

Dynamic modelling of Heat Exchanger fouling in multistage flash (MSF) desalination



Salih M. Alsadaie, Iqbal M. Mujtaba *

Chemical Engineering Division, School of Engineering, University of Bradford, Bradford BD7 1DP, UK

HIGHLIGHTS

- A dynamic fouling model including the deposit and removal rate in MSF is presented.
- The study focused on the deposition of calcium carbonate and magnesium hydroxide.
- The fouling model considers the effect of salinity variation due to recycled brine.
- The effect of temperature and velocity on the fouling behaviour is studied.
- The performance of MSF process is evaluated with and without antiscalant.

ARTICLE INFO

Article history:

Received 9 November 2016
Received in revised form 21 December 2016
Accepted 14 January 2017
Available online xxxx

Keywords:

MSF
Scale formation
Dynamic fouling model
Calcium carbonate
Magnesium hydroxide

ABSTRACT

Fouling on heat transfer surfaces due to scale formation is the most concerned item in thermal desalination industry. Here, a dynamic fouling model is developed and incorporated into the MSF dynamic process model to predict fouling at high temperature and high velocity. The proposed dynamic model considers the attachment and removal mechanisms in the fouling phenomena with more relaxation of the assumptions such as the density of the fouling layer and salinity of the recycle brine. While calcium sulphate might precipitate at very high temperature, only the crystallization of calcium carbonate and magnesium hydroxide are considered in this work. Though the model is applied in a 24 stages brine recycle MSF plant, only the heat recovery section (21 stages) is considered under this study. The effect of flow velocity and surface temperature are investigated. By including both diffusion and reaction mechanism in the fouling model, the results of the fouling prediction model are in good agreement with most recent studies in the literature. The deposition of magnesium hydroxide increases with the increase in surface temperature and flow velocity while calcium carbonate deposition increases with the increase in the surface temperature and decreases with the increase in the flow velocity.

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1. Introduction

Fouling, due to scale formation, is the accumulation of undesirable layer of solid materials at the heat transfer surface. With time, these materials continuously build up fouling film causing an increase in the thermal resistance and reduce the performance of process equipment [1]. The performance of multistage flash (MSF) desalination plants is mainly affected by the condition of heat transfer surfaces, therefore, scales on these surfaces by seawater containing salts can impede the rate of heat transfer and reduce the efficiency of the heat transfer process resulting in poor performance of the plant. Moreover, increasing the layer thickness of the scales results in narrowing the tubes pass and consequently increase the energy consumption (of pumps) to maintain a constant flow rate. Seawater always has the tendency for

scale formation and fouling problems due to dissolved salts and finely suspended solids. As highlighted in Mujtaba [2,3], at high temperature, water with soluble salts allows deposits to form scale which can reduce the heat transfer rate and can increase specific energy consumption and operating costs. This can cause frequent shutdowns of the plant for cleaning. Due to the fouling tendency, the heat transfer equipment are oversized with allowable 20 to 25% excess in heat transfer surface area thus increased capital cost. This results in an increase of about 30% of the total cost [4]. In thermal desalination process such as MSF, the scale formation is mainly caused by precipitation of calcium carbonate (CaCO_3), and at higher temperature, magnesium hydroxide $\text{Mg}(\text{OH})_2$. Both of them are commonly referred to as alkaline scales. Non-alkaline scale such as calcium sulphate (CaSO_4), on the other hand, is also considered to be the most common scales found in MSF process [5]. Nevertheless, Anhydrite sulphate scale (CaSO_4) would be expected to form at temperature above 40 °C due to its low solubility (Fig. 1) [6], most of the calcium sulphate scale in thermal units is

* Corresponding author.

E-mail address: I.M.Mujtaba@bradford.ac.uk (I.M. Mujtaba).

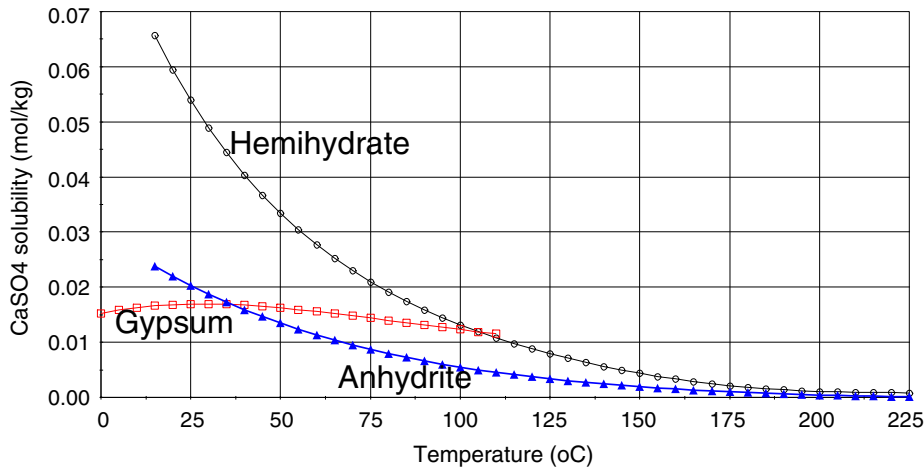


Fig. 1. The solubility of CaSO_4 in its three different forms [9].

hemihydrate [7,8]. However, there is large agreement among the MSF fouling researchers that CaSO_4 , in any forms, precipitates in MSF plants at temperature above $120\text{ }^\circ\text{C}$ [5]. Since, in this work, the highest temperature in the condensing tubes is considered to be less than $112\text{ }^\circ\text{C}$, the precipitation of CaSO_4 is neglected in this work and only the precipitation of CaCO_3 and $\text{Mg}(\text{OH})_2$ are considered.

The fouling phenomena on hot surfaces is affected strongly by number of factors such as time, surface temperature, velocity of the bulk, diffusion rate of the ions, bulk composition, solubility of the scale species and the pH of the seawater. For carbonate systems, the amount of carbonate species is related to the pH as shown in Fig. 2 [10]. The increase in the seawater pH causes the condition of calcium carbonate to be super-saturation which in turn results in scale deposit. Therefore, controlling pH value is required to prevent excessive carbonate scale formation. Calcium sulphate, however, is pH independent and tends to deposit in different forms once its solubility limitation exceeds [11]. Hofling et al. [12] reported that the saturation index for CaSO_4 is almost constant between pH 4 and pH 10.

Although a good amount of studies were carried out on the experimental study of scaling, corrosion, scale formation at heat transfer surface is still very complex problem to understand and it is the weakest point in the design of heat transfer equipment. One of the early attempts to model fouling behaviour was conducted by Kern and Seaton [13]. They confirmed that the fluid velocity plays an important role in

limiting the increase of the fouling thickness by considering a constant deposit rate and increasing removal rate, so that the process of fouling reaches steady state when the removal rate becomes equal to the deposition rate [14]. Although it is a simple model and ignored several parameters that may be responsible for the scale formation, it is considered to be the basic model on which further models have been developed. Hasson et al. [15] developed a diffusion model to control only CaCO_3 scale deposition in heat transfer surface. Experimental data from double pipe heat exchanger was used to validate their model and found out that the scale growth of CaCO_3 varies with Reynold's number and is only slightly dependent on surface temperature. Later, Gazit and Hasson [16] developed a kinetic model to study the parameters that affect the CaCO_3 scale formation in film flow desalination process. Using a heated aluminium tube, the main parameter to be examined was the effect of evaporation temperature on the kinetic of scale formation.

Taborek et al. [17] developed fouling model to study the CaCO_3 scaling on cooling tower water. It was assumed that the deposit rate depends on the flow velocity. However, the model was criticised on having many unknown variables and no experimental data were presented to estimate these variables. Hasson et al. [18] developed an ionic diffusion model to predict the fouling rates of CaCO_3 . Later, in 1981, Hasson modified his model to predict the crystallization rate of CaSO_4 [19]. Müller-Steinhagen and Branch [20] modified Hasson's

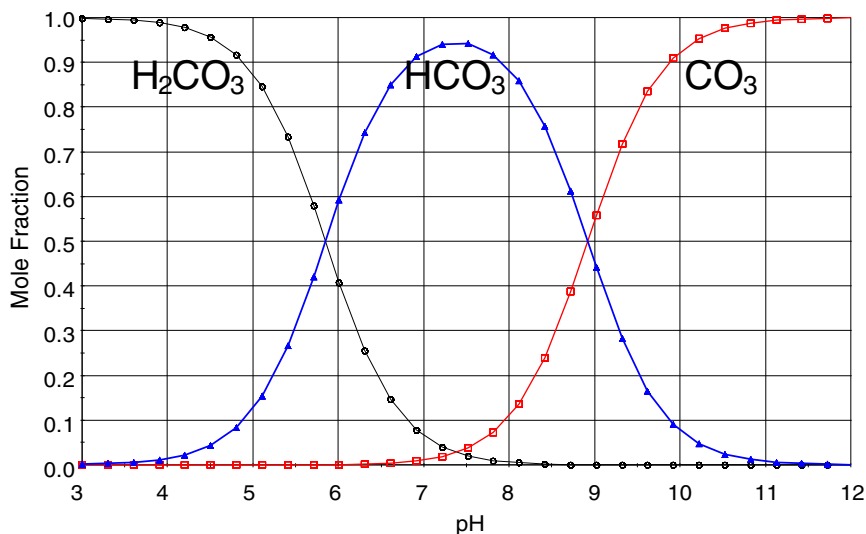


Fig. 2. Mole fraction of CO_2 , HCO_3^- and CO_3^{2-} as a function of pH in carbonate system at ($T = 25\text{ }^\circ\text{C}$ and salinity = 35 g/l) [10].

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