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The Effort to Decrease Fouling Resistance of $CaCO_3$ Scale on Shell and Tube Heat Exchanger Using Organic Materials

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ABSTRACT: $CaCO_3$ fouling in Shell and Tube Heat Exchanger has been reported by many researchers that its existance declines heat transfer process until 30 times. The current research was conducted to study the effort in decreasing fouling resistant using organic material namely citric acid. A module of Shell and Tube Heat Exchanger was employed and installed to the experimental rig and operated as a computerize system. Citric acid was given to the solution only in a meager degree i.e., 0.00, 0.50 and 0.10 ppm. Fouling resistance was calculated based on the phases distribution of $CaCO_3$ crystals have been found from the experiments which every phase has different magnitude. The calculation of fouling resistance was performed based on the formula given by Muttairi. The use citric acid as the inhibitor reagent successfully decrease fouling resistance from 788 × 10^{-6} to 659 × 10^{-6} and 611 x 10^{-6} $m^2.{}^oK/W$ for the addition citric acid in 0.00, 5.00 and 10.00 ppm.

KEYWORDS: Fouling resistance, $CaCO_3$, Heat Exchanger, Citric acid, Organic materials

I. INTRODUCTION

$CaCO_3$ fouling in Shell and Tube Heat Exchanger (STHE) has been known as the disturbance in heat transfer processes.[1,2,3,4] Several researchers reported that the existance of $CaCO_3$ fouling declines heat transfer process until 30 times lower which the term is usually called as fouling resistance.[5,6] $CaCO_3$ is predominate scale that exists in STHE which in most cases the scale potential to reduce flow rate, decreases overall heat transfer coefficient and leads to unschedule equipment shutdown.[7,8,9] When the phenomenon was taken place, STHE design would not suitable to the system anymore as same as those the design and capacity too smaller. To answer those fouling resistance problem, STHE designer marks up the capacity approximately in 35% of the initially even though higher cost must be paid.[10] Therefore, the current research was conducted to investigate the fouling resistant and addressed to minimize of investment cost. In the current research, chemical method will be used to solve the problem through the addition chemical substances to the solution which often called as inhibittor.[11,12]

The inhibitor was choosen from the organic material with any consideration, i.e : i). The chemical substance must be save material, not toxicity, not harvest the environment, construction and human.[13] ii). It must be has capability to inhibit scale growth in some way for example through thermodynamically or physically. The chemical substance that match to the criteria is citric acid which have been known as organic material and it save for the human and environment.

The effects of the use of organic material to the fouling resistant was assesed through the calculation of fouling resistant (R_f) that promoted by Al-Mutairi as equation :

$$W = {*}\pi/4\ (D0_2 – Df_2)\ L{+}\rho_f \qquad (1)$$

$$R_f = [\ln (D_o/D_f){+}/2\pi k_f L. \qquad (2)$$

Here, W is mass of scale, D_f is inner diameter after fouling, Do is initial inner diameter, ρ_f is scale density, L is pipe length, R_f is fouling resistant, k_f is thermal conductivity of the fouling.[14]

II. MATERIALS AND METHODS

A. *Materials*

$CaCO_3$ scale in STHE module was carried out experimentally by mixing the solution of $CaCl_2$ and Na_2CO_3 which made by the powder that supplied by Merck® to guarantee its purity. Demineralized water which supplied by PT Brataco Indonesia was used as the solvent.

The reaction of those two materials were supposed that occured according to the reaction as shown in equation (3).

$$CaCl_2(aq) + Na_2CO_3(aq) \rightarrow CaCO_3(s) + 2NaCl(aq) \qquad (3)$$

Concentration of calcium was determined as 3,500 ppm and sodium solution was set in its stoichiometry. The solution was subsequently filtrated two times by 0.22 µm micropore® paper to waste the dirty material. Citric acid was given in 0.00, 5.00 and 10.00 ppm that inserted in to carbonate solution. Calcium and carbonate solutions were then keep in separated vessels and covered as well to avoid the dirt materials.

B. Experimental design

Citric acid inhibitor was defined as independ variable other wise concentration of calcium; solution temperature and flow rate were defined as fixed variable. Calcium concentration was set at 3,500 ppm; inhibitor concentration was set at 0.00, 5,00 and 10.00 ppm; inlet temperature of STHE was set at 60ºC and flow rate at 30.00 ml/min. Scale deposited was defined as depend variable either of with and without inhibitor. Cold water that was needed to absorb the heat was inserted in the STHE modul at 30ºC either for lineair flow and cross flow, both at the flow rate 60 ml/min. Temperature of cold and hot water that left the modul was also measured and stand as depend variable.

C. Experimental process

Experimental process was schematically ilustrated in Figure 1. Vessel (1) contained solution of $CaCl_2.2H_2O$ and vessel (2) contained solution of Na_2CO_3. An electrical heater was employed in each vessel (3) to control solution temperature automaticaly at the value needed and helped by a sensor (4) under computerized program control(7).

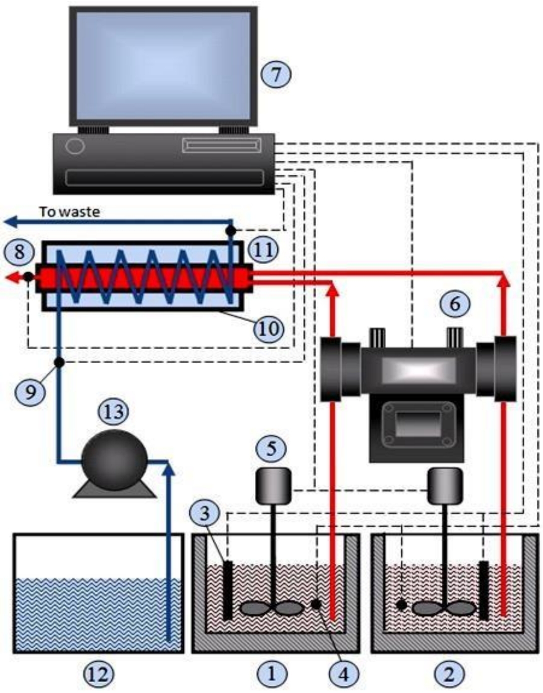

Figure 1. Experimental rig

To provide the solution in homegeneous either in temperature and chemical substance, a stirrer (5) was employed and set at 10 rpm automatically by computer program. Solution in vessel (1) and (2) was drained by dosing pump CHEM FEED Ca-92683 (6) similarly in flowrate 30.00 mL/min and was met in STHE module (10). Ground water in cool water tank (12) was pumped by pump (13) to the module. Temperature at point (8), (9) and (11) was acquisitioned by computer program.

D. Shell and Tube Heat Exchanger Module

STHE module was employed to conduct the experiment which fouling process was investigated. Design STHE module was depicted in Fig.2. Pipe lenght was determined 250 mm and its inner diameter in 16 mm. The pipe made of copper which comercially sold in the market. Nomenclature of D_o; D_f; k_f; ρ_f and L are obviously described that those needed for the substitution into the equation (1) and (2).

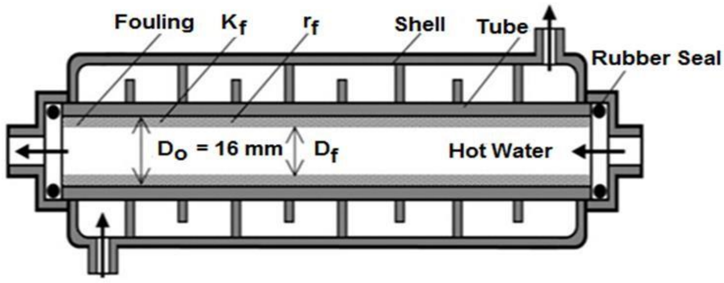

Figure 2. Shell and Tube Heat Exchanger module

In Figure 2, rubber seal was mounted at the end of pipe to avoid the leakage. The material of the shell was made of PVC that it has a lower thermal conductivity than the metal. Temperature of inlet and outlet either for cold and hot water was measured and recorded in computer program. The direction of cold water flow could be replaced from right to left to provide even for cross flow or lineair flow model. Out side cover at two ends of the pipe could be released which was needed when drying process was performed or when collect the scale mass and pipe cleaning.

III. RESULTS AND DISCUSSION

A. Deposition

Deposition of scale mass either of blank and antiscalant sample are listed in Figure 3 after dryer processing was done in 600C for six hour duration. In the current research the data shows that the deposition of STHE in lineair flow less than the deposition of cross flow model. It could be caused by the heat absorbsion in the first shell by cold water of lineair model of STHE was better than cross flow model.

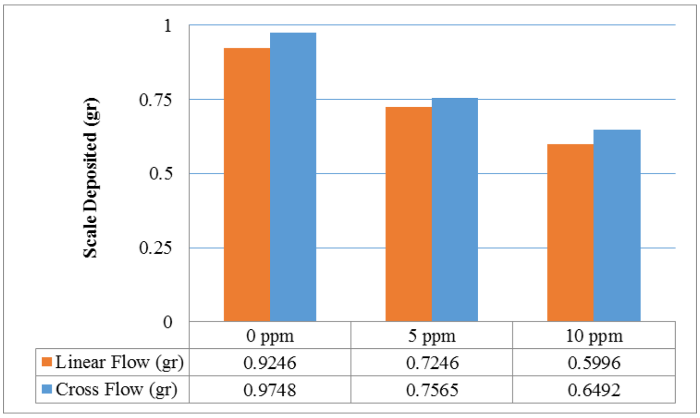

Figure 3. Scale deposition of the experiments under influence of citric acid

The table also shows that scale deposition of blank experiment has higher magnitude and the experiment in the presence of citricic acid 10.00 ppm is fewer. This would be the evident that citric acid enable to use to inhibit CaCO3 fouling.

B. X-Ray Diffraction analysis and crystal phase distribution

Phases identification and phases quantification were conducted using XRD analysis.. Rigaku Smart Lab engine of X-Ray Diffractometer was used for phase identification of the data of XRD that has been collected by Cu-K monochromated radiation in a conventional Bragg-Brentano parafocusing geometry. The parameters of scan were defined in 10-90o 2θ, in 0.02 steps and in 15 second of every step. In the matching crystalline phases, a PC-based search-match program was operated for all the data collected. Position and height of the peak were also matched to the entry of ICDD power diffraction data.

Rietveld method was also operated under FullProf-2k software version 3.30. The model of crystal structure that been used in the refinement was refered from American Mineralogist Crystal Structure Database, supported by FullProf program version 2.0 and confirmed by ICDD-PDF number 00-005-0586; 00-041-1475; 01-072-0506 for calcite, aragonite and vaterite.15 In Figure 4, the intensity of the peak between C (calcite), A (aragonite) and V (vaterite) are different for the various citric acid concentration. The use citric acid in 10 ppm affected the phases quantification with the absence of aragonite (line green). This is evidence that citric acid is very efficient in inhibiting crystal growth.

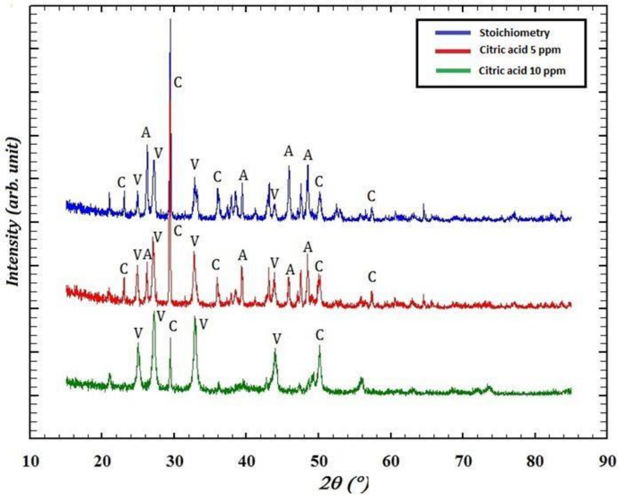

Figure 4. XRD graph of the sample with various citric acid concentration

The results of the quantification was listed in Table 2 and was used to calculate average crystal density (ρ_f) and average thermal conductivity (k_f) of all experiment. Calculation average fouling density and thermal conductivity was done through equation 4 and 5.

$$\rho_f = \rho_{vat} \,.\, \%\, Vat. + \rho_{ar}. \%Ar. + \rho_{cal} .\%Cal \qquad (4)$$

$$k_f = k_{vat} \,.\, \%\, Vat + k_{ar} \,.\, \%\, Ar + k_{cal} \,.\, \%\, Cal. \qquad (5)$$

Here, ρvat ; ρar; ρcal is the density of vaterite; aragonite and calcite respectively other wise k_{vat} ; k_{ar} ; k_{cal} is thermal conductivity of vaterite; aragonite and calcite respectively. % Vat ; % Ar and % Cal is the percentage of crystal phases that had been quantificated through Rietveld method. The results are listed in Table 1.

Table 1. Phases identification and quantification

No	Experiment	Percentage (%)		
		Vaterite	Aragonite	Calcite
1	Citric acid, 0.00 ppm, LF	31	32	37
2	Citric acid, 0.00 ppm, CF	34	31	35
3	Citric acid, 5.00 ppm, LF	43	33	24
4	Citric acid, 5.00 ppm, CF	51	36	13
5	Citric acid, 10.00 ppm, LF	34	29	37
6	Citric acid, 10.00 ppm, CF	37	24	39

Abbreviation LF in the table represent the experiment was operated as Lineair Flow otherwise CF is Cross Flow model. The operation of equation 4 and 5 was performed based on the data of Fig.3 and Table 1 which resulted the data of crystals density (ρ_f) and thermal conductivity (k_f) such have been listed in Table 2.

Table 2. Density and thermal conductivity of the sample

No	Experiments	Group	
		Fouling Density, ρ_f (kg/m^3)	Fouling Resistance, k_f (W/m.ºK)
1	Citric acid, 0.00 ppm, LF	2.757	2.706
2	Citric acid, 0.00 ppm, CF	2.758	2.672
3	Citric acid, 5.00 ppm, LF	2.751	2.540
4	Citric acid, 5.00 ppm, CF	2.754	2.450
5	Citric acid, 10.00 ppm, LF	2.749	2.712
6	Citric acid, 10.00 ppm, CF	2.736	2.726

D. Fouling resistance

Fouling resistance was calculated through equation that has been promotted by Mutairi to define diameter of inner pipe after fouling (D_f) and the result substitute to next equation to complete the calculation. The results are graphed in horizontal bar such shown in Figure 5. Fouling resistance of STHE operated in lineair flow (LF) produces fewer scale than operated as cross flow (CF). It might affected by the temperature of each shell which tends lower than the other as the first shell at where hot fluid inserted to the STHE modul was feeded by fresh water.

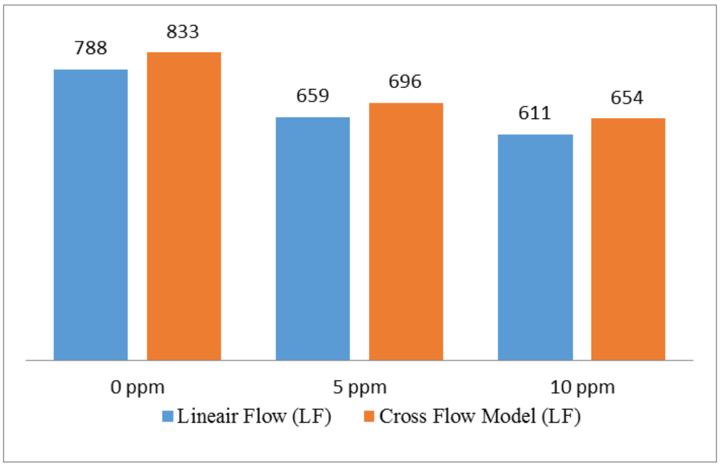

Figure 5. Fouling resistant of six experiments (× 10-6 m2.0K/W)

In the experiment of Lineair Flow model successfully decrease fouling resistant from 788 to 659 and 611 x 10^{-6} $m^2.^oK/W$ for the addition citric acid in 0.00, 5.00 and 10.00 ppm. In the experiment of Cross Flow model successfully decrease fouling resistant from 833 to 696 and 654 x 10-6 $m^2.^oK/W$ for the addition citric acid in 0.00, 5.00 and 10.00 ppm.

IV. CONCLUSIONS

Fouling resistance in the pipe of STHE operated as lineair and cross flow model has been investigated. STHE operated as lineair flow produced fewer fouling resistance than cross flow. The use citric acid as inhibitor succesfully declined fouling resistant in significant. Citric acid also successfully retarded the growth of the crystals as has been shown by the absence of aragonite phases when it was implemented in 10 ppm. Flow model in lineary resulted aragonite phase fewer than those cross model which in the calculation by Mutairi formula resulted less fouling resistant.

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