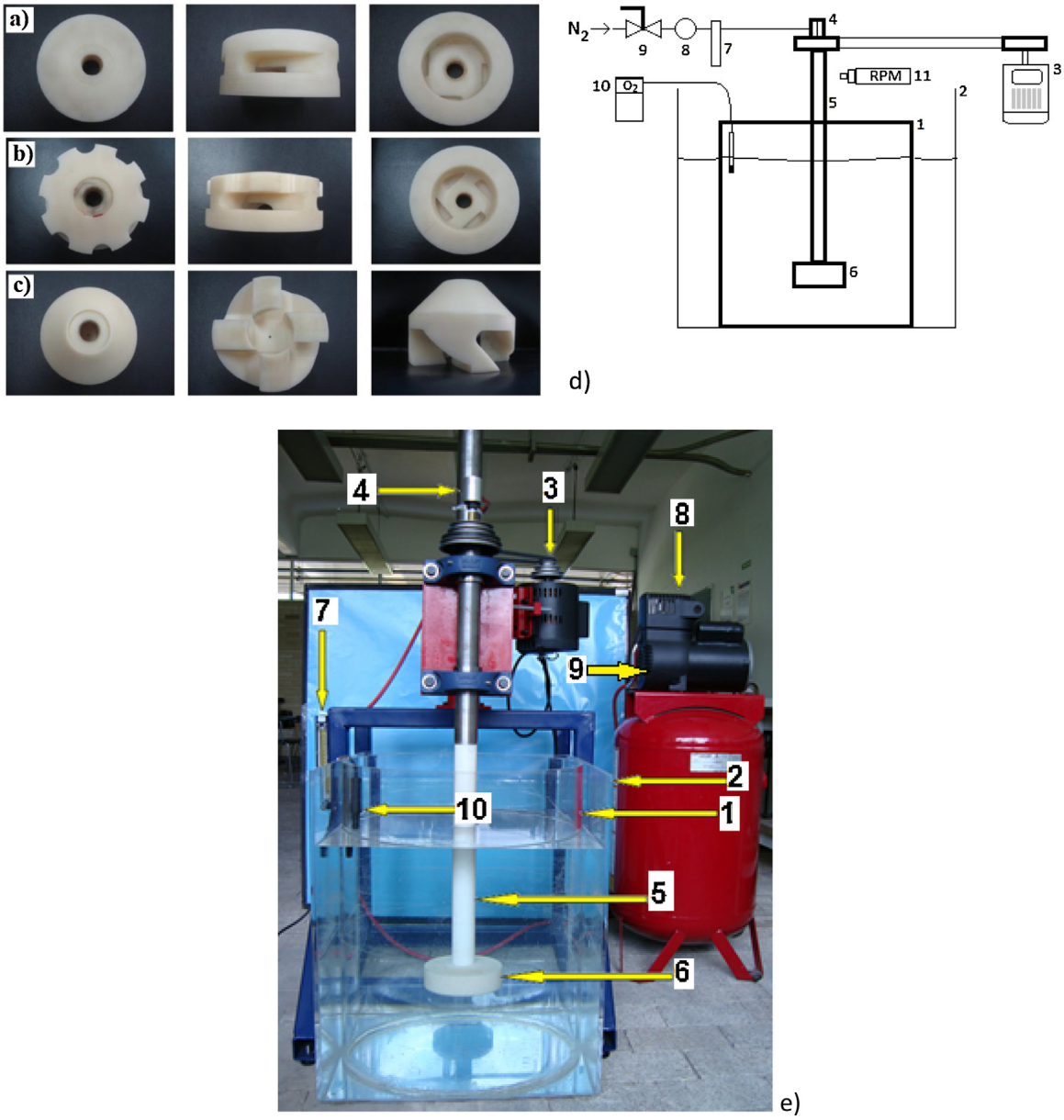

Fig. 1. (a) Commercial impeller design A. (b) Commercial impeller design B. (c) Impeller design proposed in this work. (d) Scheme of the experimental setup: 1 acrylic vessel, 2 acrylic container, 3 motor, 4 rotary joint, 5 shaft, 6 impeller, 7 flowmeter, 8 pressure regulator, 9 valve, 10 oxymeter, and 11 tachometer. (e) Photograph of the setup.

ble sizes in systems stirred with impellers have been reported based on the stirring power, although Sigworth (1999) acknowledges that some authors suggest sizes of bubbles in liquid aluminum below 5 mm, while Johansen et al. (1996) mentioned that others report a wide range of bubble sizes being small just leaving the impeller and a quadruple size close to the free surface due to coalescence, and finally Tovio et al. (2000) mentioned that the bubble size depends on the injection device (lance, impeller, diffuser, or porous plug) but it is independent on the type of gas. Also Chen and Zhao (1995), claimed that the ratio of the stirring power due to the impeller over the stirring power due to the bubbles, determines the degree of dispersion of the bubbles and Oldshue (1969) presents four degrees of dispersion of bubbles. More recently and using in situ synchrotron X-ray radiography, Xu et al. (2016) studied the dynamic behavior of ultrasonic cavitation gas bubbles in a molten Al–10 wt% Cu alloy. They found that, under the applied sonication conditions, bubbles exhibited a log-normal size distribution with an average radius of 15.3 ± 0.5 μm, and that the growth rate of bubble radius as a function of time, R(t), followed a power law. Simple algebraic equations were obtained by Chiti et al. (2004) to describe the gas holdup, while Johansen et al. (1998) also uses simple algebraic equations to quantify residence times and terminal velocities of ascending bubbles.

Regarding mass transfer coefficients, Engh (1992) emphasize that most of the values are obtained by the standard theories (boundary layer theory, or penetration theory) or by fitting the kinetic equation obtained from the mass balance, and only a few correlations have been reported for degassing units with the impeller.

Additionally, the CFD numerical simulations have become important in the last decade, where flow patterns, turbulence structure and gas holdup are estimated by solving the conservation equations of mass, momentum and a model of turbulence for a two fluid model either under an Euler-Euler or Euler-Lagrange frame of references. Simulations are usually done in 3D using different commercial software. Mirgaux et al. (2009) used FIDAP, Warke et al.