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Pipe Blockage Prediction of Shell and Tube Heat Exchanger under Linear and Cross Flow Operation

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Abstract

Usually boilers are fed by some water that blended from demineralized water and groundwater. Commonly, this such water comprises any impurities such as Ca; Mg; Na; Cl; SO_4 which the minerals tend to precipitate as the scale. The scale forms a layer and blocks the pipe, furthermore obstructs water circulation. This research aims to predict the time that the pipe entirely blocked under linear and cross-flow operation. The results showed that the operation STHE in linear flow need the time in longer than cross flow to fully blockage the pipe.

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Keywords: shell and tube heat exchanger; $CaCO_3$; linear flow; cross flow; blockage

1. Introduction

Shell and Tube Heat Exchanger (STHE) can be operated as linear flow or cross flow under consideration of thermal efficiency. In this research, the model of the operation (linear flow or cross flow) is considered as its probability in blocking the pipe. It has been known that the pipe of STHE is potentially blocked by $CaCO_3$ fouling. The fouling exists if the saturation of the minerals are exceeded [1] and becomes the disturbance in heat transfer processes [2-4] and leads to unscheduled equipment shutdown [5-7].

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Nomenclature

Df	Diameter of pipe after fouling
Do	Diameter of pipe before fouling
CF	Cross Flow
LF	Linear Flow
W	Scale mas or scale deposition
Wt%	Weight percent
ρfdensity of fouling	
ρvat	density of vaterite
ρar	density of calcite
ρcal	density of calcite

The existence of $CaCO_3$ fouling in STHE pipe declines heat transfer process until 30 times lower [8] which the term is named as fouling resistance [5]. When the phenomenon istook place, STHE design would not be suitable anymore as the capacity to be smaller.

Therefore, STHE designer marks up the capacity approximately 35% higher than the initially even though higher cost must be paid [9]. This research predicts the blockage probability as the pipe is operated under linear and cross flow.

Pipe blockage prediction was conducted through a laboratory experiment in which STHE operated in the linear and cross-flow model. An experimental rig was completed by STHE module operated in 4 h duration for each experiment. The scale that found in the inner pipe surface of STHE were collected and subsequently analyzed by SEM and XRD to study the morphology and phase quantification. The mass of scale and the phases quantification will be the basic in determining average density (ρ_f) of the scale which useful to calculate the blockage prediction through the formula has been promoted by Mutairi as eq.1 [3].

$$W = [\pi/4\ (D_0^2 - D_f^2)\ L]\rho_f \qquad (1)$$

Here, W is scale mass/hr; D_f is inner diameter after fouling; D_o is initial inner diameter; ρ_f is scale density; L is pipe length. As deposition rate has been identified along the experiment, so the time of blockage could be found through the divide of W or mass of scale by deposition rate and then named as the time of pipe blockage prediction. The difference of pipe blockage between STHE under operation in the linear and cross-flow model is supposed will be fruitful for STHE designer to definite flow model in address avoiding the blockage.

2. Methods

2.1. Material

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

2.2. Experimental rig and process

The rig was used to react those two minerals of calcium and sodium and supposed that the reaction underwent such as shown in Eq. 2.

$$CaCl_{2(aq)} + Na_2CO_{3(aq)} \rightarrow CaCO_{3(s)} + 2NaCl_{(aq)} \qquad (2)$$

The concentration of calcium was determined as 4.000 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.

Schematic of the experimental process shown in Fig. 1. Vessel (1) contained a solution of $CaCl_2.2H_2O$ and vessel (2) contained a solution of Na_2CO_3. An electrical heater was employed in each vessel (3) to control solution temperature automatically at the value needed and helped by a sensor (4) under program control (7). The homogeneous solution either in temperature and chemical substance was obtained by stirring (5) at 30 rpm automatically by a computer program. The solution in the vessel (1) and (2) was pumped by dosing pump CHEM FEED Ca-92683 (6) similarly in flowrate 30.00 mL/min and was met in STHE module (10). Groundwater in cold water tank (12) was drained by a pump (13) to the module. The temperature at point (8), (9) and (11) was an acquisition by a computer program.

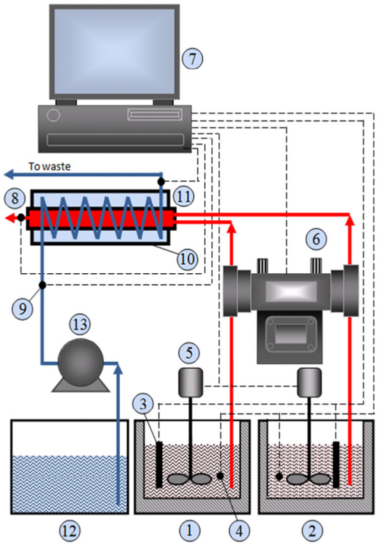

Fig. 1. Experimental rig

2.2. 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 length was determined 250 mm and its inner diameter in 16 mm. The pipe made of copper which commercially sold in the market. Nomenclature of D_o; D_f; ρ_f and L are obviously describe the parameter of STHE design. The parameters were then substituted to the eq. (1) to predict the blockage. D_o is the inner diameter without scale and D_f is inner diameter after fouling. ρ_f is the average density of the scale and L is pipe length.

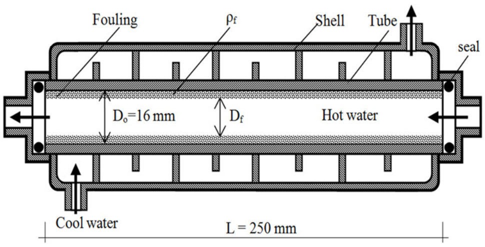

Fig. 2. Shell and tube heat exchanger module

The rubber seal was mounted at the end of the pipe to avoid the leakage. The temperature of inlet and outlet either for cold and hot water was measured and recorded in a computer program. The direction of cold-water flow could be replaced from right to left to provide even cross flow or linear flow model. Outside cover at two ends of pipe could be released which was done when dryer processing i.e. mass collecting and pipe cleaning.

3. Results and discussions

3.1. Deposition

Mass of deposition of two experiments after dryer processing was done in 60 °C for 6 h duration, are found as 0.9089 gr and 0.9876 gr for linear flow and cross flow experiment, respectively. Deposition of STHE operated as linear flow resulted in fewer scale mass than cross flow. The difference could be analyzed based on the temperature of each shell in which temperature has been understood as the primary factor in the scaling process [10].

The data of the experiment show that the temperature of the first shell was at 44 °C and 52 °C for linear and cross flow experiment. The difference of the temperature is caused by the heat absorption in the first shell which temperature input of the shell is lower as STHE operated as linear flow. In a cross-flow experimentin which the temperature of the first shell was high, the reaction rate increased significantly as the temperature is a physical factor that helpful for the reaction where the results of mass deposition show in agreement to the research of Hoang [10].

3.2. X-Ray diffraction analysis and crystal phases distribution

Crystal phases distribution was found by XRD analysis and quantified through Rietveld refinery method, supported by FullProf program version 3.30 [11]. AMCSD (American Mineralogist crystal structure database) was used as a crystal structure model for Rietveld refinement [12]. The results of the quantification are listed in Table 1. in which can be used in calculating average crystal density (ρ_f) of all phases which is needed to predict the blockage.

Table 1. Phases quantification of the sample

Phases and Density	Unit	Linear Flow	Cross Flow
Vaterite	Wt%	33	30
Aragonite	Wt%	30	32
Calcite	Wt%	37	34
Average density	Kg/m^3	2.757	2.758

Calculation average fouling density (ρ_f) was done through eq. (3) based on each percentage of every phase either for linear flow and cross flow experiment.

$$\rho_f = \rho_{vat} \, . \, \% \, Vat. + \rho_{ar} . \, \%Ar. + \rho_{cal} \, .\%Cal \qquad (3)$$

Here, ρ_{vat}; ρ_{ar}; ρ_{cal} is the density of vaterite; aragonite and calcite, respectively. Density of vaterite is known as much as 2,645 kg/m^3; aragonite 2,745 kg/m^3 and calcite 2,720 kg/m^3. Once they bond together, average density should be calculated as Eq. 3.

Scale mass density of both two experiments resulted in a little different between linear flow and cross flow experiment. It caused by aragonite phase for linear flow and cross flow experiment in different percentage which cross-flow experiment resulted 6% higher than linear flow. As aragonite phase is the densest, so, the average density of scale mass is affected. In cross-flow experiment, the percentage of aragonite phase shows in the most but this could be well accepted since aragonite phase commonly exists in higher temperature. The result shows in agreement to the research of Trushina in which starting point of aragonite formation takes place in 4 °C [13].

3.3. Pipe blockage prediction

Pipe blockage prediction of STHE was conducted through an appropriate approach which the blockage was investigated only in 4 h duration. Scale mass resulted in every hour that known as deposition rate (W) was then substituted to eq. (1) to predict the time of blockage in 25%; 50%; 75% and 100% or fully blockage. The results are depicted in Fig. 3.

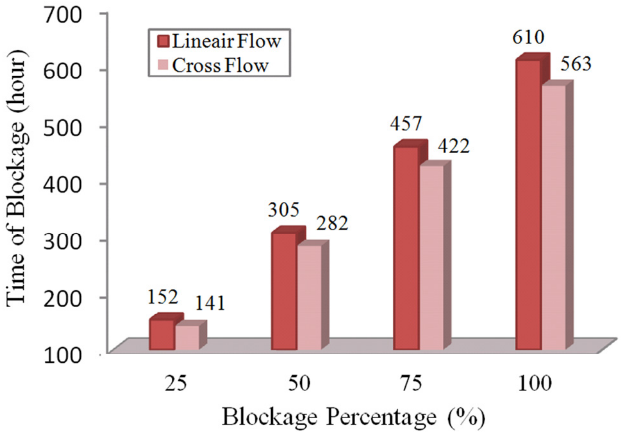

Fig. 3. Diagram of blockage percentage versus time of blockage

Fig. 3. shows the prediction of pipe blockage in which are described in the time (hour) to blockage in four percentages either for linear and cross flow experiment. In a case the blockage at 100% or fully blockage, STHE operated as linear flow needed the time in 610 hours otherwise STHE operated as cross-flow needed the only time in 563 hours. This means that the operation STHE as cross-flow model tends to blockage faster than linearlyeventhough for 25%; 50% and 75% blockage. The phenomenon is caused by the temperature of the first shell in which higher than linear flow and affects scale formation develop in higher mass. The results show in agreement to the research of Hoang in which he stated that the increase of the temperature speeds up the scaling process by significantly reducing the induction time and enormously increases the scaling rate [10].

4. Conclusion

The prediction of pipe blockage of STHE operated as the linear and cross-flow model has been investigated. The blockage prediction of STHE operated as cross-flow needed the time as much as 563 h otherwise linear flow model needed the time about 610 h. This means that STHE operated as the cross-flow model is blockage faster than linearly. The phenomenon is affected by the temperature of the first shell in which recorded at 52 °C for cross-flow model and 44 °C for linearly.

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