International Communications in Heat and Mass Transfer 37 (2010) 1261–1265

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

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

Effect of vibrating disc electrode on ionic mass transfer in an electrolytic cell ☆

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ARTICLE INFO

Available online 27 August 2010

Keywords:
Mass transfer
Vibration
Disc electrode
Electrolytic cell

ABSTRACT

In the present investigation, a vertical disc electrode was vibrated in a rectangular electrolytic cell. The cell consisted of equimolal potassium ferricyanide and ferrocyanide electrolyte with excess indifferent electrolyte, sodium hydroxide. The mass transfer data were obtained on the disc electrode by varying the amplitude of vibration (0.033 to 0.089 m), frequency of vibration (2.93 to 16.16 Hz) and diameter (0.0125 to 0.0315 m) of the disc electrode. The mass transfer coefficient was increased with the decrease in the diameter of the disc electrode. The mass transfer coefficient was enhanced from 12 to 52 fold due to vibration.

Introduction

The transfer rates have become a key element for the success of any industry and increase in mass transfer rate is of considerable interest. The experience of earlier investigations reveals that though the application of any augmentative technique makes the system characteristics more complicated, it offers tremendous improvements in transfer coefficients. Hence the application of such technique has become necessary for carrying out the process rapidly, effectively and efficiently. Augmentation of transfer rates can be achieved by applying any of the techniques such as,

i. Vibration of the electrode or electrolyte [1,2]
ii. Rotation of the electrode or electrolyte [2]
iii. Use of cross flow elements [3]
iv. Insertion of turbulence promoters [4]
v. Presence of the packed or fluidizing solids [5]
vi. Periodic current reversal [6] etc.

The mass transfer investigations on vibration of the electrode were extensively carried out by vibrating different shapes of electrodes. The mass transfer rates at a vibrating sphere were studied by Noordsiji and Rotte [1]. They correlated their data as

$$Sh_v = 2 + 0.24(f\rho dH/\mu)^{1/2}. \tag{1}$$

Bharathi et al. [2] investigated the ionic mass transfer rates at vibrating spherical copper electrodes and proposed the equation:

$$Sh_v / Sc^{1/3} = 0.97Re_v^{0.4}. \tag{2}$$

Cylindrical copper and stainless steel electrodes were subjected to horizontal transverse vibrations by Rao et al. [7]. Their mass transfer data were correlated as

$$J_{dv} = 0.41Re_v^{-0.38}. \tag{3}$$

The mass transfer rates at vertical cylinders subjected to non harmonic transverse vibrations were investigated by Rao et al. [8] studying the sublimation of naphthalene into still air. They proposed the equation:

$$J_{dv} = 0.64(Re_v)^{-0.48}. \tag{4}$$

Sripathi et al. [9] reported the equation:

$$J_{dv} = 0.725(\rho D_e v_v/\mu)^{-0.38} \tag{5}$$

studying the effect of horizontally vibrating flat plate on the rates of mass transfer for dissolution of benzoic acid coated plates in water and air. The effects of frequency, amplitude and the size of the electrode on mass transfer coefficient were studied by Ramaraju et al. [10]. In their investigations, plate electrodes were subjected to horizontal transverse vibrations in a ferri-ferrocyanide system.

The effect of vibration on mass transfer rate from regularly vibrating single sphere and packed bed into a fluid stream was reported by Kitaura et al. [11]. They investigated the sublimation rate from vibrating camphor spheres and suggested the relation:

$$Sh_v / Re_v^{1/2} = f\left[(\pi Hf/\nu_v)^2 \text{and} (3\nu_v/2\pi df)^{1/2}\right]. \tag{6}$$

The effects of frequency and amplitude of oscillation and the diameter of the cylindrical copper electrode on ionic mass transfer

☆ Communicated by A.R. Balakrishnan.
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doi:10.1016/j.icheatmasstransfer.2010.08.008

Nomenclature

A	Area of the disc electrode, m^2
C_i	Concentration of ferricyanide ion, kg moles/m^3
d_d	Diameter of the disc electrode, m
d_e	Equivalent diameter of the cell, m
D_e	Equivalent diameter of the flat plate, 4hW/2(h + W), m
d	Diameter of the sphere, cylinder, m
D_L	Diffusivity, m^2/s
F	Faraday constant, 96500 coulombs/equivalent
f	Frequency of vibration, Hz
H	Amplitude of vibration, m
h	Height of the cathode support, m
I	Limiting current, A
k_L	Mass transfer coefficient, m/s
k_{L0}	Mass transfer coefficient at stationary disc electrode, m/s
L	Length of the cathode plate, m
n	Number of electrons involved in the reaction
V	Factor of vibration
v	Vibrational velocity for flat plate, 2Hf, m/s
v_o	Average angular oscillational velocity, m/s
v_v	Vibrational velocity, 2Hf, m/s
W	Width of the cathode support, m
ρ	Density of the electrolyte, kg/m^3
μ	Viscosity of the electrolyte, N–s/m^2
ϵ	Voidage
θ	Local position, degrees
ω	Angular frequency of vibration, 2πf, rad/s
J_{dv}	Mass transfer factor, $(k_L/v_v)\,Sc^{2/3}$
J_{do}	Mass transfer factor with angular oscillation, $(k_L/v_o)\,Sc^{2/3}$
Re_d	Reynolds number based on maximum velocity of vibration, 2πfρdH/μ
Re_o	Reynolds number with angular oscillation, $\rho d v_o/\mu$
Re_v	Vibrational Reynolds number, $\rho d \nu_v/\mu$
Sc	Schmidt number, $\mu/(\rho D_L)$
Sh_v	Sherwood number for vibration, $k_L d/D_L$
Sh_{av}	Overall Sherwood number

rate were studied by the Rayapa Raju and Raju [12]. They correlated the mass transfer data with the equation:

$$J_{do} = 0.54Re_o^{-0.43}. \tag{7}$$

The influence of sinusoidal vibration on forced convection mass transfer between a solid sphere and a liquid had been studied by Gilbert and Angelino [13]. The vibrations were described by two characteristics parameters, the relative intensity of vibration ($2Re_v/Re$) and the relative level of vibration (2H/d). The data obeyed the empirical relation:

$$Sh_v / Sc^{1/3} = 0.477Re_v^{0.538}\left[1 + 1.05(V-0.06)^{1.26}\right]. \tag{8}$$

Mass transfer at spheres subjected to horizontal transverse vibrations was investigated by Rao et al. [14] and they correlated the data as:

$$J_{dv} = 0.558Re_v^{-0.44}. \tag{9}$$

Takahashi and Endoh [15] studied the effect of vibration on forced convection mass transfer at spheres, discs and cylinders in flowing electrolyte. They reported the following correlations.

For spheres:

$$Sh_v = 2.9(Hd\rho\omega/\mu)^{0.61}, 1000<(Hd\rho\omega/\mu)<14,500. \tag{10}$$

For discs:

$$Sh_v = 9.1(Hd_d\rho\omega/\mu)^{0.53}, 1520<(Hd_d\rho\omega/\mu)<13,500. \tag{11}$$

For cylinders:

$$Sh_v = 5.5(Hd\rho\omega/\mu)^{0.57}, 1000<(Hd\rho\omega/\mu)<14,300. \tag{12}$$

The effect of vibration on local and overall mass transfer coefficients from a single cylinder was determined by Takahasi et al. [16]. For a vibrating single cylinder, the local Sherwood numbers showed the maximum value at the position of $\theta = 0°$ and 180°, and the minimum value at $\theta = 90°$. They developed the following correlations.for in-line tube banks:

$$Sh_{av}Sc^{-1/3} = 0.85\epsilon^{-1/3}Re_d^{0.53} \tag{13}$$

for the staggered tube banks:

$$Sh_{av}Sc^{-1/3} = 0.88\left[1 + 17.9(1-\epsilon)^{2.45}\right]^{0.5}Re_d^{0.5}. \tag{14}$$

The combined convection mass transfer in a vibrating flow imposed on a steady fluid flow in a pipe, using electrochemical method, was determined by Takahashi et al. [17]. They investigated the mass transfer for pulsating flow.

The individual and synergic effect of rotation and vibration of cylindrical electrode on mass transfer was evaluated by Appaji et al. [18]. They proposed the following correlation for vibrating cylindrical electrodes:

$$Sh_v / Sc^{1/3} = 0.78Re_v^{0.5}. \tag{15}$$

Ravi et al. [19] obtained mass transfer data at horizontally vibrating electrode support with and without perforations. The mass transfer coefficient was enhanced from 1.4 to 6 fold due to the vibration of the electrode support over the data obtained on stationary electrode support. They correlated the mass transfer data as:

$$J_{dv} = 2.19(\rho W\nu_v/\mu)^{-0.47}(1 + L/W)^{-0.7}. \tag{16}$$

Venkateswarlu et al. [20] obtained mass transfer data at copper microelectrodes fixed flush with a vibrating square perplex plate. They reported that electrode support without perforations was advantageous than a perforated electrode support. In this investigation, the effect of vibration of the bluff body, vertical disc electrode, on mass transfer coefficient is investigated using electrochemical method, diffusion controlled electrode reaction. The objective of selecting this investigation is to improve the efficiency of electrolytic cell, to enhance the mass transfer coefficient and to keep the mass transfer surface clean and unaltered. The electrochemical method is chosen for its simplicity, reproducibility, precision and negligible polarization.

Experimental procedure

The experimental set-up comprised of a 0.466 kW variable speed motor, an eccentric, a framework to carry the oscillating shaft and an electrode holder. The eccentric mainly consisted of a crank fixed in between two specially fabricated flanges. The crank was forged out of steel rod such that the flat circular plate formed an eccentric with other end of the rod. The amplitude of vibration was varied by changing the rod to the desired position on the crank plate. The crank