THE INFLUENCE OF VIBRATION ON $CaCO_3$ SCALE FORMATION IN PIPING SYSTEM

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ABSTRACT

Carbonate scale is a common problem found in a piping system of industrial process. The presence of mechanical equipment such as turbine, compressor, blower, mixer and extruder produce a mechanical vibration on the piping system which is placed near these equipments. The influence of vibration on the $CaCO_3$ scale formation in the piping system was experimentally investigated in the present study. The aim of the research was to understand the effect of vibration on the kinetics, deposition rates and the crystals formation in the synthetic solution. The solution was prepared using $CaCl_2$ and Na_2CO_3 for concentration of calcium of 3.500 ppm, while the induction time, deposition rate, crystal growth were investigated at temperature of 25^0C. In generating the vibration force, the mechanical equipment consisting of electrical motor, crankshaft, connecting rod and a vibration table were employed, including four coupons inside the pipe for investigating the scale formed. Frequency of the vibration was set at 0.00, 1.00 Hz and 2.00 Hz, respectively. A dosing pump with two inlets and two outlets was used to circulate the solutions at flowrate of 30 ml/min from each vessel to the coupons. After running for three hours, the induction time was recorded at 17; 10 and 8 minute with vibration frequency of 0.00; 1.00 and 2.00 Hz, respectively. The scale formed was then characterized using SEM/EDX for crystal morphology and elemental analysis. The results show that the deposition rates were 0.9457 and 3.3441 gram/h for the frequency of 1.00 and 2.00 Hz. The carbonate crystals found in coupon and filter were vaterite.

Keywords : Carbonate scale, mechanical vibration, crystals, vaterite, aragonite, calcite

INTRODUCTION

The $CaCO_3$ crystals have been widely known as a scale formed into the piping system of industrial installations (Abdel and Sawada, 2003; Tzotzi et al, 2007) which could lead to industrial disturbances namely reduction of mass transport and heat transfer including brake-down of the industrial process (Setta and Neville, 2011; Jamialahmadi and Steinhagen, 2007). Generally, the growth of scale depends on the chemical factors such as solution concentration and the type of impurities (Curcio et al, 2010; Euvrard et al, 2004) as well as physical factors; flowrate and temperature (Ang et al, 2006). The two previous factors have been investigated widely by a large number of researchers, however, the influence of vibration on $CaCO_3$ scale formation has not been well documented in the literature.

The mechanical vibration is generally found in many mechanical industrial equipment during operation of such turbine, generator, blower, mixer, extruder, compressor (Ruiz et al, 2015), in particular, it will affect on the scale formation in the piping system. The vibration of a pipe is commonly caused by the fluid flowing inside the pipe and some external force (Liang and Bangchun, 2014). However, the occurrence of vibration on the scale formation may significantly affect the scale formation in the piping system and thus need to be controlled.

The vibration will drive an exitation force to the solution in the pipes and providing more energy to the system (Liang and Bangchun, 2011). Excitation force in the system increases the kinetic energy. If the amount of the kinetic energy is in excess of the activation energy of the ions, the collision of the ion would be more effective (Shubashini et al, 2014). On the other hand, the vibration is also potential to remove newly-formed scale inside pipes since the attachment of such scale to the pipe walls is not strong enough. Thus vibration may have two influences on scale formation, i.e. increasing or decreasing mass of the scale. Efforts to predict the calcium carbonate formation under the influence of the mechanical vibration needs a complete materials characterization of scale.

The aim at the present research was to examine the effect of vibration on the kinetics, deposition rate for the $CaCO_3$ crystal formation. In the present study, the $CaCO_3$ crystals were grown in the prepared solution under the influence of mechanical vibration. The crystals obtained were then characterized by SEM analysis with EDX for elemental analysis and morphology.

METHODOLOGY

$CaCO_3$ scale formation was made by mixing $CaCl_2$ and Na_2CO_3 solution according to the following reaction :

$$CaCl_2 + Na_2CO_3 \longrightarrow CaCO_3 + 2NaCl \quad (1)$$

The Phreeqc program was subsequently used to predict the potential for scaling. In operating the program, the composition input of the solutions was based on the calculated concentrated namely Ca: 1.750; Cl: 3.1625; Na : 2.0125 and CO_3: 2.625 g/kg water. The program was run and the potential for scaling was obtained. Here the saturation index (SI) of 1.49 was aragonite, while 1.63 of calcite and the specific conductance of 13,448 µS/Cm. The prediction showed that the dominant crystal of the scale was calcite.

Deposition rates

The method of calculating deposition rates has firstly to be formulated because of additional vibration effect on the system. It has been reported that, deposition rates include particle scale, precipitation scale and removal scale (Sheikholeslami, 2000) and given in the equation as follow :

$$W_{net} = A.W_{precipitation} + B.W_{particulate} + W_{removal} \quad (2)$$

Where $W_{precipitation}$ is deposition rate in the coupon, $W_{particulate}$ is deposition rate due to the existence of particle in the solution, $W_{removal}$ is deposition rate of removal crystal, A and B are dimensionless constant.

Particle scaling can be defined as deposition process of particles carried by a flowing fluid as well as by matters generated in the solution. The term "particle" is general and may refer to particulate matter, bacteria, corrosion product (Young, 2004). In this present work, by straining the solution with strain paper 0.22 µm, all particles in the solution are separated and deposition rate of particle scaling can be neglected. More over, deposition rate of removal ($W_{removal}$) was captured by straining paper namely deposition rate of strainer (W_{strain}). Thus, equation 2 can be modified into the new equation to acomodate the influence of vibration on deposition rate, as shown in equation 3.

$$W_{vib} = (W_{prec}+W_{strain})_{vib} - (W_{prec}+W_{strain})_{without\ vib} \quad (3)$$

Where W_{vib} is deposition rate as the influence of vibration and called as deposition rate of vibration. $(W_{prec} + W_{strain})_{vib}$ is all deposition rate measured when the system running with vibration frequency 1.00 and 2.00 Hz. $(W_{prec}+W_{strain})_{withhout\ vib}$ is all deposition rate measured when the system running without vibration or in this term it has frequency 0.00 Hz. W_{precip} is the scale mass precipitated and attached to the coupon. W_{strain} is deposition rates, which was measured in the filter paper and has the amount as the mass of the bulk crystallization diminished by the mass of precipitation.

Mechanical vibration

The vibration used in this research was the force vibration. It means that all parameters of vibration such as frequency, amplitudo, acceleration, displacement were induced by mechanical equipment. The mechanical equipment consisted of several components such as: crankshaft, connecting rods and table vibration. Force given to the system was calculated with the Newton'second law F = m . a, where *m* is the mass of solution to the pipe, *a* is the acceleration in root mean square (RMS).

The vibration was produced by an electrical motor in an intermittent manner i.e. the vibration given in 10 minute every 20 minute long. Furthermore, the energy given by vibration to the piping system was called as Excitation Energy in kJ/hr, i.e. 350 and 700 kJ/hr for the low level test and the high level test, respectively. The vibration parameter of the experiment is given in Table 1.

Table-1. Vibration parameter of the experiment

Vibration parameter	Control Test	Low Level	High Level
Frequency (Hz)	0	1	2
Acceleration(m/s^2,RMS)	0	11	22
ExcitationEnergy(kJ/hr)	0	350	700

Variables

Independent variabel of this experiment was energy excitation driven by frequency of the vibration, while dependent variables included induction time, deposition rate and polymorph of the crystals.

The effect of flowrates, concentration and temperature were netralized to strenghten the influence of vibration on the scale formation. The temperature was set at 25^{0}C. The concentration of Ca of 3,500 ppm, and the flowrate of 30 ml/min and atmospheric pressure were selected for all testing. This vibration-induced scale formation was conducted using the experimental rig (**Figure 1**).

Experimental rig and materials characterization

The experimental rig was schematically shown in Figure 1. It consists of two vessels (1) and (2) which contained $CaCl_2$ and Na_2CO_3 solutions, respectively. The concentration of Ca in solution was set at 3,500 ppm, while temperature of 25^{0}C was selected. To get the homogeneous solution, a stirrer was attached in each vessel and run at 30 rpm. All solution in each vessel was pumped by dosing pump CHEM FEED Ca-92683 (3) similarly, with 30 mL/min of flowrate to the test pipe section (4). In this test pipe, four pairs of coupons was inserted in, where scale was needed to form. The pipe was attached to a table (5) and vibrated by electrical motor HF-12207 (6).

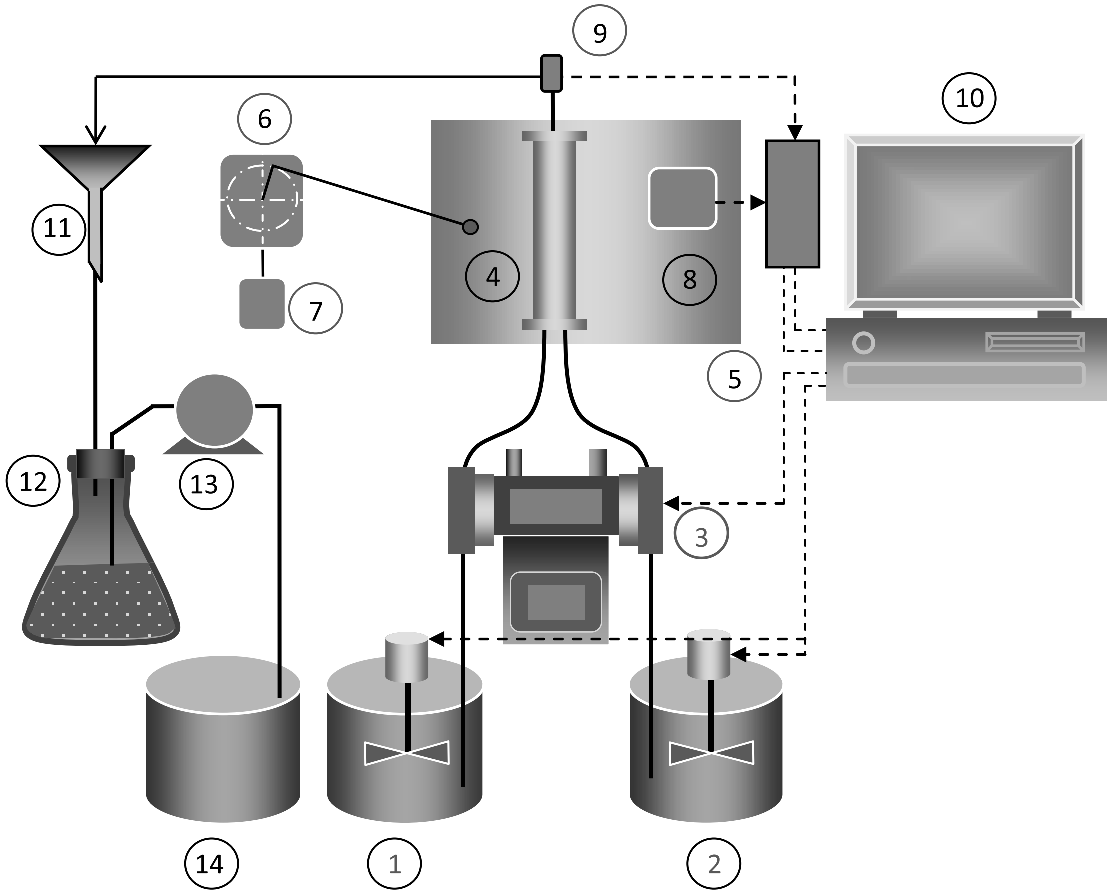

Figure-1. Experimental rig used in the research work

The vibration frequency was set by frequency regulator (7) to find the frequency needed i.e. 0.00; 1.00 and 2.00 Hz. Vibration meter Lutron VT-8204 (8) was used to observe the vibration parameter such as displacement peak to peak, velocity and acceleration in RMS. The conductivity of the two solution after leaving the coupon was measured by TDS meter produced by Komatsu (9), acquisition data of conductivity and vibration was held by data logger and computer program (10) to fulfill the accuracy. A filter paper of 0.22 μm (11) was used to capture the mass of scale which will be removed from the pipe wall or the mass brought by flowing force. A vacuum tube (12) and pump (13) was also employed.

Further, scanning electron microscopy (SEM) on a JEOL DSM apparatus equipped with an EDX was employed for characterizing the microstructure and morphology. For the observation, the powder crystals were mounted on a circular metallic sample holder and subsequently sputtered with gold. To suck the water in the fllter, the fllter paper was replaced every ten minute to keep the formation of the crystal remain of its phase. The scaling process was done in three hours duration of every running.

RESULTS AND DISCUSSIONS

After running in three hours duration all the data needed was formed, namely induction time and deposition rate. Moreover, the scale was characterized by SEM/EDX to obtain morphology and chemical elements of the crystal.

Induction time

During the scaling formation, the conductivity of solution after leaving the coupon was measured with TDS meter and recorded by the computer program every one minute. Measurable change of conductivity showed that a number ions in solution have reacted and precipitated as scale. The time of first measurable change of conductivity is called as an induction time. Figure 2 shows a variation on conductivity of the solution to the time. The induction time found this work was 17; 10 and 8 minute for frequency of vibration 0.00; 1.00 and 2.00 Hz respectively. The data proved that the vibration controlled the $CaCO_3$ scale formation by decreasing nucleation time and increasing mass of scale production.

No references were found to explain the mechanism of vibration in affecting the nucleation time. However, it could be caused by the increasing of ion collision, in which for frequency 2.00 Hz of vibration will produce 14,000 times per hour of mechanical collision. Furthermore, this result does not contrary to other previous research in which vaterite will be formed after 8 minutes (Chen, 2014).

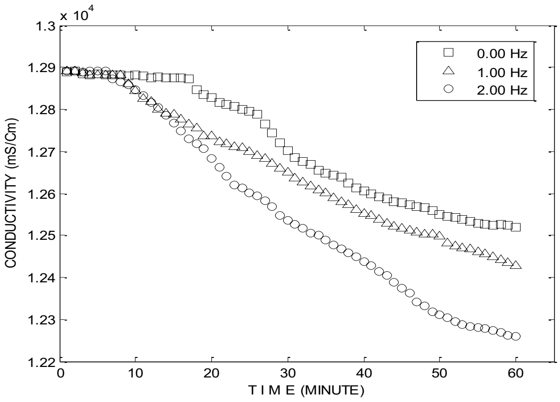

Figure-2. Conductivity of the solution over the time

Mass of scale

As it has been discussed before that the mass of scale formation in this system was classified into deposition rates of precipitation (W_{precip}), deposition rate in the strainer (W_{strain}) and deposition rate of vibration (W_{vib}).

Table-2. Deposition rate of $CaCO_3$ (gram/h)

Frequency	$W_{precipitation}$	$W_{strainer}$	$W_{vibration}$
0.00 Hz	0.0507	5.2157	0.00
1.00 Hz	0.0722	6.0892	0.9457
2.00 Hz	0.1207	8.4391	3.3441

The deposition rate of precipitation was measured in the coupon, deposition rate of the strainer was measured in the strainer for every running. The deposition rate of vibration was calculated as the difference between all deposition rates with vibration to all deposition rates without vibration. All of the deposition rates are presented in Table 2. It shows that the deposition rates of vibration in 2.00 Hz of frequency was calculated as : (0.1207 + 8.4391) – (0.0507 + 5.2157) = 3.3441.

This calculation as well as the logical consequency that scaling without vibration has been functioned as a control test to investigate the influence of vibration it self. Moreover the correlation between deposition rate of precipitation ($W_{precipitation}$); deposition rate of the strainer (W_{strain}) and deposition rate of the vibration ($W_{vibration}$) was plotted in Figure 3 to show the influence of vibration on the deposition rate.

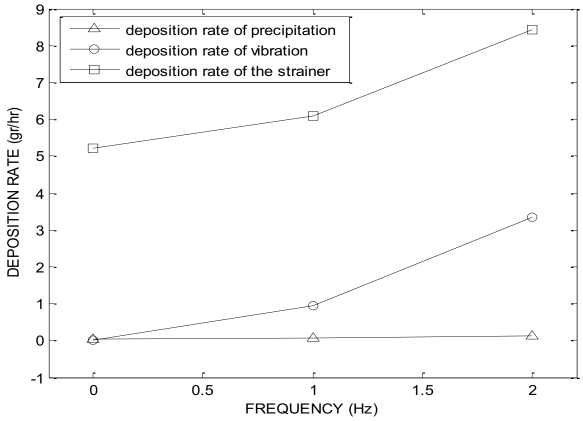

Figure-3. Deposition rate of scale formation

This graphic justifies that the vibration increases the deposition rate of $CaCO_3$ scale even precipitation rate, vibration rate and deposition rate in the fllter.

Crystal morphology

Morphology of $CaCO_3$ crystal was investigated by SEM/EDX for the specimen with 2.00 Hz of frequency obtained after running in three hours (Figure 4).

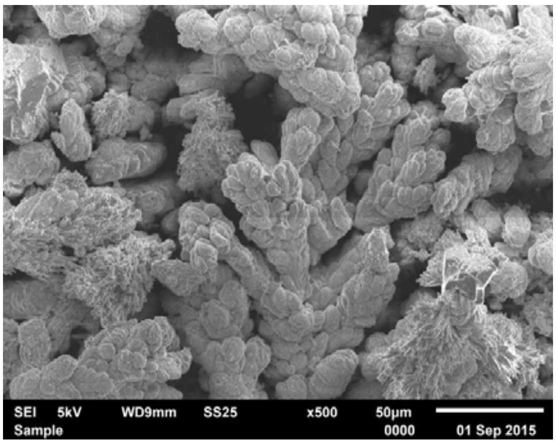

Figure 4. Crystals polymorph of precipitation scaling

Crystal of the precipitation scaling which is shown in Figure 4 was vaterite with the absence of aragonite and calcite. This fenomenon was unusual and showed the contradiction to the prediction by the phreeqc program in which it has predicted that the polymorph of the crystal were aragonite and calcite. The difference between the prediction of the phreeqc program to the crystal resulted by the research could be explained as follow : In the phreeqc program, calcite was predicted to dominate

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the crystals polymorph. Furthermore, crystallization of $CaCO_3$ may be very changeable, because the crystalline polymorph of calcium carbonate i.e. calcite, aragonite and vaterite are highly sensitive to the local condition (Su, 2009). The term “local condition” in this investigation was the vibration. Vibration produced excitation energy to the system and affect the crystaline polymorph.

More explanation to answer this fenomenon as it has published in previous research, among vaterite, aragonite and calcite, only aragonite is stable at room temperature (Heberling, 2014). This is the reason why calcite was not appear since aragonite was not formed. So, the absence of calcite on the precipitation could be accepted.

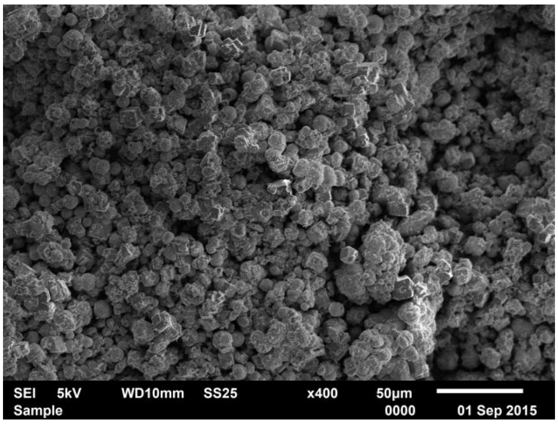

Figure-5. Crystals polymorph on the fllter

Crystal found in the fllter paper was vaterite with sperical shaped morphology. This fenomenon could be understand clearly because of replacing time of the fllter was done no more than 10 minutes, so vaterite has not enough time to transfer into aragonite or calcite. The low temperature and pressure may also bring vaterite at its stability condition (Heberling, 2014). That’s why all crystals in the filter was vaterite.

Chemical composition

Composition of the crystal was characterized by SEM/EDX JEOL JSM-6510JA providing the composition in % weight i.e. 17.26; 57.16 and 25.33 for C, O and Ca respectively. The peak shown in Figure 6 proved that $CaCO_3$ crystal was pure. It indicates that the downstream process of this research such as washing, filtrating, drying and powder storaging was done very well (Ralf Beck, 2009).

The differences between the theoretical and the actual value in % weight of crystal composition are 5.26 ; 9.16 and 15.33 for C, O and Ca respectively. These differences could be driven by the presence of vibration to the system.

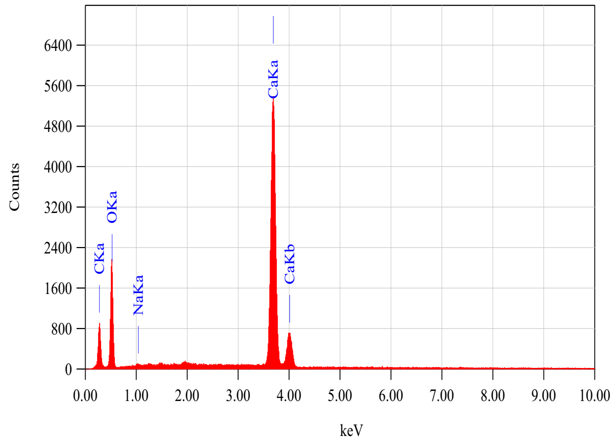

Figure-6. Composition of aragonite crystal obtained after running in three hours and frequency 2.00 Hz

CONCLUSIONS

Vibration has positive correlation between the kinetic and deposition rate.This can be proved in the graph of conductivity of the solution to the time and deposition rates of scale formation. The results confirm that, when the vibration increases, the kinetic and deposition rate also increase. Crystals polymorph was not really the same to the prediction by phreeqc program in which all the crystals of precipitation scaling was vaterite.

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