Chemical Engineering Science 65 (2010) 6425–6434

Contents lists available at ScienceDirect

Chemical Engineering Science

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

Intensification of *G*/*L* absorption in microstructured falling film. Application to the treatment of chlorinated VOC's – part I: Comparison between structured and microstructured packings in absorption devices

H. Monnier*, L. Falk, F. Lapicque, R. Hadjoudj, C. Roizard

Nancy Université, LRGP CNRS, 1 rue Grandville, 54001 Nancy, France

ARTICLE INFO

Article history:
Received 29 March 2010
Received in revised form
17 September 2010
Accepted 22 September 2010
Available online 29 September 2010

Keywords:
VOC
G/*L* absorption
Structured packing Sulzer EX®
Microstructured contactor
Falling film microreactor IMM
Tetrachloroethylene

ABSTRACT

The absorption of tetrachloroethylene – the VOC – in di-ethyl-hexyl-adipate – the solvent – was carried out as an example of gaseous waste treatment. Two gas–liquid contactors were used: a column provided with as structured *Sulzer EX*® packing and a microstructured falling-film absorber provided with thin vertical channels, manufactured by the *Institut für Mikrotechnik Mainz* (IMM). The overall transfer coefficient of VOC, K_Ga, was calculated from the absorption efficiency of the various runs carried out, allowing comparison of the two gas–liquid contactors. Due to the high solubility of the considered VOC, mass transfer was shown to be mainly controlled by gas-side transfer rates. Transfer coefficient K_Ga of the two absorbers were found to be comparable, but with gas and liquid velocity in the microstructured absorber from one to two orders of magnitude below those in the column, expressing the high transfer performance offered by the microsystem. Moreover, the thickness of the liquid film in the channels was below 100 μm, much lower than that in a structured packing near 500 μm. This shows that lower liquid flow rates can be used for efficient absorption in the microsystem. It is shown that contrary to conventional structured packing, the designed contact specific area in the microabsorber strictly corresponds to the interfacial *G*/*L* surface. This enables more compact and to miniaturize *G*/*L* contactors to be designed.

1. Introduction

Volatile organic compounds (VOCs) are the source of serious environmental issues and their emission has been subjected to more and more stringent legislation. Absorption of VOCs into selective solvents represents an alternative technique to other processes such as thermal or catalytic incineration, adsorption on activated coal, biological, or membrane processes. Removal of chlorinated species by incineration can result in the formation of hydrochloric acid and dioxins. Potential solvents for absorption are generally selected by considering the following criteria: high absorption capacity, high selectivity with respect to other gases, reduced volatility, and low toxicity.

Moreover VOC absorption is often carried out in conventional packed-bed columns, with counter-current flows of gas and liquid. Pressure drops have to be maintained at a reasonable level, and large specific areas can be offered with liquid flows fixed below the flooding capacity of the column. For the sake of intense transfer rates, structured packings have been developed, in particular to increase the effectiveness of gas–liquid separation in distillation towers (Sperandio et al., 1965). Such packings have been used for absorption of VOCs or CO_2 (Brunazzi and Paglianti, 1997; Aroonwilas and Tontiwachwuthikul, 1998; Dang Van et al., 1998; Wang et al., 2001), gas–liquid desorption, e.g. removal of VOCs from wastewater by stripping (Hwang et al., 1992; Ortiz-Del Castillo et al., 2000; Cypes and Engstrom, 2004).

The use of structured packed columns in the chemical processing industries dates back to decades. This development gave rise to a family of packings that was not only efficient for mass transfer and pressure drop but also promised to be amenable to rational modeling for predicting performance. Therefore they have been rapidly adopted in chemical industry because it was recognized that their efficiency is due to their geometry, which allows a large specific area in comparison with conventional packings, e.g. Pall rings.

However various experiments with structured packing have shown that the surface of the solid packing was not always completely wetted (Bravo et al., 1992; Rocha et al., 1993). The effective interfacial area is not strictly equal to the specific surface area of the packing considered. This result may lead to less efficient contactors or to oversized contactors, and to inappropriate operations by using excess of liquid solvent for total wetting of the surface. This can be much more dramatic for very soluble VOCs is in the solvent considered, since the absorption could be operated with low flow rates of liquid.

* Corresponding author. Tel.: +33 383 17 50 89.
E-mail address: hubert.monnier@ensic.inpl-nancy.fr (H. Monnier).

0009-2509/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ces.2010.09.027

A question arises as to the right estimation of value for the effective interfacial area to properly design absorption columns.

In order to avoid *G*/*L* transfer hindrance by only moderate wetting, a novel *G*/*L* contactor has been developed by using microtechnology processes: the micro-flow falling film absorber, which offers significantly higher performance in comparison to conventional devices. This technology was developed by the Institut für Mikrotechnik Mainz (Mainz) for chemical reactions such as the direct fluorination of toluene with elemental fluorine (Hessel et al., 2000).

As a matter of fact, conventional falling film systems generate films with thicknesses ranging from 0.5 to 3 mm (Karimi and Kawaji, 1998; Hessel et al., 2000), whereas films formed at the surface of microstructured contactors have a thickness below 100 μm. Thus, using the microstructured support would allow efficient absorption with lower solvent flow rates than those in conventional devices.

However the process of extrapolation and its design remain questionable for industrial application. To perform the above extrapolation, numbering-up calculation has to be carried out with the innovative microstructured falling film contactor in order to treat industrial gaseous flow rates (Mhiri, 2009). Extrapolation of microdistillation contactor is already used in the industry (*Velocys*, USA). The application of such a microstructured falling film contactor is possible once the numbering-up calculations is made. Another application consists in building micro-hybrid processes or micro-integrated processes, which do not require any scale-up step.

The aim of this paper is to compare two absorption contactors, first a column provided with a structured packing (*Sulzer EX*®), and second with the microstructured falling film reactor, depicted in Figs. 1 and 2. The overall mass transfer and the absorption efficiency were measured for the case of tetrachloroethylene (TCE) diluted in an air stream at ambient temperature and pressure, and di-ethyl-hexyl adipate (DEHA). This system was selected because of the industrial significance of TCE and the fair absorption capacity of the solvent. Vapour–liquid equilibrium of the (TCE-DEHA) system has been extensively investigated by Hadjoudj et al. (2004). As expected from the high solubility of TCE in DEHA, absorption experiments showed that the mass transfer resistance was mainly located near the gas laminar film. The efficiency and the transfer rates obtained with the two contactors are presented and discussed.

2. Experimental section

2.1. Chemicals

All chemicals were of analytical grade. TCE was purchased from *Merck*, and DEHA was obtained from *Acros Organics*. Physical properties of the various chemicals are reported in Table 1. The value for the diffusion coefficient of TCE in the solvent was determined by the falling film method in the laminar regime (Hadjoudj, 2004; Hadjoudj et al., 2008).

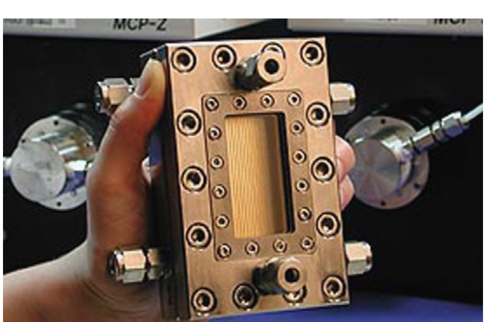

Fig. 1. Microstructured falling film reactor(IMM).

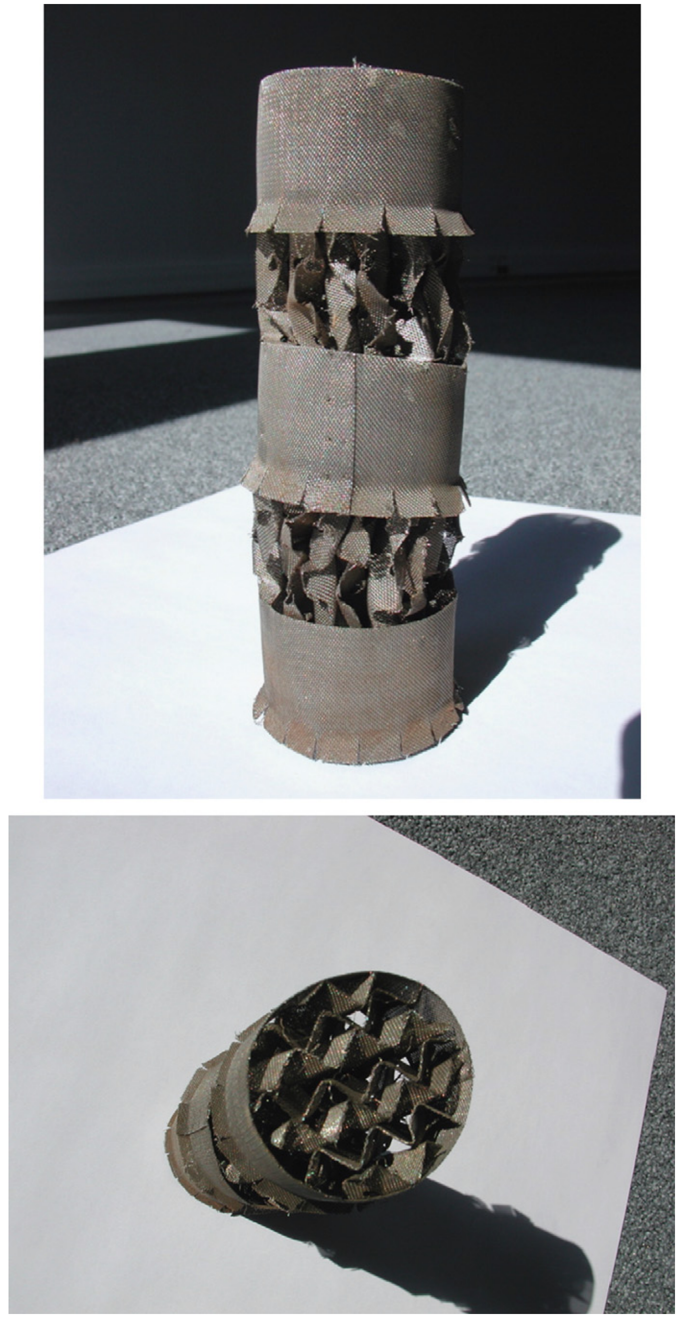

Fig. 2. Pictures of the structured packing Sulzer EX®.

Henry's law constant of TCE (VOC) in DEHA was deduced from vapour–liquid equilibrium of the binary system (Hadjoudj et al., 2004) at 1.67 kPa at 303 K. Henry's constant in water at the same temperature was reported at 1.046×10^5 kPa at 303 K by Jian (1998), Doi and Yoshikawa (1975), Alnova and Volkov (1989) corresponding to a solubility nearly 50 000 times lower than that in DEHA (Table 2).

2.2. Column with structured packing

2.2.1. Experimental setup

The experimental setup is schematically shown in Fig. 3. The column was a Plexiglas® tube, 1 m long and with an internal