Preliminary Test Results for Analogy Experiment Methodology Developments

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1. Introduction

Expanded use of hydrogen as an energy carrier could help address concerns about global climate change and energy security. Hydrogen can be derived from a variety of domestically available primary sources such as fossil fuels, renewables, and nuclear power. The idea of hydrogen production by using the heat from nuclear power, HTGR (High-Temperature Gas-cooled Reactor), seems to be promising. The knowledge of detailed heat transfer phenomena in gaseous phase emerges as an important factor for HTGR, where buoyancy force plays a significant role. Large and expensive test facilities are to be constructed to assess the detailed mixed convection phenomena. However, using the analogy concept, a simple and cheap test facility could replace those. This study explores the feasibility of the idea.

2. Methods and Results

2.1 Heat and Mass Transfer Analogy

It is well-known that heat transfer and mass transfer systems show similar behavior: Analogy [1]. Also, Agar [2] pointed out that electrochemical mass-transfer correlations should resemble closely those established for heat transfer. Thus, the heat transfer correlations of Nu, Re, and Pr numbers could be constructed in terms of Sh, Re and Sc.

Table 1. Dimensionless group for analogy.

Heat transfer		Mass transfer	
Nusselt number	$\frac{hd}{k}$	Sherwood number	$\frac{h_m d}{D}$
Prandtl number	$\frac{\upsilon}{\alpha}$	Schmidt number	$\frac{\upsilon}{D}$
Reynolds number $\frac{\overline{u}d}{\upsilon}$			

2.2 Electrochemical System

An electrochemical system was devised to simulate the heat transfer phenomena in Poiseuille flow for which well-established heat transfer correlation is available. The electrochemical cell was filled with electrolyte containing 1.5 M H_2SO_4 and 0.1 M $CuSO_4$ and cupric electrodes are adopted. The electrical circuit consisted of a stabilized power unit, a voltmeter, an ampere-meter and a resistor, was constructed and the schematic is shown in Figure 1.

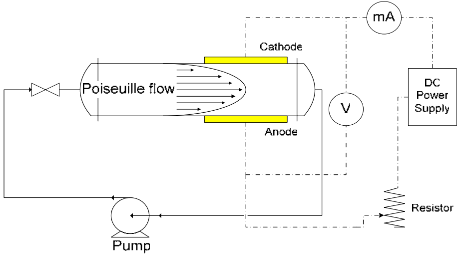

Figure 1. The system circuit.

2.3 Limiting current technique

When the electric potential is applied to the electrochemical system, copper ions are discharged from anode and move to cathode. Increasing the applied potential slowly, the current increases rapidly and then reaches a current plateau. Further increase of applied potential will incur hydrogen reduction reaction in the cathode resulting in current increase.

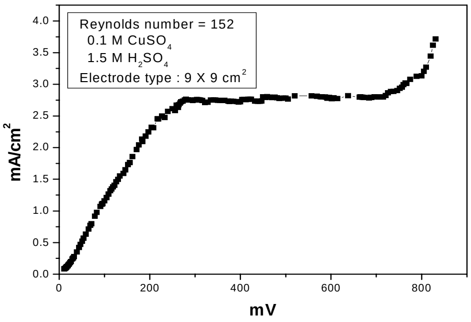

Figure 2. Typical limiting current curve.

This limiting current density is determined by the composition and transport properties of the electrolytic solution and by the hydrodynamic condition at the electrode. Thus the mass transfer coefficient is expressed in terms of the limiting current density [3]. However care should be taken to minimize the effect of the electric migration, as the transport characteristics of copper ion is affected by the electric field.

$$h_m = \frac{(1-t_n)I_{Lim}}{nFC_b} \qquad (1)$$

2.4 Tests and Results

In order to assess the possibility of using analogy concept in the assessment of heat transfer, an analogy experimental facility simulating Poiseuille flow was constructed for which well-established heat transfer correlation is available. Varying the *Re* numbers, the limiting currents were measured and mass transfer coefficients were calculated by the method proposed by Fenech and Tobias [3].

$$Sh_{av} = 1.467\left(\mathrm{Re}\,Sc\,\frac{d}{L}\right)^{1/3} \qquad (2)$$

Table 2. Nomenclature.

$n(valence\ electron): 2$	$d(channel\ height): 2\ cm$
$F(Faraday\ const.): 96485\ c/mol$	$\overline{u}(bulk\ velocity,\ cm/s)$
$D(mass\ diffusivity): 5.55357\times10^{-6}$	
$t_{Cu^{+2}}(transference\ no.): 0.01103$	
$I_{Lim}(Limiting\ current\ density,\ mA/cm^2)$	
$C_b(bulk\ concentration): 0.1\ mol$	

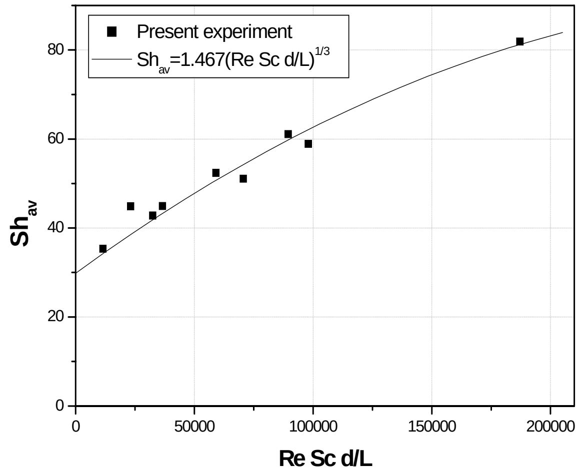

Figure 3. Average mass transfer under forced convection.

Figure 3 shows the comparison of test result with known heat transfer correlation for Poiseuille flow in equation (2). The test results show good agreement with the heat transfer correlation.

As the electrochemical system measures the current between electrodes, it has inherent limitation of average measurement. In order to overcome the limitation and to assess the local mass transfer coefficients, varying the plate widths, limiting currents were measured, which is presented in Figure 4. Again, the test results show reasonable agreements with the heat transfer correlation.

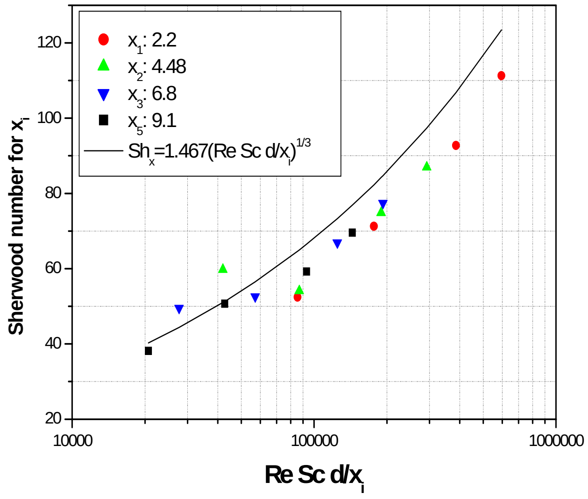

Figure 4. Local mass transfer under forced convection.

3. Conclusions

The validity of the present experimental method was confirmed through comparison between the present experimental data and well-known heat transfer correlation by using the experimental results under forced convection between two flat plates. It was shown that the experimental data agreed closely with results of previous work within the error bound of 20%. With these results, it is concluded that analogy method, between heat and mass transfer, using electrochemical system makes it possible to predict the unknown heat transfer correlations. This electroplating method not only provides with useful information on heat transfer but also has cost-effective advantage than any other experiments.

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[3] E. J. Fenech and C. W. Tobias, Mass Transfer by Free Convection at Horizontal Electrodes, Electrochimica Acta, Vol 2, p 311-325, 1960.