Heat Transfer Between a Heated Probe and liquid in a Gas Stirred Tank

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Abstract

This experiment studied the heat transfer between a heated probe and liquid in a gas stirred tank. The probe consisted of a vertical cylindrical rod containing of an electrical heater, with a heat flux sensor mounted on the outside of the rod to measure the local heat flux Q and surface temperature T_s. The temperature of the liquid T_b was also measured, and heat transfer coefficient would be calculated from

$$h = Q/(T_s - T_b)$$

The variables studied were gas flow rate, distance from the tip of the probe to the middle of the heat flux sensor dh and the viscosity of fluid. The fluid used were water and a 60% glycerol-water solution, with a viscosity of 0.001 Pa.s

It was observed that the heat transfer coefficient generally increased with increasing gas flow rate. At the highest gas flow rate tested, the heat transfer coefficient decreased slightly, possibly due to high gas holdup in the bubble plume which reduced the effective thermal conductivity of the liquid. The highest heat transfer coefficient was observed close to the tip of the probe, when the transition from a laminar to a turbulent boundary layer occurred. Increasing the liquid viscosity caused the heat transfer coefficient to decrease.

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1. Introduction

Heat transfer between solid additions and bulk liquid steel is an integral feature of numerous processing operation carried out in present day steel making ladles. Frequently, to increase the rate of heat transfer, the contents of the ladle are stirred by injecting a non-reactive gas such as argon.

Therefore, from a technological point of view,the heat transfer between solid additions and the bulk liquid steel in gas-stirred reactors has been, for some time, the subject of considerable interest.

In high temperature metallurgical processes, experimental investigation is not practical at very high temperature where estimation of heat transfer rates is difficult. For this experiment a water model was used. In this water model, the heat flux was measured by thin-film heat flux sensor between a heated copper cylindrical rod and ascending plume of bubble in the bulk liquid. The water temperature was measured by thermocouples.

2. Experimental study

The equipment consisted of a square tank made of acrylic plastic containing 0.116 m^3 of fluid and the cylindrical acrylic tank containing 0.03 m^3 of fluid used for the water & 60% glycerol experiment. The probe consisted of three section. The first and the last section made of stainless steel diameter of 2.5 cm. and 25, 5 cm. in length respectively and the middle section was 4 cm-long copper, which was heated by an electrical heater. The last section was attached to a stainless steel cone. The heater was connected to a variac, so that a specific voltage could be applied to the heater.

The heat flux and temperature at the copper surface were measured by a thin film heat flux sensor. Thermocouples type T were used to estimate the water temperature (see Fig.1). The thermocouples and heat flux sensor were connected to the data logger via electrical leads connected to a computer, running a Quick-basic program to calculate the heat transfer coefficient. The probe and lance, immersed in the liquid were supported by an aluminum mounting, which enabled their accurate positioning. The aluminum mounting had three circular holes to allow the lance to be correctly positioned so that the center of the lance lay directly under the tip of the probe. The aluminum mounting was supported over rthe top of the fluid bath. Three Rota meters were used to measure and control the flow rate of air for low flow rate, medium flow rate and high flow rate. (see Fig 1)

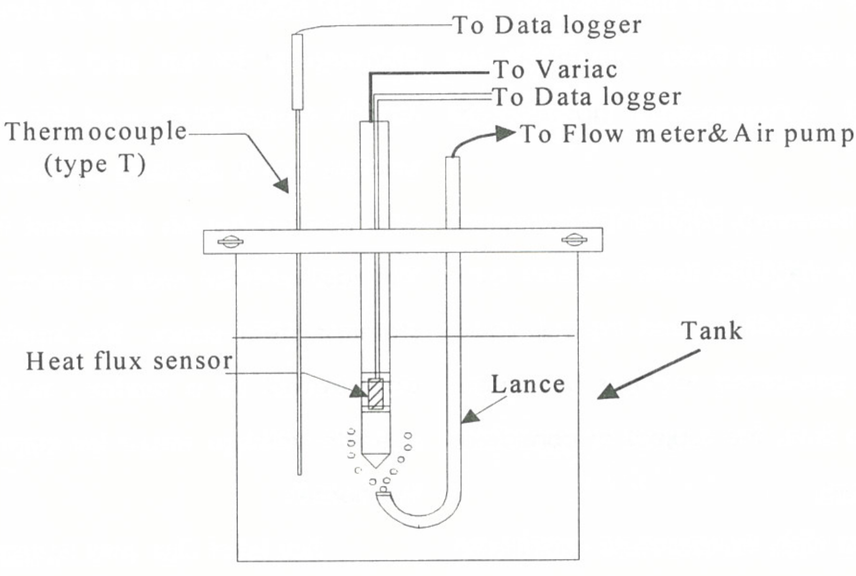

Figure 1. show the experimental equipment

The tank was filled with the test fluid and the stainless steel probe with heat flux sensor was assembled and the gas turned on. The electrical lead from variac was turned on reading 120 V. Gas flow rate will be the variables (0.000017, 0.00011,0.0002,0.0003,0.0004 and 0.0005 m^3/s), and distance from tip of probe to middle of heat flux sensor (19,14, and 9 cm respective). The distance from nozzle to tip of probe (d_p) was fixed at 5 cm. In the last experiment the viscosity of fluid was increased by adding 60% of glycerol to the water to increase the viscosity to 0.01 Pa.s.

3. Result and Discussion

This experiment measured the effects of gas flow rate, the d_h and the viscosity of the fluid on the heat coefficient. Heat transfer was by forced convection. The results were as follows:

The first experiment involved varying the gas flow rate and recording the heat transfer coefficient for 10 minutes. The experimental data (see fig 2-3)were plotted to show the relationship of the heat transfer coefficient which was dependent on the gas flow rate. If the gas flow rate was low, the heat transfer coefficient would increase, but at high gas flow rates where the gas holdup was so high that it could decrease the thermal conductivity of the liquid, the heat transfer coefficient decreased. The d_h length was the second variable that affected the heat transfer coefficient. From figure 2,3 it was shown that if d_h was large, the heat transfer coefficient would decreases. From figure 2 at d_h=9.5 cm at flow rate=0.0004 m^3/s, the heat transfer coefficient increased rapidly possibly due to the onset of turbulence, which decreased the boundary layer thickness (δ). In the water experiment the difference between temperature of copper and the water temperature was small so from the equation $Q = hA\Delta T$ when heat flux decreased, the heat transfer coefficient must be decreased. The comparison between Fig. 2 and Fig. 3 showed that the small tank would have faster circulation. The heat transfer coefficient will be influenced by the liquid circulation so that the transition zone was reached at lower flow rates than in the large tank.

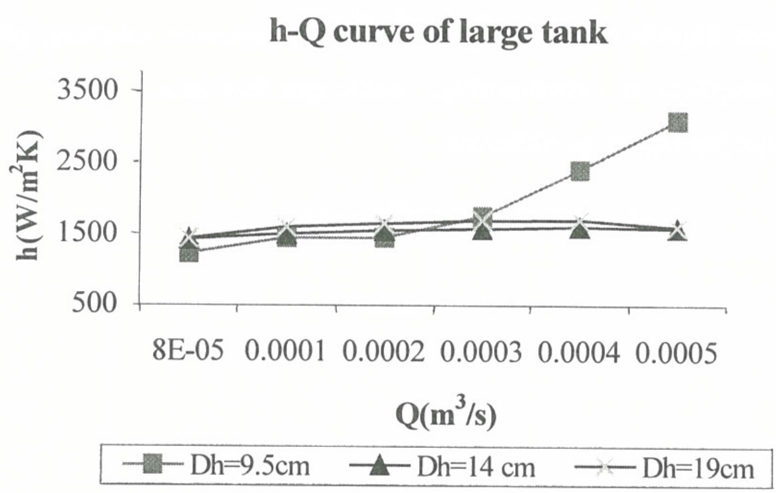

Fig 2. Show h&Q curve of large tank

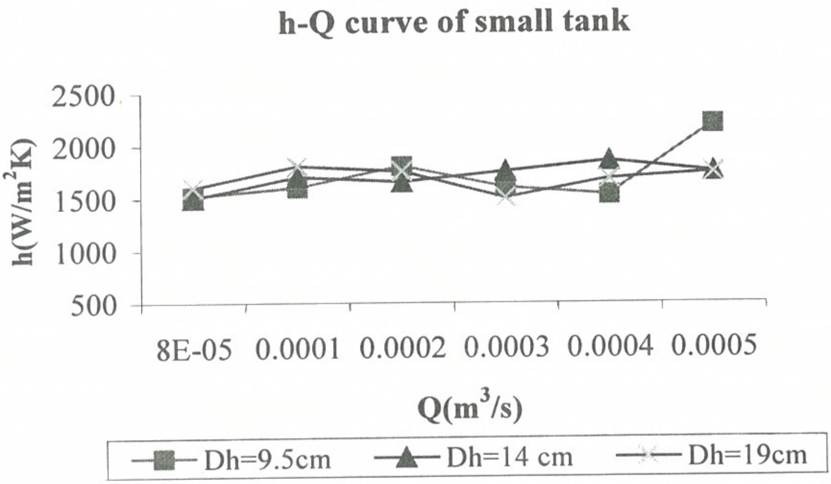

Fig 3. Show h&Q curve of small tank

The last variable was the viscosity of the fluid (see fig. 4). From this figure it was shown that if viscosity was increased, the heat transfer coefficient would decrease. Figure 3 and 4 compared the results using water and 60% of glycerol solution respectively. The 2 different liquids were used to determine whether a relationship couldbe found for liquid of different viscosities. It was interesting to note from figure 4 that a d_h value of 14 cm the highest heat transfer coefficient was obtained. However, this was not the case of figure 3.

The values for heat transfer were all generally higher than that for 60 % of glycerol solution, given the same gas flow rate.

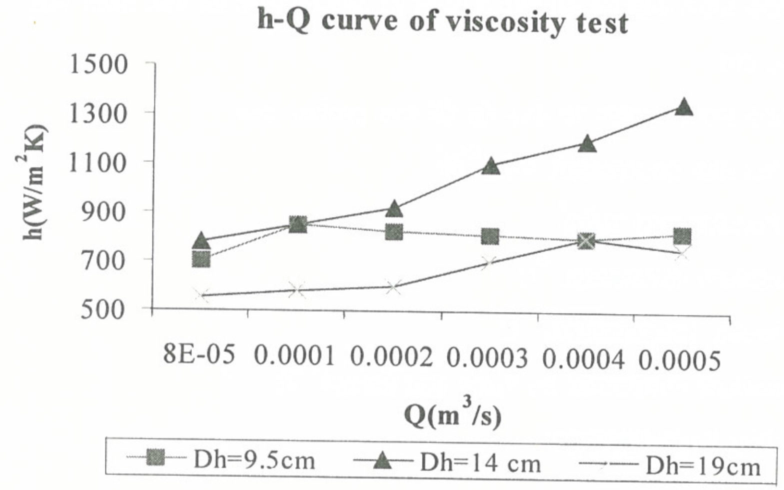

Fig 4. Show viscosity test (Test in 60% glycerol-water solution)

4. Conclusion.

The following conclusion was drawn from the experimental results:

I. The heat transfer coefficient increased with increasing gas flow rate at low gas flow rate. At gas flow rate between 0.00011-0.0004 m^3/s, the heat transfer coefficient increased only slightly with increasing gasflow rate. At higher gas flow rate, the heat transfer coefficient decreased, possibly due to high gas holdup in the bubble plume

II. The highest heat transfer coefficients were observed at the shortest distance from the end of the probe which was transition from a laminar to turbulent boundary layerpossibly occurred.

III. Increasing the liquid viscosity by a factor of 10 caused the heat transfer coefficients to be approximately halved, at the same gas flow rate and sensor position.

5. Nomenclature

A area of heat transfer, m^2

d_h distance from the tip of the probe to the middle of the heat flux sensor, cm

d_p distance from nozzle to the tip of the probe, cm

h heat transfer coefficient, $W/m^{2\,o}C$

Q heat transfer rate W/m^2

ΔT temperature difference, ^oC

TB bath water temperature, ^oC

TS temperature measured by heat flux sensor, ^oC

δ boundary layer thickness

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