Chemical Engineering and Processing xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Chemical Engineering and Processing: Process Intensification

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

Design and performance of the rotating liquid sheet contactor

Leigh T. Wardhaugh[a,c,*], Christopher B. Solnordal[b], Andrew Allport[a]

[a] CSIRO Energy, P.O. Box 330, Newcastle, NSW 2300, Australia
[b] CSIRO Mineral Resources, Clayton, Victoria, 3169, Australia
[c] CSIRO Energy Technology, Steel River Estate, 10 Murray Dwyer Circuit, Mayfield West, NSW 2304, Australia

ARTICLE INFO

Article history:
Received 27 February 2016
Received in revised form 22 August 2016
Accepted 6 September 2016
Available online xxx

Keywords:
Absorption
Packed bed
Gas liquid contactor
Mass transfer
Computational fluid dynamics
Liquid sheet

ABSTRACT

The Rotating Liquid Sheet (RLS) contactor is a new gas-liquid contacting device that is based on the formation of continuous liquid sheets in the shape of multiple blades or helices issuing from slots in a centrally rotating tube. The resulting rotating liquid sheets provide a high interfacial area of contact with the gas and are shaped in such a way that the rotation of the liquid sheet is able to pump the gas through the otherwise empty column at rates comparable to that seen in packed bed contactors. The centrifugal action of the device significantly reduces the entrainment of droplets, while the control of the generation of the liquid surface also makes the device suitable for solvents that are too viscous to be utilized in a packed bed or similar conventional contactors.

This paper sets out the design equations for the RLS contactor, provides a basis for comparison with conventional contactors including packed beds consisting of random or structured packing. Experimental evidence for the pumping capacity and Computational Fluid Dynamics (CFD) modelling are applied to justify the performance of the RLS contactor and the choice of the design approach.

1. Introduction

Many industrial processes require the intimate contact of liquid and gas streams often with the intent of removing specific components from either of the streams by mass transfer and/or the transfer of heat from one stream to the other. In many processes a chemical reaction, usually in the liquid phase, serves to remove diffusing components from the boundary layer thus increasing the driving force for mass transfer. Post-Combustion Capture (PCC), which involves the removal of CO_2 from flue gas streams from, for example, coal or gas fired power stations, is an extreme situation of gas liquid contacting in which enormous quantities of a low pressure gas must be cost effectively processed for the removal of the undesired components (CO_2 and trace acid gases) using a liquid absorbent. The typical PCC process uses an aqueous solution of an amine or amine blend that is cycled between the absorber vessel and the desorber or stripping vessel.

A new gas-liquid contactor – the Rotating Liquid Sheet (RLS) contactor – was developed as a way of overcoming the limit on gas velocity (throughput) set by the flooding point of conventional packed beds with random or structured packing, and also to maintain the intensity of gas-liquid contacting while reducing the total pressure drop of the contacting device. The concept of the RLS contactor has been described in Wardhaugh, Allport, Solnordal and Feron [1].

The aim of the current paper is to present a broad overview of the work performed so far in designing and testing the RLS contactor, while providing considerable detail of the equations used to guide the potential scale-up of the device. In this section the concept and key parameters are described. In Section 2 the design procedure is presented, with consideration given to process constraints, geometric and fluid dynamics considerations, and the implications of energy and capital cost on overall design. Section 3 provides details of the experimental apparatus constructed to investigate the device operation, and some key results of these investigations are presented in Section 4. A brief overview of the range of numerical models used to aid in structural design is given in Section 5. Finally, Section 6 presents conclusions from the work so far.

1.1. Description of the rotating liquid sheet contactor

The device operates by forming continuous sheets of liquid at the outlet of slots in an axially located rotating tube. The liquid sheets travel outwards reaching the wall of the otherwise empty column prior to break-up into droplets, while the gas travels in a

* Corresponding author at: CSIRO Energy Technology, PO Box 330, Newcastle NSW 2300, Australia. Tel.: +61 2 4960 6026; fax: +61 2 4960 6021.
E-mail address: leigh.wardhaugh@csiro.au (L.T. Wardhaugh).

http://dx.doi.org/10.1016/j.cep.2016.09.002

Nomenclature

A Area
B_s Spacing between liquid sheets
D Diameter; diffusivity
E_i Capture efficiency
F Performance, correction factor
g Gravitational constant
G Gas mass flowrate
H Height of packing segment/ RLS module
K_m' Mass transfer coefficient (gas phase)
L Liquid mass flowrate
L_0 Unloaded liquid mass flowrate
L_m Total liquid mass flowrate (from all the slots in a single module)
L_s Slot length
M Molecular weight
n Slotted tube rotation rate (rpm)
N_r Number of slot rows (blade type design)
N_{st} Number of slot starts (per row for blade type design)
N_{tn} Number of slot turns (<1 for blade design; ≥ 1 for helical design)
P Pitch (height 1 turn of helix or 1 blade)
ΔP Pressure drop
r, R Radial dimension, radius
R_B Distance of liquid sheet breakup point from origin along flight path
t Time
V Velocity
V_{Fl} Flood point (or other limit) gas velocity
Y_i Mole fraction of component to be captured in incoming gas
W_s Slot width
z Axial direction

Dimensionless numbers
Re Reynolds number
Sc Schmidt number
Sh Sherwood number
We Weber number

Greek letters
α Liquid projection angle (from horizontal) at slot exit
α_L Lean loading (module or process inlet)
α_R Rich loading (module or process inlet)
η_p Gas pumping efficiency of rotating liquid sheet
σ Surface tension
Ø Slot angle (from horizontal) in θ direction
μ Viscosity
ρ Density
θ Longitudinal axis/dimension

Subscripts
a Annulus (in RLS column)
A Amine/active component in liquid
b Blade
c Column
cn Centrifugal
d Drive rod
Fl Flood point
fp Flight path
G Gas
h Helix
i Component/ inside dimension
j Module index; jet
L Liquid
m Module
o Outside dimension
p Packing (material or segment)
r Recycle
t Total
x Excess/over-design amount

spiral path between adjacent sheets thus achieving a very high surface area of contact. The shape and rotation of the liquid sheets formed at the slots impart momentum to the gas thus enabling the pumping of the gas through the column.

Two kinds of slots have to date been investigated:

1. Helical slots which form the rotating liquid sheet into the shape of an auger (Fig. 1a). In this figure the rotation of the tube in an anti-clockwise direction pumps gas upward through the column.
2. Blade slots which form individual sheets of liquid similar in appearance to the blades of an axial compressor (Fig. 1b). In this figure the rotation of the tube in a clockwise direction pumps gas upward through the column, since the blade slots face the opposite direction to the helices in Fig. 1a (manufacturing choice).

The advantages of the RLS contactor to be discussed further in this paper are:

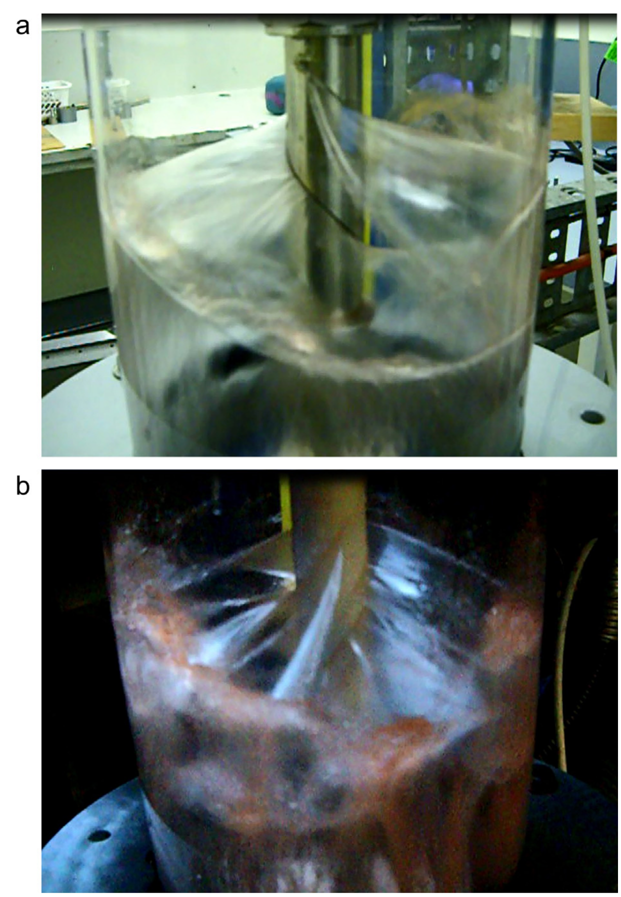

Fig. 1. Two examples of the Rotating Liquid Sheet contactor configurations. (a) single helix (1 turn; 2 start; slot angle 45°, anti-clockwise rotation to pump upwards); (b) $^1/_4$ turn blades (3 rows, no overlap; slot angle 45°, clockwise rotation to pump upwards).

Please cite this article in press as: L.T. Wardhaugh, et al., Design and performance of the rotating liquid sheet contactor, Chem. Eng. Process. (2016), http://dx.doi.org/10.1016/j.cep.2016.09.002