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LIQUID CURTAINS—II. GAS ABSORPTION

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Abstract—The absorption of mass by a liquid curtain is determined both analytically and numerically as a function of the Froude and Peclet numbers, pressure difference, convergence parameter, initial thickness-to-radius ratio and nozzle exit angle. Two analytical methods have been used. The first one considers the finite thickness of the liquid curtain, whereas the second method calculates the mass absorption rate by assuming that the curtain is a semi-infinite medium. The mass absorption rate was also determined numerically by accounting for the velocity distribution across the liquid curtain. The results of the two analytical methods agree very well with the numerical results for high Peclet numbers; however, the predictions of the semi-infinite medium approximation are inaccurate at low Peclet numbers and for positive nozzle exit angles. It is shown that the mass absorption rates are mainly a function of the liquid curtain convergence length and thickness, and increase as the Froude number, convergence parameter and nozzle exit angle are increased, but decrease as the pressure coefficient, initial thickness-to-radius ratio and Peclet number are decreased.

INTRODUCTION

Vertical annular jets or liquid curtains can be used as chemical reactors for the reduction of zirconium from zirconium tetrachloride and sodium (Roidt and Shapiro, 1985), reaction and control of toxic wastes, gas–liquid chemical reactions, scrubbing of radioactive and non-radioactive particulates and soluble materials, determination of gas diffusivities in liquids, etc. Liquid curtains can also be used as protection systems in inertial confinement laser fusion reactors (Ramos, 1988). The hydrodynamics of liquid curtains was studied both analytically and numerically in Part I (Ramos, 1988). Ramos and Pitchumani (1989a) studied the effects of the laminar boundary layer on liquid curtains, and showed that the influence of the Reynolds number on the convergence length of the curtain is small, except for positive angles at the nozzle exit. Ramos and Pitchumani (1989a) also showed that liquid curtain geometry can be determined accurately using the analytical solutions obtained in Part I (Ramos, 1988).

The problem of gas absorption by liquid curtains was studied by Baird and Davidson (1962) who derived a theoretical expression for the gas absorption rate assuming that the penetration depth of the gas is much smaller than the thickness of the curtain, thereby reducing the problem to one of diffusion in a semi-infinite medium. Their objective, however, was to devise a method for determining the diffusivities of various gases in liquids using mass absorption data.

Baird and Davidson (1962) obtained an analytical expression for the mass absorption rate which is proportional to the square root of the volume enclosed by the liquid curtain. However, their analytical expression is based on the assumption that the effective velocity for gas absorption is equal to the mean velocity of fall. In the studies presented in this paper, analytical and numerical results are obtained using the analytical and numerical solutions reported in Part I (Ramos, 1988) for pressurized and nonpressurized liquid curtains.

The need to be able to determine the mass absorption rate accurately arises for the following reasons:

(1) In the application of liquid curtains as chemical reactors, it is important to determine the rate at which the gases are absorbed by the liquid curtain from the volume it encloses.
(2) If toxic products result from the reactions, it is of utmost concern not to let the reaction products seep through the curtain thickness and escape into the medium surrounding the liquid curtain.
(3) Since the liquid curtain absorbs mass continuously from the volume it encloses, there is a resulting depletion of mass in the volume enclosed by the curtain, and the curtain tends to collapse. In order to prevent the collapse and to keep the curtain at steady state, a continuous flow of mass into the volume enclosed by the curtain equal to the rate of mass removal by the liquid curtain, i.e. equal to the mass absorption rate, should be maintained.

In this paper, the problem of mass absorption by a liquid curtain is studied both analytically and numerically. Analytical and numerical solutions for the concentration profile as well as for the mass absorption rate are obtained for liquid curtains of finite thickness. These solutions are compared with those corresponding to an analysis which treats the liquid curtain as a semi-infinite medium. Analytical solutions for both the liquid curtain geometry and mass absorption rate are also obtained using the results of Part I (Ramos, 1988) and those presented in this paper.

The equations governing the fluid mechanics of liquid curtains have been derived in Part I (Ramos,