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Fouling resistance of brackish water: Comparision of fouling characteristics of coated carbon steel and titanium tubes

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ABSTRACT

In the present study, the fouling resistance of the coated carbon steel and the titanium tubes are examined for various brackish water velocities and different tube surface temperatures. In the fouling experiments, the brackish water inlet temperature and its elemental composition are kept constant. In line with the experimental conditions, the numerical simulation of flow field and particle concentration distribution in tube is realized. The discrete phase model is introduced to account for the particles in the simulations. To characterize the morphology of the deposited residue on the tube inner surface, scanning electron microscopy is carried out. It is found that the mitigation of fouling through increasing the flow velocity becomes important to reduce the fouling resistance. The fouling resistance increases with increasing tube wall temperature because of the increased rate of chemical reactions despite the solubility crystallization increase. The residue crystals is in a patchy type and locally distributed at the surface for the coated carbon steel tube; however, the residue crystals appear to deposit and growth normal to the surface and branches in needle like shapes laterally while covering the entire surface for the titanium tube.

1. Introduction

Fouling is one of the major problems associated to heat exchanger operations. Although many types of fouling takes place in heat exchanger tubes, salt deposition is one of the major type of fouling, in particular in the Arabian gulf region. The dissolved inorganic salts are normally present in the cooling fluid of the heat exchanger and their maximum concentration is limited with the saturation level. However, during heating or cooling periods, the supersaturation takes place in the dissolved inorganic salts while contributing to the fouling rate. As the heat exchanger tube wall temperature exceeds the corresponding saturation temperature of the salts dissolved, a crystal formation takes place on the surface of the wall. However, the crystallization starts, especially at nucleation sites such as scratches and pits and often after induction period spread to cover the entire surface. However, introducing selective tubes such as titanium tubes or selected tube surfaces such as coated carbon tubes, this phenomenon partially suppressed and the rate of fouling may be reduced. Consequently, investigation into fouling rate due to different tube materials and coating becomes essential.

Considerable research studies were carried out to examine fouling in heat exchanger tubes [1–18]. Coletti and Macchietto [1] developed a mathematical model to investigate local and average fouling rates for heat exchangers which were used in crude oil operation while Cho et al. [2] studied experimentally the efficiency of physical water treatment technique to prevent fouling accumulation on heat transferring surfaces, especially, formation of calcium scale. Their findings revealed that as the solubility of treated water decreased, the small particulates produced by physical water treatment grow in size which aided to prevent crystallization fouling. Experimental investigation of the fouling was carried out by Honfling et al. [3] and Bansal et al. [4]. The results of Honfling work revelas that high fouling tendency of the solution took place at pH value of 4.0 and the crystalline upper and middle layers were formed in the scale residue. Helalizadeh et al. [5] studied crystallization fouling mechanism on heat transfer surfaces for convective and sub-cooled flow situation. while Puhakkaet al. [6] investigated calcium carbonate ($CaCO_3$) deposition on stainless steel surfaces including the molecular modeling. Khan et al. [7] introduced the dimensionless parameters for presenting the fouling rates as a function of dimensionless time, Reynolds number,

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Nomenclature

C_D	drag coefficient
C_p	specific heat
D_i	tube inner diameter
D_o	tube outer diameter
d_p	particle size
E	energy
F	force
F_D	drag force
F_x	virtual force
h_i	tube side heat transfer coefficient
h_o	shell side heat transfer coefficient
k	thermal conductivity
L	tube length
p	pressure
Re	Reynolds number
R_{fb}	tube side fouling resistance
R_{fo}	shell side fouling resistance
S	source term
T	temperature
t	time
u_f	fluid velocity
u_p	particle velocity
v	velocity
Greek symbols	
ρ	density
μ	viscosity

and $CaCO_3$ concentration in the scaling salt solution. Tubman [8] presented the data on average fouling potential, low fouling potential, and severe fouling potential. Hopkinson and Hernandez [9] used titanium tubes in petroleum refining heat exchangers and Gogenko et al. [10] presented the importance of fouling in plate heat exchanger design. Gawlik et al. [11] investigated the fouling rates due to different types of polymer-based coatings on tubes. Hodgkiess and Morizot [12] demonstrated that the technique provided the assessment of the scale buildup on metal surfaces, and their results were supported with the image analysis, which showed similarity especially at high surface coverage. Quddus and Allam [13] showed that a high rate of scale deposition took place on the surface for high Reynolds numbers and the morphological examination of the scale by Scanning Electron Microscopy (SEM) revealed that the $BaSO_4$ crystals were dense and they were uniformly distributed over the metal surface. Chen et al. [14] demonstrated that the precipitation in the bulk solution in the fouling was affected by the concentration of ions in the solution, and for bulk precipitation, a higher concentration resulted in a shorter induction period. Fahiminia et al. [15] investigated experimentally the effect of temperature and velocity on the initial scaling rate of the inverse solubility salt and they indicated that, as temperature and velocity of the bulk increased, the delay time (the period of time elapsed between the occurrence of supersaturation and the first detection of fouling deposition on the metal surface) decreased for velocities below 0.5 m/s. Sheikhholeslami and Ng [16] studied the fouling in heat exchanger tubes due to the co-precipitation of inorganic salts. They concluded that, as the concentration of $CaCO_3$ increased, the fouling residue tended to be tenacious and more strongly adherent. Mwaba et al. [17] examined calcium sulfate ($CaSO_4$) crystallization behavior using heated plates They demonstrated that the one in direct contact with the heat transferring surface resulted in strong adhesion fouling layer. Siegel and Carey [18] investigated the fouling accumulation on finned tubes heat exchangers. They showed that the fouling particulate of 1.0 μm size and greater was contributed to fouling accumulation, which caused significant effect on the performance of the heat exchanger.

Most of the water cooling heat exchangers used in the corrosive industrial applications are made of titanium or coated carbon steel tubes; however, the fouling deposition on titanium and coated tubes was not investigated in details. Therefore, in the present study, fouling rates in titanium and coated carbon steel tubes resembling the heat exchanger conditions are examined. An experimental is carried out to measure the thermal resistance of the tube wall for different flow velocities, wall temperatures, and particle concentrations. A numerical simulation of the flow system in line with the experimental conditions is realized and the distribution of the particle concentration along the tube preference is obtained. The study is extended to include the morphological examination of fouling residues at the tube wall by using the scanning electron microscope.

2. Experimental

A schematic view of water heater test facility and the size of the tubes used in the experiment are shown in Fig. 1. The water heater test facility consisted of an insulated vessel representing shell side of a heat exchanger, a test specimen which represents the bundle of an exchanger, a hot water bath, water inlet and outlet piping and instrumentations to measure brackish water terminal temperatures, tube surface temperature and brackish water velocity. Coated carbon steel and titanium tubes were fitted at the center

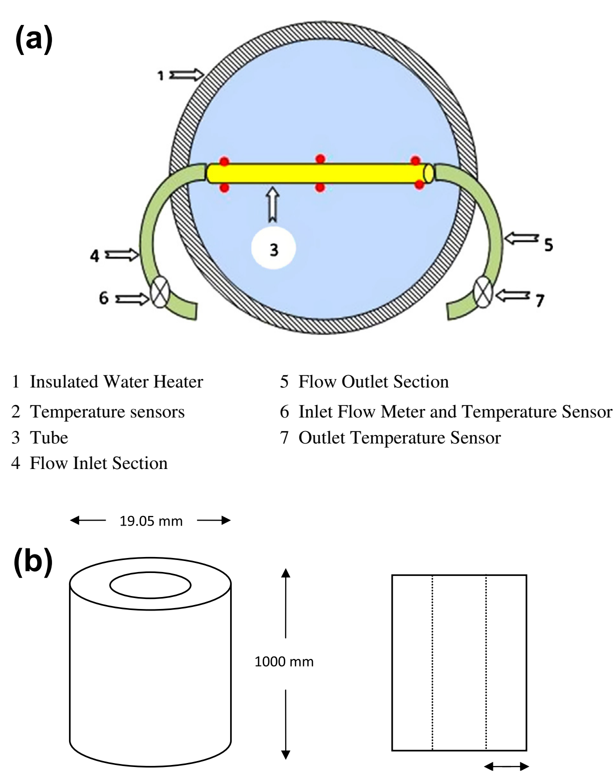

Fig. 1. (a) Schematic of the experimental setup and (b) size of the tube used in the experiments.