# EXPERIMENTAL STUDY ON FLOW AND THERMAL CHARACTERS OF CALCIUM CHLORIDE HYDRATE SLURRY

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## Abstract

Phase change material has been used as secondary refrigerant mixing ingredients to reduce energy consumption. Salt hydrate from calcium chloride with the composition of 55% calcium chloride dihydrate and 45% water matched with the temperature of chiller evaporator. Flow of slurry has given effect on the flow and heat transfer characteristics. Equipment used to know this is double pipe heat exchanger with flow counter flow. Pipe material is copper. The test results showed that the temperature salt hydrate containing solid particles. Salt hydrate slurry can improve the heat transfer coefficient, but the pressure drop and friction factor was also increased.

**Keywords:** Calcium chloride, Phase change material, Secondary refrigerant

## Introduction

Air conditioning (AC) chiller type where water as a secondary refrigerant can reduce the using of primary refrigerant and this able reduce the greenhouse effect. In commercial buildings use AC provide a major contribution to the energy consumption of buildings [1,2,3]. One method currently being developed to minimize the energy consumption of air conditioning systems are the use of phase change materials (PCM). In its application, the PCM is used as the secondary refrigerant mixing ingredients. PCM serves as a thermal energy storage in the form of latent heat. Several studies have shown positive results on reducing energy consumption, such as the use of trimethylolethane (TME) can reduce energy consumption 54% [4], and tetrabutylammonium bromide (TBAB) clathrate hydrate slurry (CHS) by 42%. [5].

PCM based on materials are classified; organic, inorganic, and eutectic. Salt hydrate is a kind of inorganic PCM which has high latent heat and thermal conductivity [6]. Use of this PCM on the secondary refrigerant can improve the thermal density. At the evaporator working temperature range of 5 - 12$^{o}$C, flows in the form of slurry. In these conditions, for the process of cooling generated of the solid particles, and for the heating process occurs melting of solid particles. Replacement of water into a slurry influence the flow losses in the piping system, so the impact on the pump power. Increasing the concentration of solids in the slurry can improve the pressure drop in the pipe [7]. Calcium chloride is a salt hydrate-forming material. Mixing calcium chloride dihydrate with water at a ratio of 55%: 45% have freezing temperatures 5.36 - 5.26$^{o}$C [8]. This composition matches the chiller evaporator working conditions. This study aims to investigate the characteristics of flow and heat transfer salt hydrate of calcium chloride.

## Experimental Apparatus and Procedure

### Material

Salt hydrate used is a mixture of calcium chloride dihydrate 55% and 45% water. Calcium chloride dihydrate ($CaCl_2.2H_2O$) have been containing 75.49% calcium chloride. At low temperature, salt hydrates are turn into slurry. Determination of the concentration of $CaCl_2$ is based curve salt hydrate phase diagram, as shown in Figure 1.

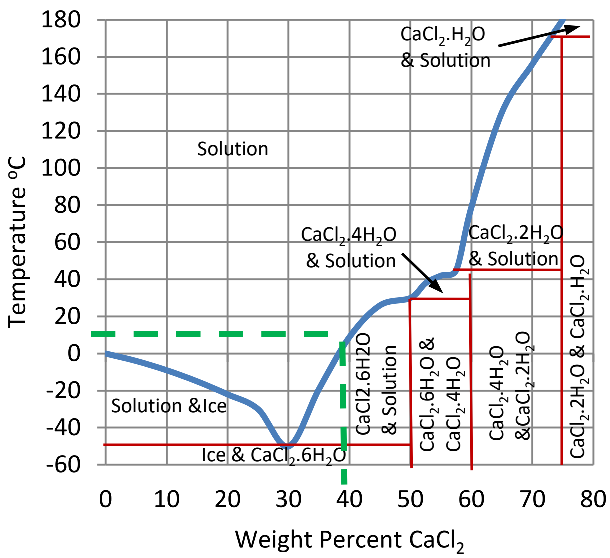



Figure 1. Phase diagram of calcium chloride and water compound [9]

Some properties of calcium chloride hydrate salt needs to be known for the calculation of the flow and heat transfer characteristics are shown in Table 1.

**Table 1. Properties of Calcium Chloride Hydrate**

| Properties | Value | References |
|---|---|---|
| Density (kg/m$^3$) | 1352 | [10] |
| Viscosity (Pa.s) | 0.001088 | [11] |
| Thermal conductivity (W/m.K) | 0.54 | [12] |
| Specific heat capacity (kJ/kg.K) | 3.58 | [11] |
| Latent heat (kJ/kg) | 315.57 | [10] |

*Solid Factor Test*

Solid factor is the ratio between the solid mass contained in the slurry with slurry mass. Solid mass for the cooling process is taken after a once cooling and heating cycles. While the solid mass of the heating process is taken after it was once cooling cycle. Temperature range testing cycle is 15 – 2°C.

### Flow and Thermal Characteristic Test

Flow and heat transfer characteristics testing were made on test equipment with the scheme shown in Figure 2. The flow characteristics were tested on a copper pipe with a diameter of ½ inch and 3.2 meters long. Pressure drop was measured using the U manometer. Fluid of manometer is $CCl_4$. Heat transfer characteristics were tested in double-pipe heat exchanger counter flow type. The geometry of equipment is as follow: the length of pipe is 3 m, the inner diameter of pipe is ½ inch and outer diameter of pipe is 1 inch. The material of pipe is copper. Temperatures inlet and outlet of each pipe was measured using a thermocouple type K and data logger Omega OM-DAQ-USB-2401.

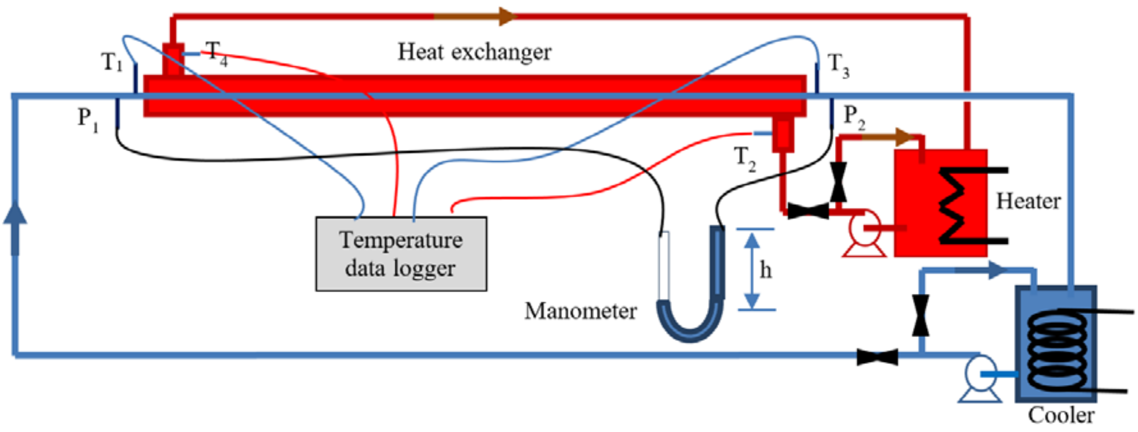



Figure 2. Schema of flow and heat transfer characteristic test

## Result and Discussion

Salt hydrate tested is in the form of slurry. In the cooling process of the formation of solid particles and the heating process occurs melting of solid particles. Solid mass percentages in the slurry at cooling and heating processes are shown in Figure 3. From the test results in the cooling process, the solid mass formed at temperatures of 15° C is 4.3% and at a temperature of 2 °C is 44.9%. While in the heating process after a cooling cycle, the percentage of solid mass has been decreases with temperature increasing. Solid mass that remains is slightly more than the cooling process at the same temperature. This shows that the melting temperature slightly higher than the freezing temperature. Solid mass fraction is needed in the calculation of the heat transfer coefficient.

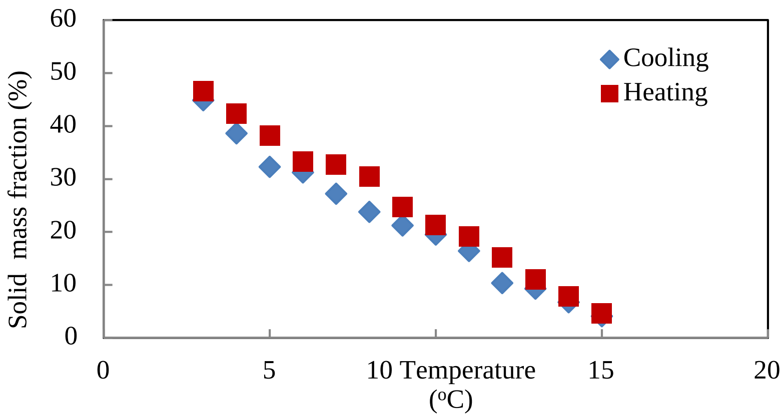
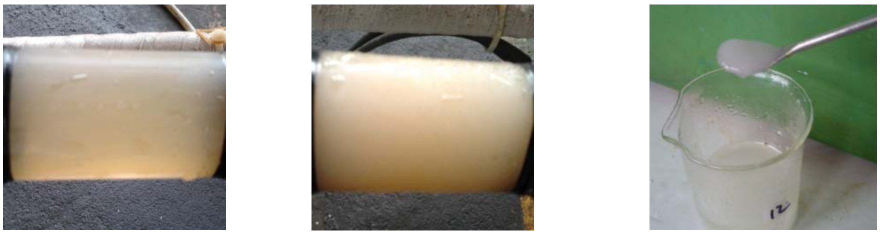



Figure 3. Solid mass fraction of calcium chloride slurry to cooling and heating process

Visualization of flow in the test of flow and heat transfer characteristics have shown that salt hydrate already slurry, as shown in Figure 4. Solid particles in slurry have very small and soft.



Water flow CaCl$_2$ x H$_2$O slurry flow Solid phase of CaCl$_2$ x H$_2$O

Figure 4. Visualization of water and slurry flow

**Pressure Drop/ Friction Factor**

Pressure drop that occurs in the pipeline based on the Darcy-Weisbach equation is affected by the coefficient of friction, fluid density, length and diameter of the pipe, and the flow rate, as shown in Equation 1.

$$h_{L_{mayor}} = f \frac{l}{D} \frac{V^2}{2g} \quad (1)$$

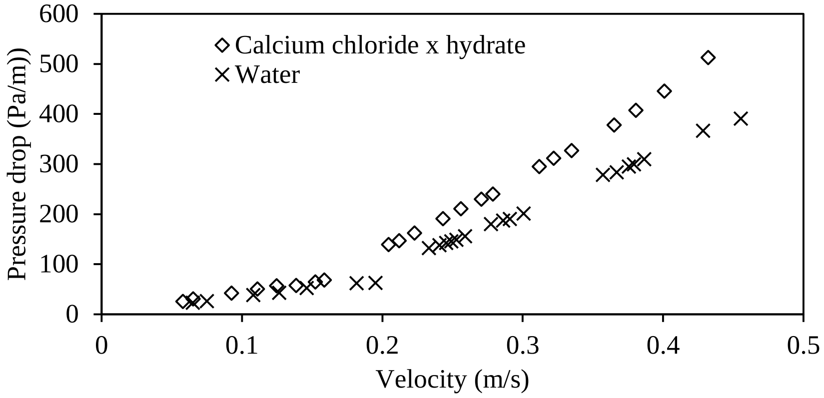



Figure 5. Pressure drops as function of velocity of the water and salt hydrate slurry

Figure 5 shows the pressure drop that occurs to some velocity flow at temperatures of 5 °C. In laminar flow with velocity lower than 0.2 m/s, the difference of pressure drop for the flow of salt hydrate slurry is very small compared to water. But in turbulent flow with velocity higher than 0.2 m/s, the difference of pressure drop increase in line with the increase in velocity. This is in accordance with the Darcy-Weisbach equation where the pressure drop is proportional to the square of the velocity. In addition, the value of salt hydrate density greater than water, also affect the increase in pressure drop.

Friction factor experimental results calculated using Darcy-Weisbach equation. Friction factor of theoretical for laminar flow is calculated by Equation 2 by assuming Newtonian fluid.

$$f = \frac{64}{Re_D} \quad (2)$$

As for the turbulent flow and very smooth pipe used to Blasius equation, as written in Equation 3.

$$f = 0.316\, Re^{-0.25} \quad (3)$$

Thomas equation used for turbulent flow and non-Newtonian fluid, as written in Equation 4.

$$f = 0.1988\, Re^{-0.211} \tag{4}$$

Compared with water, friction factor for the salt hydrate slurry is greater in laminar flow and turbulent flow. At 5 ° C test temperature, solid particles that have a lot of formed can improve the flow resistance. Analysis of liquid solid two phase flow is more complex than a single-phase flow, where there is interaction among the solid particles, solid particles with a carrier fluid and the pipe wall. Friction flow of slurry is divided into two parts namely; (1) mechanical friction caused by the interaction of solid particles and the walls of the pipe; (2) the viscous friction caused by fluid viscosity [13]. Improving of the friction factor caused to increased interaction with other solid particles and the wall. For turbulent flow with a Reynolds number limit of 5000, the difference with the fluid friction factor of water is not too large. This condition is almost the same when compared to the friction factor using the Blasius equation. These results are consistent with the results of testing using ammonium alum hydrate slurry fluid [14].

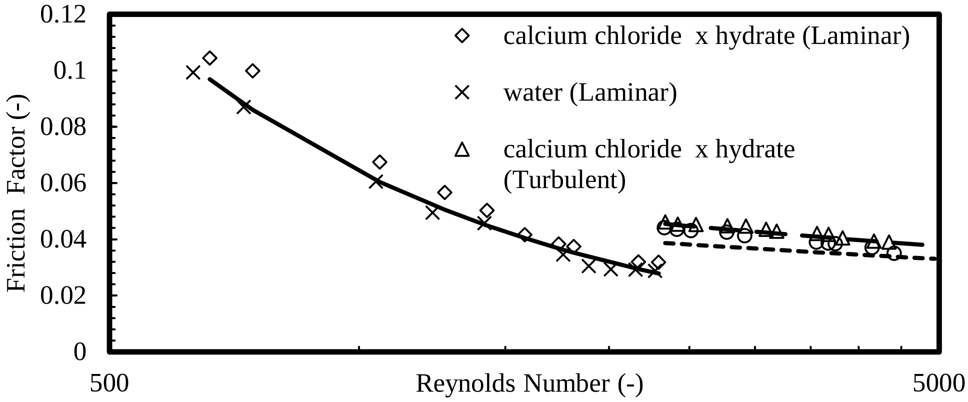



Figure 6. Friction factor of salt hydrate slurry

## Thermal Characteristic

Heat transfer occurs in the double-pipe heat exchanger with counter flow satisfy the following equations. Overall heat transfer rate can be formulated in Equation 5.

$$q = UA\Delta T_{lm} \tag{5}$$

Total heat transfer coefficient (U) with the assumption of negligible fouling due to the condition of the pipe that was new, formulated as follows

$$\frac{1}{UA} = \frac{1}{U_i A_i} = \frac{1}{U_o A_o} = \frac{1}{(hA)_i} + \frac{\ln(D_o/D_i)}{2\pi kL} + \frac{1}{(hA)_o} \tag{6}$$

$\Delta T_{lm}$ is the average temperature difference of heat exchangers. To flow in the opposite direction, the value of $\Delta T_{lm}$ is as follows.

$$\Delta T_{lm} = \frac{(T_{h,o} - T_{c,i}) - (T_{h,i} - T_{c,o})}{\ln(T_{h,o} - T_{c,i})/(T_{h,i} - T_{c,o})} \tag{7}$$

In addition, the rate of heat transfer to the cold and hot fluid satisfies the Equation 8.

$$q = \dot{m} C_p \Delta T \tag{8}$$

To know the correlation of heat transfer characteristics with fluid flow used equations Chilton-Colburn Analogy as follows.

$$\frac{C_f}{2} = \frac{f}{8} = St\,Pr^{2/3} = \frac{Nu_d}{Re_d Pr}\,Pr^{2/3} \quad (9)$$

Convection coefficient values will be compared with the empirical formula is used as theoretical equation in this research that Dittus-Boelter equation.

$$Nu_d = 0.023\,Re_d^{\,4/5} Pr^n \quad (10)$$

Heat transfer characteristics of the test results are shown in Figure 7 and 8. The use of salt hydrates of calcium chloride can improve heat transfer compared to water. Nusselt number and convection coefficient increased. Improved heat transfer in salt hydrate slurry caused by interactions among the particles of solid, fluid carrier and walls. This interaction is better than a single-phase flow, like water. Other research, such as the use of the use of ammonium alum hydrate slurry [14] showed similar results, with an increase in heat transfer.

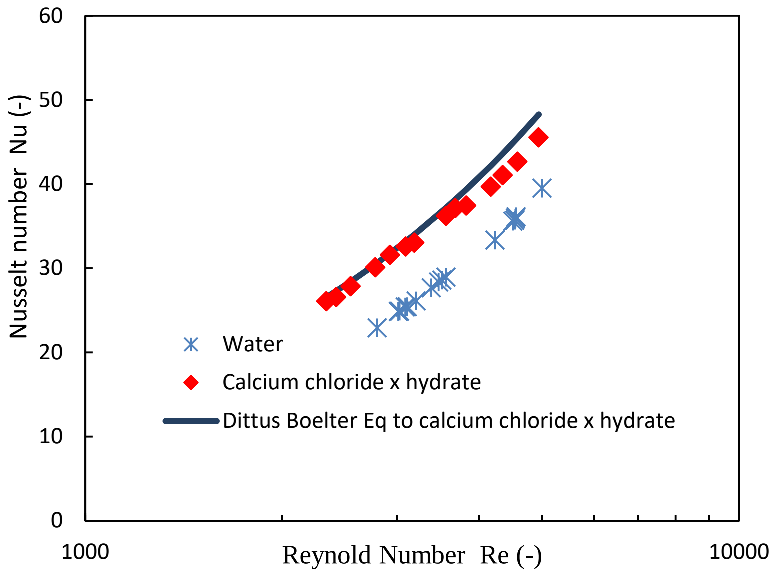



Figure 7. Nusselt number of salt hydate slurry

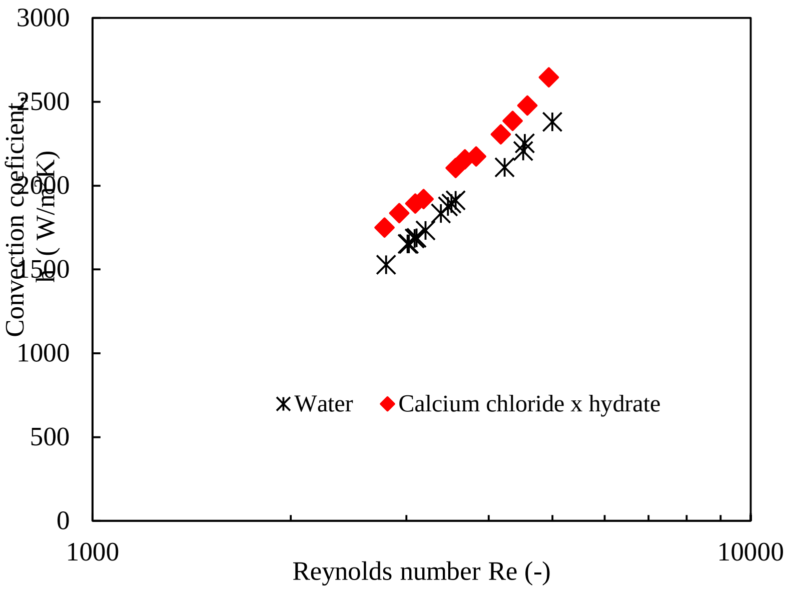



Figure 8. Convection coefficient of salt hydrate slurry

## Conclusions

In the present study, salt hydrate of calcium chloride containing solid particles that store thermal energy as latent heat. Flow of slurry has given effect to the increasing in pressure drop. Friction factor is slightly higher than water. The interaction of among the solid particles, solid particles with a carrier fluid and wall in slurry flow has improved the heat transfer.

## Nomenclature

| | | | |
|---|---|---|---|
| A | Area ($m^2$) | St | Stsnton number (-) |
| $C_f$ | Fanning friction factor (-) | T | Temperature ($^oC$) |
| $C_p$ | Specific heat capacity (J/kg.$^o$C) | U | Total heat transfer coefficient ($W/m^2K$) |
| D | Pipe diameter (m) | v | Velocity (m/s) |
| f | Friction factor (-) | Subscripts | |
| $h_L$ | Head losses (m) | c | cool |
| l | Length (m) | h | hot |
| Nu | Nusselt number (-) | i | inlet |
| Pr | Prandtl number (-) | o | outlet |
| q | Heat transfer rate (W) | | |

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