Journal of Industrial and Engineering Chemistry 20 (2014) 2650–2656

Contents lists available at ScienceDirect

Journal of Industrial and Engineering Chemistry

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

Wall to liquid mass transport and diffusion controlled corrosion in fixed bed reactors

M.H. Abdel-Aziz [a,b,*], M. Bassyouni [a,c], I.A.S. Mansour [b], A. Nagi [b]

[a] Chemical and Materials Engineering Department, Faculty of Engineering, King Abdulaziz University, Rabigh 21911, Saudi Arabia
[b] Chemical Engineering Department, Faculty of Engineering, Alexandria University, Alexandria, Egypt
[c] Department of Chemical Engineering, Higher Technological Institute, Tenth of Ramadan City, Egypt

ARTICLE INFO

Article history:
Received 26 July 2013
Accepted 25 October 2013
Available online 31 October 2013

Keywords:
Corrosion
Diffusion
Fixed bed
Heat transfer
Mass transfer

ABSTRACT

The diffusion controlled corrosion at the inner wall of a fixed bed reactor was studied in terms of the wall to liquid mass transfer coefficient. Variables studied are solution flow rate, physical properties, and packing size and geometry. The effect of drag reducing polymers on the rate of mass transfer and on the rate of corrosion was studied. The presence of the drag reducing polymer decreased the rate of both mass transfer and corrosion by a factor ranging from 8.92% to 39.47%. All variables were correlated by dimensionless equations. Possible applications of these data in heat transfer were highlighted.

1. Introduction

One of the essential parts in the chemical industry is fixed bed reactors which have a wide range of industrial and environmental applications [1–6]. Fixed bed reactors are simply described as hollow vessels that are filled with a packing material where heterogeneous reactions occur on its surface. The purpose of packing is typically to improve contact between phases and increase the surface area/unit volume. The structure of packing has a great effect on heat, mass and momentum transfer in fixed bed reactors.

The main limitations of the fixed bed system are channeling, pressure drop, and the formation of hot spots. Channeling is the preferential flow of the solution at the container wall [7]. The existence of channeling in such reactors has a strong influence on the rate of diffusion controlled processes that may occur on the inner surfaces of the column's wall.

With regard to the diffusion controlled corrosion at the inner wall of the fixed bed reactor, channeling leads to a high solution velocity at the wall, the high velocity increases the rate of diffusion of ions and increases the rate of corrosion via erosion corrosion mechanism. Corrosion of the inner wall of the fixed bed leads to contamination of the products and reduce the service life of the column. The aim of the present work is to study the influence of packing size and geometry as well as solution flow rate, and solution physical properties on the rates of mass transfer and diffusion controlled corrosion at the inner wall of fixed bed reactors.

In view of its economic importance, the phenomenon of drag reduction has found many technical applications such as corrosion inhibitors [8]. Drag reducing polymers has the potential of being used under turbulent flow to reduce the pumping power requirement; it would be of interest to examine the effect of these polymers on the rate of liquid–solid mass transfer in fixed beds. Such a study would shed light on the economic feasibility of using drag reducing polymers in fixed bed reactors.

The present experiments were conducted by using the diffusion controlled chemical dissolution of copper in acidified dichromate where the solid–liquid mass transfer coefficient was used to express the rate of diffusion controlled corrosion at the inner wall of the fixed bed column. The system has been used widely to study the role of surface geometry and the hydrodynamic conditions on the rate of liquid–solid mass transfer and diffusion controlled corrosion in view of its simplicity and accuracy [9–12].

The present data can find different applications such as: (i) estimation of the corrosion allowance in fixed bed reactors during the design stage, (ii) prediction of the heat transfer coefficient at the inner wall of the fixed bed by the virtue of the analogy between heat and mass transfer [13,14], (iii) removal of heavy metals from wastewater by cementation where the cementing agent lines the

* Corresponding author at: Chemical and Materials Engineering Department, Faculty of Engineering, King Abdulaziz University, Rabigh 21911, Saudi Arabia. Tel.: +96 6540853623.
E-mail address: helmy2002@gmail.com (M.H. Abdel-Aziz).

1226-086X/$ – see front matter
http://dx.doi.org/10.1016/j.jiec.2013.10.051

Nomenclature

A	inside surface area of the column, cm^2
C	concentration at time t, mol/cm^3
C_0	initial concentration, mol/cm^3
D	diffusion coefficient, cm^2/s
d	column inside diameter, cm
d_p	packing diameter, cm
h	heat transfer coefficient, $W/cm^2\ ^\circ C$
j	mass or heat transfer j factor ($St \cdot Sc^{0.66}$)
k	mass transfer coefficient, cm/s
Q	solution volume, cm^3
R	column radius, cm
Re	Reynolds number, $\rho_L V d/\mu$
Re_m	modified Reynolds number, $\rho_L V d_p/\mu(1-\varepsilon)$
Sc	Schmidt number, $\mu/\rho_L D$
Sh	Sherwood number, kd/D
t	time, s
V	solution superficial velocity, cm/s
ε	porosity of the bed
μ	solution viscosity, g/cm s
ρ	r/R, reduced radial coordinates
ρ_L	solution density, g/cm^3
δ	diffusion layer thickness, cm

column's wall and the packing is used as a turbulence promoter [15].

2. Experimental part

Fig. 1 shows a schematic presentation to the experimental setup used in the present study. It consisted mainly of 12 l Plexiglas tank, a 0.5 hp plastic centrifugal pump, and a cylindrical copper column. The column had an inner diameter of 10.16 cm and a length of 50.8 cm. The flow line was made of 1.27 cm inner diameter PVC pipes. The flow is fed to the column by means of the centrifugal pump through a Teflon flange to eliminate the turbulence effect of the inlet solution. The flow rate was measured by means of a rotameter and was controlled by means of PVC globe valves. The outlet solution is recycled to the Plexiglas storage tank. The wall to

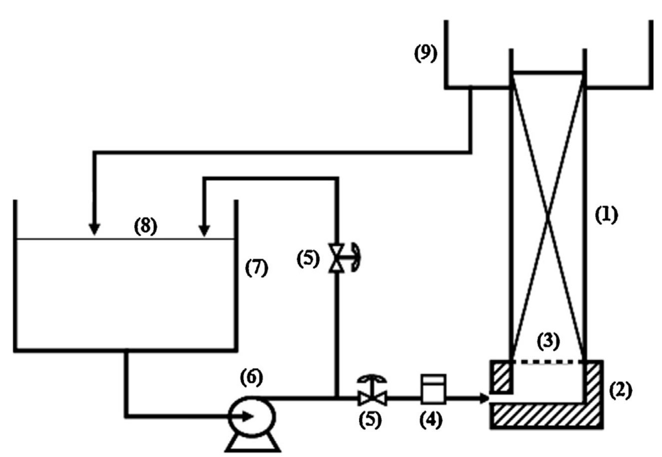

Fig. 1. Experimental setup. (1) Fixed bed packed column, (2) teflon flange, (3) perforated base, (4) flow meter, (5) PVC valves, (6) centrifugal pump, (7) plexiglas tank, (8) solution level, and (9) overflow weir.

Table 1
Overall bed porosity of different packing used in the present study.

Packing diameter (cm)	Porosity		
	Cylinders	Raschig rings	Spheres
0.8	0.473	0.7	0.456
1	0.48	0.749	0.485
1.2	0.494	0.782	0.539

liquid mass transfer was measured for two conditions namely; unpacked, and packed column. For the packed column three different geometries of inert packing were used namely; spheres, cylinders, and Raschig rings. The diameter of the packing was a variable and three different values were used namely: 0.8, 1 and 1.2 cm. Table 1 shows the measured values of the overall bed porosity of different packing used in the present study.

To study the effect of drag reducing polymers on the rate of solid–liquid mass transfer at the inner wall of the packed fixed bed, polyethylene oxide drag reducing polymer (Polyox WSR-310) a product of Union Carbide was used in concentrations of 100 ppm, 200 ppm, 300 ppm. In order to avoid mechanical degradation, the polymer was added to the blank solution in the solid form instead of the dissolved form [8].

2.1. Procedure

Before each run 8 l of freshly prepared acidified dichromate solution were placed in the storage tank. The solid–liquid mass transfer coefficient of the diffusion controlled dissolution of copper in acidified dichromate solution was used to express the rate of diffusion controlled corrosion at the inner wall of the packed and unpacked column under various conditions according to the equation [12,16]:

$$3Cu + 7H_2SO_4 + K_2Cr_2O_7 \rightarrow 3CuSO_4 + Cr_2(SO_4)_3 + K_2SO_4 + 7H_2O \quad (1)$$

The mass transfer coefficient was determined from the linear plot of $\ln(C_0/C)$ versus time according to Eq. (3) and Fig. 2. The concentration of the dichromate solution was measured at different time intervals by withdrawing samples of 5 cm^3 of the solution at 5 min intervals for analysis by the titration against a standard solution of ferrous ammonium sulfate using diphenyl amine barium salt as an indicator [17]. Three different initial concentrations of acidified potassium dichromate solution were

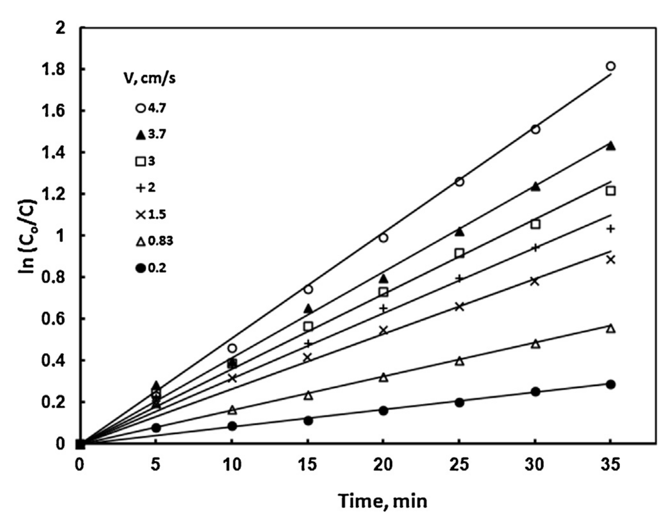

Fig. 2. Typical plots of $\ln(C_0/C)$ versus time at different solution superficial velocities (spherical packing; packing diameter = 10 mm; Sc = 1023).