

Study of mineral fouling mitigation on heat exchanger surface



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HIGHLIGHTS

- Fouling resistance is enhanced by the surface thermal conductivity.
- Fouling is enhanced by the heat exchanger surface temperature and concentration of the foulant in the solution.
- Additive gum arabic (benign to environment) retards fouling deposition on different metal surfaces.

ARTICLE INFO

Article history:

Received 6 February 2015
Received in revised form 26 March 2015
Accepted 10 April 2015
Available online 19 April 2015

Keywords:

Calcium carbonate
Crystallisation fouling
Fouling behaviour
Fouling mitigation
Gum arabic

ABSTRACT

Investigation on fouling behaviour of calcium carbonate on heat exchanger surfaces as well as mitigation of fouling are presented in this paper. By varying parameters such as concentration of the fouling solution, temperature of the heating surface, type of materials and use of additives, the fouling rate on the test specimens were observed. A set of experiments were performed by using calcium carbonate solution. Fouling rate, fouling resistances and the rate of heat transfers were determined for different heat exchanger material surfaces. Fouling resistance is enhanced by the thermal conductivity and temperature of the heat exchanging surfaces and also by the concentration of the foulant in the solution. The addition of gum arabic additive (benign to the environment) to the solution retarded the rate of deposition. The results of these investigations could be design aid for economic and enhancement of heat exchanger performance.

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1. Introduction

Dissolved inverse soluble mineral salts in cooling water such as calcium carbonate, calcium sulphates, calcium silicate, etc. often contribute to the formation of scales. Normally scale is developed from the accumulation of precipitation of mineral crystal salts from water on metallic surfaces. However, crystallisation fouling or scaling is caused by crystalline deposition from water-soluble salts. All these are essential factors which affect the water fouling rate [1]. Deposition rate on metal surfaces is dependent on surface characteristics. Mineral fouling could be retarded by addition of additives. Most of the additives presently used are hazardous to the environment [2,3]. So to explore ecofriendly additives it is also a prime objective of the present work.

Fouling can be defined in the simplest way as undesired deposition or sedimentation on heat transfer surfaces which may reduce the effectiveness of the equipment. Thus, the operational capacity is more likely to be negatively affected as well [4]. Some of the typical

deposits that appear on heat exchanger surfaces are mineral substances such as calcium carbonate (CaCO_3), calcium sulphate (CaSO_4), and calcium silicate (CaSiO_2). These depositions create a layer that has been proven to resist the rate of heat transfer in heat exchangers mainly due to the very low thermal conductivity (i.e. $2.9 \text{ Wm}^{-1} \text{ K}^{-1}$) of the mineral salts. This occurrence decreases efficiency and increases pressure drop and maintenance cost. For these reasons, engineers need to pay heed to the effects of fouling on heat exchangers when the designing work is done.

There are a few significant parameters which need to be considered [5]:

- Velocity: high flow velocities disrupt the formation of deposition and lessen the fouling.
- Bulk temperature of fluid: chemical reaction of fouling is affected by this factor since it determines the adequacy of activation energy for a chemical reaction.
- The heat exchanger surface temperature (heat transfer site): this temperature governs the solidification rate on the surface.
- pH: determines suitable alkalinity or acidity for certain minerals to form.
- Surface material: some surfaces are prone to encourage biological fouling and some enhance mineral deposition.

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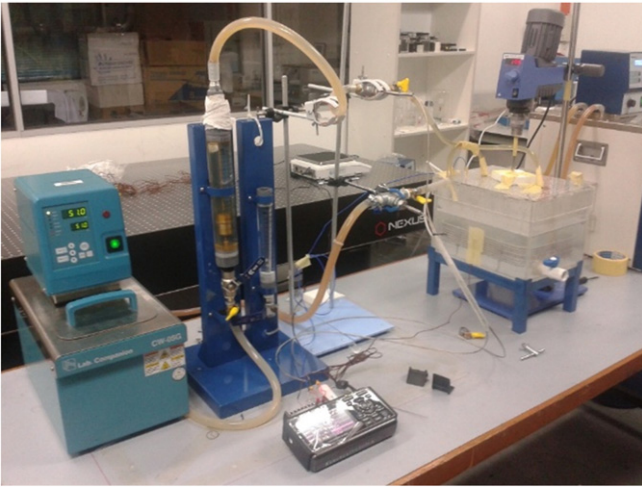


Fig. 1. Schematic diagram of the experimental set-up.

- vi. Surface roughness: rough surface provides a wider total surface area which serves as a better attachment site for fouling.
- vii. Heat exchanger configuration: heat exchanger type is one of the main issues which affect the fouling rate.

Crystallisation fouling is formed by the deposition of salts on the heat transfer surface by attraction [6]. The deposition rate of salts on surfaces is asymptotic in nature where the mixed salts may have different patterns from solutions of only single salts [7]. Demopoulos [8] informed that the supersaturation is the important controlling parameter of aqueous precipitation. Mwaba et al. [9] had conducted an experimental investigation of calcium sulphate deposition on a flat plate and observed that nucleation started on the downstream side and then propagated upstream. They have also informed that the rates of nucleate-front propagation and scale layer growth increase with the surface temperature and decrease with the flow velocity. It is reported that the fouling deposition rate of CaSO_4 increases with the increase of concentration of the fouling solution [10].

Amjad [11] studied gypsum deposition on various metal surfaces and found that the order of the rate of deposition on different metals is as follows: copper > brass > stainless steel. It is also noted that the

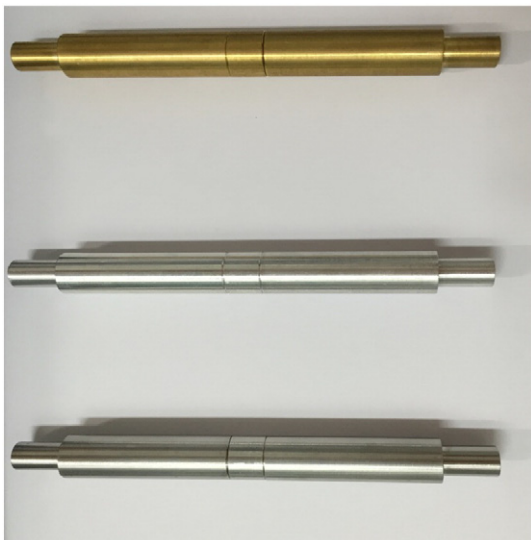


Fig. 2. Experimental test specimens with different materials.

Table 1
Specimen physical properties [31].

Materials	Properties at 300 K			
	ρ (kg/m^3)	C_p (J/kg.K)	k (W/m.K)	R_a (μm)
Aluminum	2702	903	250	2.16
Brass	8530	380	109	2.18
Stainless Steel	8238	468	16	1.27

molecules or atoms at the deposition surface interact with those of the solution and the types of forces or interactions are governed by the chemistry of both the surface and the fouling liquid [12]. The adhesion of deposits is dependent on total surface free energy. The higher the surface free energy the stronger the adhesion of deposits on it [13]. Low energy surfaces are more resistant to build-up of fouling and easier to clean due to weaker binding at the substratum–liquid interface [14]. When the total interactive force is negative then fouling occurs [15].

Crystallisation of calcium sulphate on different metal surfaces by using a constant heat flux method was investigated by Gill and Nancollas [16]. They observed more deposition with metals of higher thermal conductivity. They inferred that the metals with the higher thermal conductivity yielded higher initial steady state temperatures in the order of $\text{Cu} > \text{Al} > \text{brass} > \text{stainless steel 304}$. Similar results were reported by Kazi et al. [17,18]. Effective surface area increases with the surface roughness which enhances more deposition and adhesion and also augments the initial deposition rate by providing sites for crystal nucleation [19,20]. Kazi et al. also observed enhanced deposition of calcium sulphate crystals on stainless steel surface with the increase of roughness [18]. Herz et al. [21] also obtained more tenacious calcium sulphate deposition with the enhancement of the degree of surface roughness.

Zhao and Muller-Steinhagen [15] treated metal heat exchanger surfaces with selected elements by ion implantation, sputtering, electrolytic deposition or a combination of these, etc. They obtained reduced fouling resistance by up to 78% when CaSO_4 was used. In preventing fouling some anti-foulants have been used which may have some undesired product contamination or adverse environmental effects. Some methods have been used to reduce fouling such as changing plant operational parameters, use of electromagnetic devices, electrostatic and acoustic fields, ultraviolet light, radiation or catalytic treatments. The results have been mixed and the outcomes inconclusive.



Fig. 3. Calcium carbonate fouling on different specimens.

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