THE EFFECT OF BUBBLE FORMATION AND DETACHMENT ON MAGNETITE DEPOSITION ON ALLOY-800 SURFACES DURING BOILING HEAT TRANSFER

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Fouling of heat transfer surfaces leads to a decrease in efficiency of heat exchanger equipment. The mechanism of deposition of magnetite particles from suspension in water onto Alloy-800 heated surface can be described as five steps: initiation, transport, attachment, re-entrainment and ageing. How re-entrainment and ageing affect the overall deposition remains unclear. Nonetheless, it is believed that when the particle has been deposited, it will be either re-entrained or bonded to the surface. Experiments have been conducted in an atmospheric-pressure, recirculating water loop under isothermal, non-boiling and boiling conditions. The effect of bubbling at various heat fluxes, magnetite concentration and surface roughness on the magnetite deposition has been investigated using photographic technique. Particle trapping at the liquid-vapour interface is believed to play an important rôle on the magnetite deposition. The experimental results and postulated mechanisms will be presented.

Introduction

Heat transfer systems consist of different types of material but, mostly of tubes made of Alloy-400, Alloy-600 or Alloy-800; these are subject to the formation of deposits of iron oxide - mainly magnetite. Magnetite is one of the principal corrosion products removed from metal surfaces in the form of dissolved ions. It is transported by the feedwater as a suspension of colloids or particle agglomerations to the heated surface where it deposits again. The formation of deposits on heat transfer surfaces affects their thermal-hydraulic performances by changing the resistance to heat transfer and by increasing the resistance to fluid flow. Furthermore, if thick enough, deposits can provide an environment for corrosion by harboring aggressive chemicals. It is therefore important to understand the mechanisms of fouling; this will help to control it better and will improve the design of heat transfer equipment.

A study of the mechanisms of the effect of bubbling on magnetite deposition under boiling conditions in a heat exchanger is expected to lead to strategies for the suppression of fouling. Models of bubble formation affecting the fouling on heated surface result from the study. It is aimed at controlling fouling and improving the design of heat transfer equipment.

In this phase of the study, a laboratory program is undertaken to investigate the preliminary step of the formation of corrosion product deposits on the heated surface. The deposition of magnetite colloidal particles from suspension in water onto Alloy-800 surfaces, under various modes of heat transfer, magnetite concentration and surface roughness is measured.

Magnetite Deposition on a Heated Surface of Alloy-800

The fouling process is considered to be the combination of two competitive stages, which usually occur simultaneously: the deposition and the re-entrainment processes. The net fouling rate is then the result of the balance between what is deposited and what is removed from the collector surface, as described by Epstein [1].

The mechanism of deposition of colloidal magnetite from a suspension in water onto Alloy-800 surfaces at temperatures of 100°C was studied by Basset et al [2]. The deposition of magnetite particles from suspension in water at nominally 90°C onto Alloy-800 surfaces has been studied by chemical and radiotracing techniques under various conditions of flow, chemistry and boiling heat transfer. The investigation of pH effects indicated that pH 7.5 gave a deposition rate close to the maximum due to the opposite electrostatic charges on the surface of Alloy-800 tube and the magnetite particles. In addition, the experiments indicated that, under non-boiling conditions, mechanisms based on diffusion and thermophoresis control deposition while removal is negligible. For sub-cooled boiling at a low rate, the trapping of particles by bubbles is important. Diffusion of magnetite to the metal surface between bubble nucleation sites is slowed down by bubble nucleation and growth. At a high rate, deposition during microlayer evaporation dominates. Removal occurs during sub-cooled boiling.

Thermal Resistance of Fouling under Different Modes of Boiling

There are two types of boiling heat transfer; pool boiling and forced-convection boiling. The first process involves a contact between the heated surface and a pool of liquid whereas forced-convection boiling involves the process of flowing fluid along the heated surface. Klimas et al [3] studied the fouling of different iron corrosion products on Alloy-600 and Alloy-800 heated surfaces under flow boiling conditions at low and elevated steam quality. The experiments were undertaken at operating conditions close to the typical thermohydraulic conditions of steam generators used in CANDU-6 reactors. It was found that the fouling rates increase in the region of subcooled nucleate boiling but remain unchanged in the region of saturated nucleate boiling. A comparison of the corrosion product deposited on the metal surface is shown in Figure 1. The surface at the inlet of the test section, where the steam quality was lower, was bare metal, whereas the surface at the outlet of the test section, where the steam quality was elevated, was completely covered with crud. The explanation of the phenomena is not clearly understood. It is believed that the flow pattern in the region of the elevated steam quality and the bubble nucleation play significant parts on the fouling.

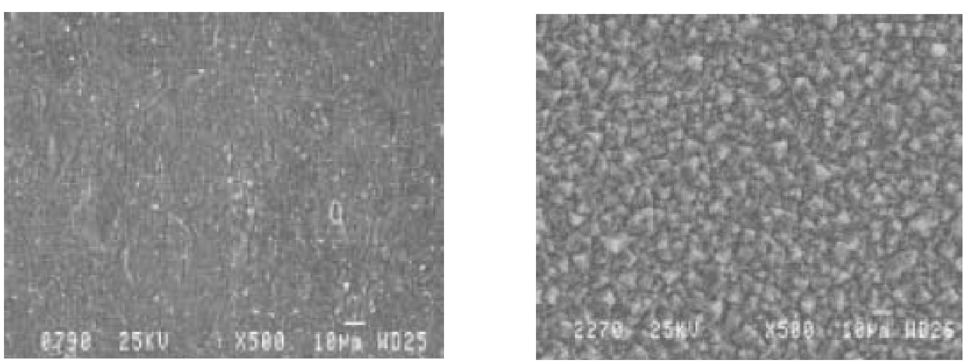

Figure 1 SEM micrograph of the metal surface at the inlet and the outlet of the test section where steam quality is increasing[3] (the left and the right hand side represent the inlet and the outlet conditions, respectively.)

Measurements of the thermal resistance of porous deposits of various thicknesses under both single-phase forced convection and flow-boiling condition were made by Turner et al [4]. Both synthetic deposits and deposits on tubes removed from operating steam generators were investigated. The thermal resistance was modeled as the sum of two components: one associated with conduction through the porous deposit and the second associated with the effect of surface roughness. The conductive component of the thermal resistance was always positive, whereas surface roughness made a negative contribution to the thermal resistance, for example, roughness enhanced the rate of heat transfer. Thermal conductivity of the porous deposits was higher for single-phase forced convection, whereas the effect of deposit roughness on thermal resistance was higher under flow boiling conditions.

Effect of Surface Condition on Deposition of Magnetite

There is experimental evidence to show that surface roughness influences deposition and boiling, notably for particle sizes less than 5 micrometers[1]. Surface roughness initially enhances the rate of transport of the particle to the surface by increasing the turbulent intensity. Cavities in the surface at bubble nucleation sites assist the bubble formation and hence increase the mass transfer rate. On the other hand, deposition on roughened surfaces can lead to declining rates of transport due to the particles filling the cavities.

The initial experiments in the study aim at studying magnetite deposition at different roughnesses of Alloy-800 tube. The surface roughness is expected to enhance the boiling as well as the amount of magnetite deposited onto the surface.

The Experimental Design

The experimental set-up in Figure 2 is mostly of stainless steel, comprising a 200-litre reservoir equipped with a stirrer and electric heater, a centrifugal pump and a cooler. The test section is a vertical glass column, 1.5 m long and 9.93 cm I.D., with two outlet ports at the top. The Alloy-800 heat exchanger tube has a 1.6 cm O.D. and is cut to a length of 30 cm. It is inserted into the closure seal at the top of the test section.

Experimental procedure

To study the effects of boiling on the deposition on heated Alloy-800, magnetite is added to the deionized water of the loop operating at about atmospheric pressure and at temperatures between 96 to 100^{o}C. The pH of the feedwater is maintained using dilute nitric acid or potassium hydroxide solution. The flow rate of water is kept at the possible maximum of 14 L/min, giving the approximate Reynolds number of 7,300 in the annulus around the Alloy 800 tube. Various heat fluxes upto 240 kW/m^2 are applied to induce different modes of boiling. When the surface condition is studied, the Alloy 800 tube is polished with various grades of sandpaper. Alloy-800 bands are fixed along the Alloy-800 tube, and later removed for analysis. The magnetite deposit is removed by dissolution in HCl solution. The dissolved magnetite is analysed using an AA spectrometer. The morphology of magnetite deposit on the Alloy-800 band is investigated using SEM and the bubble formation and the deposition on the heated surface are observed using photographic techniques.

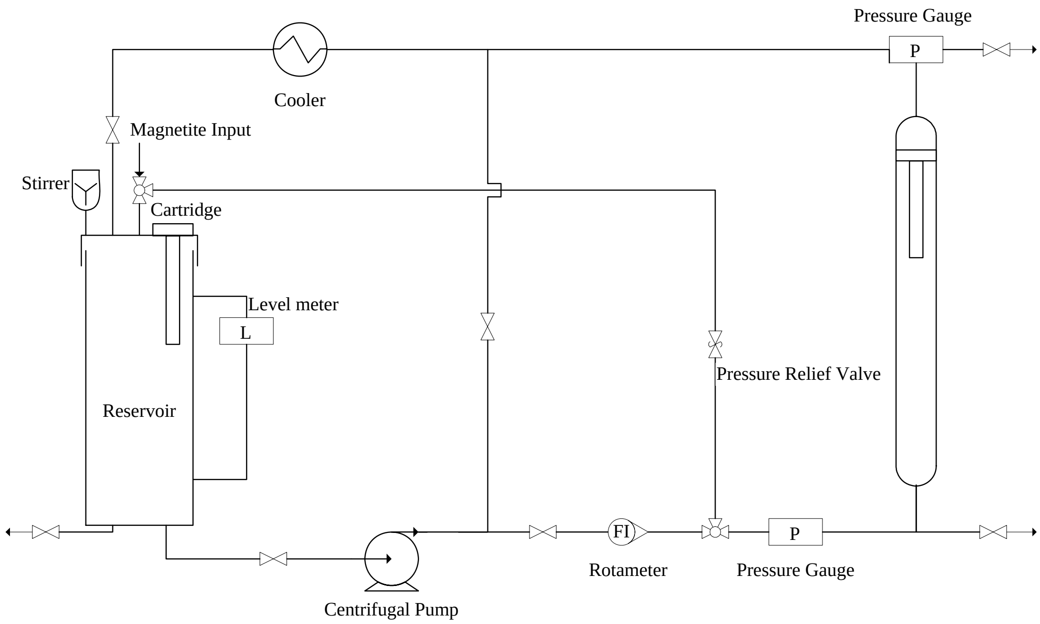

Figure 2 The design of the experimental set-up.

Result and Discussion

Results are presented in the form of plots showing the amount of magnetite deposition as a function of time and heat flux for different surface roughness. The distribution of boiling and deposition is determined from still photographs.

- The effect of heat flux on the magnetite deposition

  Experiments have shown that the magnetite deposition rate increases with increasing rate of heat transfer. Under non-boiling conditions, where the controlling mechanism is the diffusion with contributions from thermophoresis, the deposition is uniform along the tube. Under boiling conditions, the formation of bubbles apparently increases the rate of deposition but the pattern of deposition is disturbed by the bubble nucleation.

- The effect of time on the magnetite deposition under heat transfer

  In the presence of heat transfer, the deposition of magnetite on an Alloy-800 tube increases with time. The rate of attachment dominated the total rate of deposition, while the rate of particle removal is small and negligible during the first 10 hours of the experiment.

- The effect of magnetite concentration in feedwater on the magnetite deposition

  At different concentrations of magnetite with fixed heat flux, the amount of magnetite deposition is proportional to the magnetite concentration initially added to the feedwater in the range of 10-20 g/m^3.

- The effect of surface roughness of Alloy-800 tube on the magnetite deposition

The surface roughness affects the distribution of bubble nucleation sites which then affects the magnetite deposition.

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