Application of calcium chloride as an additive for secondary refrigerant in the air conditioning system type chiller to minimized energy consumption

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Abstract. One way to resolve the energy problem is to increase the efficiency of energy use. Air conditioning system is one of the equipment that needs to be considered, because it is the biggest energy user in commercial building sector. Research currently developing is the use of phase change materials (PCM) as thermal energy storage (TES) in the air conditioning system to reduce energy consumption. Salt hydrates have been great potential to be developed because they have been high latent heat and thermal conductivity. This study has used a salt hydrate from calcium chloride to be tested in air conditioning systems type chiller. Thermal characteristics were examined using temperature history (T-history) test and differential scanning calorimetry (DSC). The test results showed that the thermal characteristics of the salt hydrate has been a high latent heat and in accordance with the evaporator temperature. The use of salt hydrates in air conditioning system type chiller can reduce energy consumption by 51.5%.

1. Introduction

Issues on energy which are encountered in many countries have become a global concern. The problem is that electricity consumption keeps increasing while its energy supply is declining. To narrow this gap, efficiency of energy consumption has to be escalated. Air Conditioning in commercial buildings is recognized as the contributor of the largest quota of its total energy consumption in different countries such as the United States and China 38% [1], Malaysia 57% [2], and Indonesia 65% [3]. Efforts for efficiency of energy on Air Conditioning are applying new air conditioner with higher efficiency, designing integrated and innovative system, or managing control and operation [4].

Innovative design which is being developed is the use of *phase change material* (PCM) as thermal energy storage in air conditioning system. One of its applications is in the secondary refrigerant. To apply this air conditioning system, such criteria should be employed as phase change temperature between 5°C to 12°C, large fusion heat, good thermal stability, good thermal conductivity, stabile chemical features, low corrosions, low environment impact, low viscosity, simple manufacture, and relatively cheap [5]. Some PCMs whose phase change temperature on the range between 5°C up to

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12°C are fatty acids and paraffin from organic material and hydrate gas and salt from inorganic ones[6]. Inorganic materials have advantages over organics, i.e. high latent heat and conductivity, low volume change, and available in economical prices. Yet their sub cooling and corrosion characteristics should be considered when the materials are applied [6}.

Calcium chloride is one of materials to build hydrate salt compound. This material is generally utilized to save thermal energy in calcium chloride hexahydrate ($CaCl_2.6H_2O$) compound form with melting point on 29.9°C. The benefits of using this material is it is accessible widely with low-cost, it has high latent heat and low corrosion compared to other similar compound and it is non-toxic[8]. Considering the thermal characteristic displayed on phase diagram in Figure 1, solid to liquid phase change and the reverse can be generated as it is expected by adjusting the $CaCl_2$ concentration. Adjusting concentrate to 39-40% of $CaCl_2$ mass basis into water, the melting and freezing temperature are matched to chiller evaporator working temperature. To identify whether the compound can be applied in secondary refrigerant of chiller type air conditioning system, further study needs to be experimented.

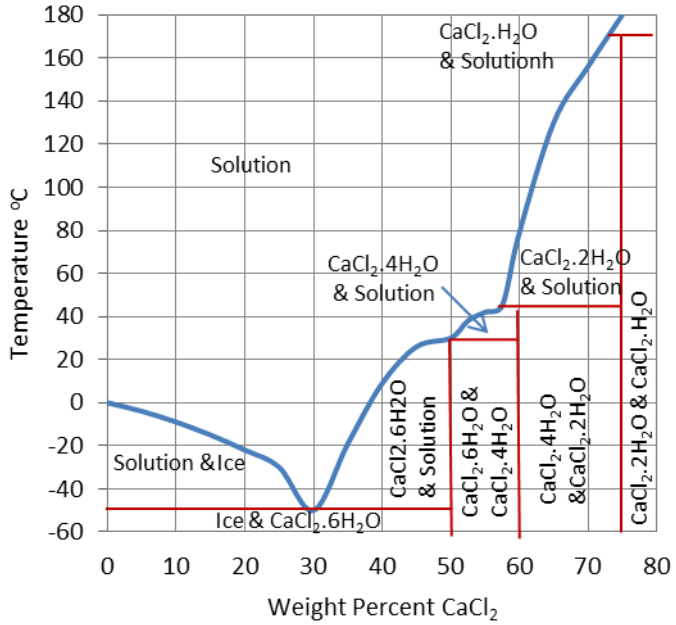

Figure 1. Phase diagram of calcium chloride and water compound [8]

2. Research Methodology

Hydrate salt in the study is the mixture of calcium chloride and water. The calcium chloride found in stores is calcium chloride bi-hydrate ($CaCl_2.2H_2O$) which contains 25% water. The thermal characteristics of the hydrate salt are examined by performing two types of tests. Firstly, temperature history (T-history) method examination is performed to obtain adjusted composition in order to match the melting temperature with evaporator's working temperature. Secondly, *Perkin Elmer's Differential Scanning Calorimetry* (DSC) type 8500 test is used to signify the freezing and melting temperature together with the latent heat value. This test observes thermal characteristics using sample weight 5-7 mg and the applied cooling and heating flow of 2 C/min starting from 25 goes to -30°C for cooling and -30 up to 35°C for heating with flow rate of cooling nitrogen as much as 20 ml/min.

Another test for density and viscosity is executed to support the application of this hydrate salt in the air conditioning system. The study use Hitachi RCU15Y brand chiller specified with compressor power 10.8 kW and secondary refrigerant pump power 1.5 kW. The test is performed for eight hours starting from 08.00 a.m. to 16.00.p.m. Testing equipment scheme is displayed in Figure.2. The test will indicate the energy spent by the pump, compressor, and COP chiller

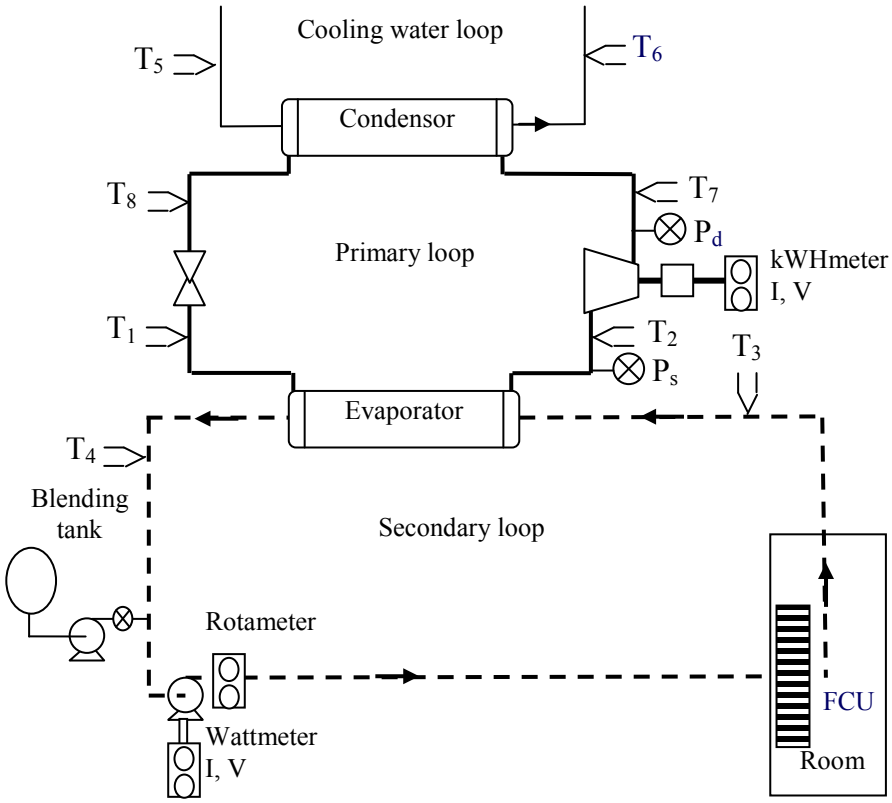

Figure 2 Schematic picture of experimental layout

3. Result and Discussion

3.1. Thermal Characteristics

The result of T-history test indicated that appropriate composition of $CaCl_2$ and water on melting temperature between 5 to 12°C was 55% : 45%. This result is dissimilar from the value obtained from phase diagram curve in Figure 1. This alteration is caused by calcium chloride applied in the test in the form of calcium chloride di-hydrate ($CaCl_2.2H_2O$) compound with water percentage around 25%. The comprehensive result on the thermal characteristics for this hydrate salt is presented in Table 1.

Table 1. Properties of salt hydrate from calcium chloride

Properties	Value
Density (kg/m^3)	1.352
Viscosity (cSt)	3.893
Melting Temperature (°C)	8.81 – 25.68
Freezing Temperature (°C)	0.08 – (-4.10)
Latent Heat (kJ/kg)	315.37

Freezing process started to form on temperature 5.36°C and ended on 5.26°C, just like the T-history curve showed on Figure 3. DSC Test obtained slightly different number on freezing temperature as shown on table 1. Strong sub-cooling character of hydrate salt caused the difference on freezing temperature as well as its melting one. The latent heat value is high as much as 315.37J/g. This is caused by the length of melting temperature range as shown in Figure 5 and the formed solid crystal contained water. The water content in the solid crystal was the result of spectroscopy as explained in Baumgartner, et.al [9].

Freezing and melting process indicated the shaped and the melted solid mass concentration. Solid mass concentration for each temperature on freezing and melting process is shown in Figure 4. In the cooling process, the solid mass is formed in the temperature between 9°C down to 6°C was 10.212%. At the same time, the heating process in the temperature between 6°C up to 10°C, the melting part of the solid mass was 9.942%. Thus, with the energy saved in the form of latent heat, the change flow on temperature in secondary refrigerant can be reduced. Concluding the result of T-history test, DSC and solid mass concentrate test as support, it is signified that the concentration of $CaCl_2$ is 55% and water 45% was fitted to the working temperature of evaporator.

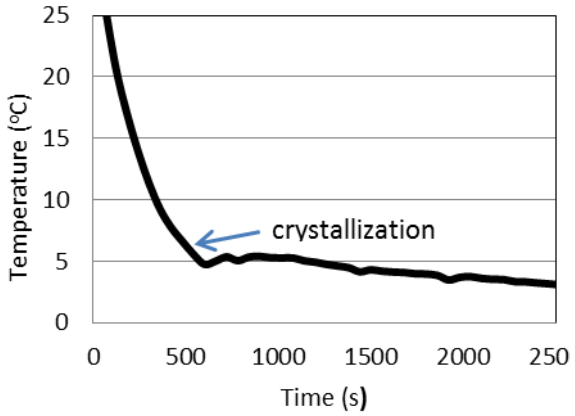

Figure 3. Cooling process of salt hydrate from $CaCl_2$ 55% and water 45% with T-history test

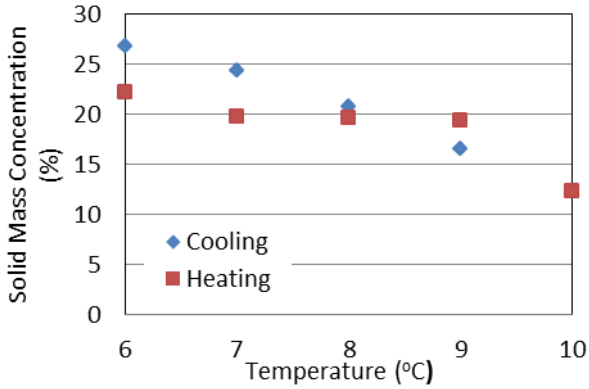

Figure 4. Solid mass concentration of salt hydrate from $CaCl_2$ 55% and water 45% in cooling and heating process

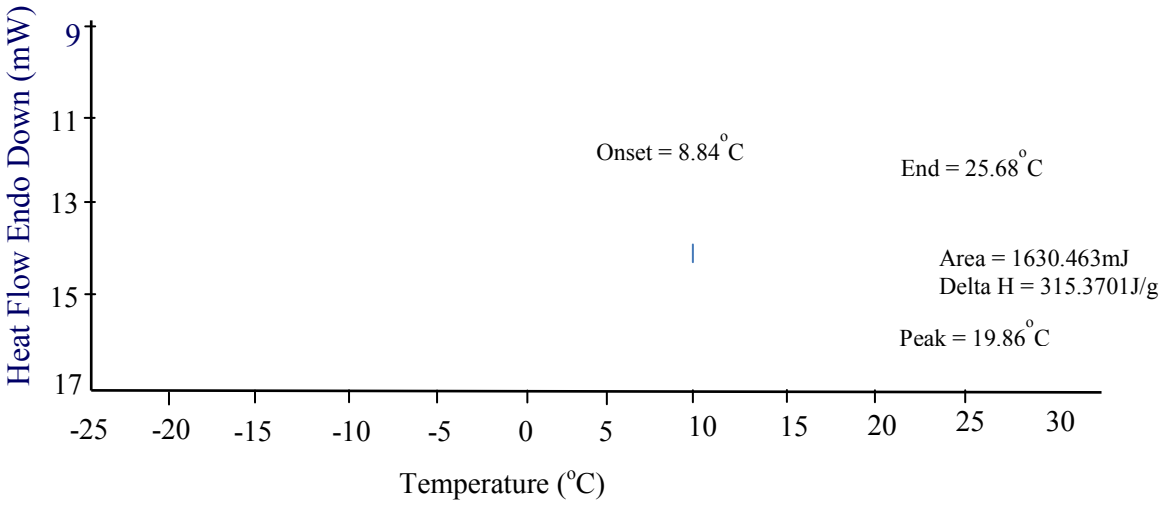

Figure 5. Melting temperature of salt hydrate from $CaCl_2$ 55% and water 45% with DSC test

3.2. Air conditioning performance

To find out the effect of the use of this hydrate salt as refrigerant for air conditioning performance system, energy consumption on chiller's compressor and secondary refrigerant pump had to be identified. The ability to save thermal energy and the effect on COP energy consumption will be discussed on chiller while the effect of hydrate salt use to pump energy consumption

3.2.1. Pump energy consumption

Salt hydrate from calcium chloride has different character from water so that it influenced the performance and energy needed by the pump. The test indicated that during eight hours experiment, the pump energy consumption increased 3.6% as displayed in Figure 6. This increase was not significant because the difference of density and viscosity is not too far. Viscosity value had not exceeded tolerated limit is 5sCt while debit, head and pump power calculation did not need corrective factor [10].

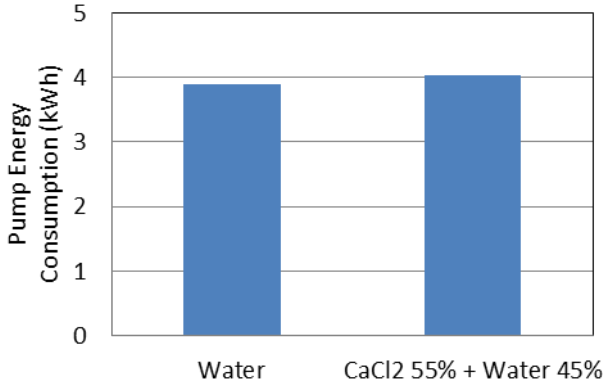

Figure 6. Energy consumption of pump

3.2.2. Chiller energy consumption

The use of salt hydrates can reduce the energy consumption of the chiller compressor, as shown in Figure 7. The total of decline was 51.5%. Thermal energy storage in the form of latent heat in PCM slurry can reduce the frequency of on/off compressor chiller. When the compressor on, some energy is stored as latent heat so that the time required to reach the temperature off of compressor is longer than water as secondary refrigerant. Likewise, when the compressor off, the release of energy in the melting process of solid particles in the slurry can extends the time over to reach the temperature on of the chiller compressor.

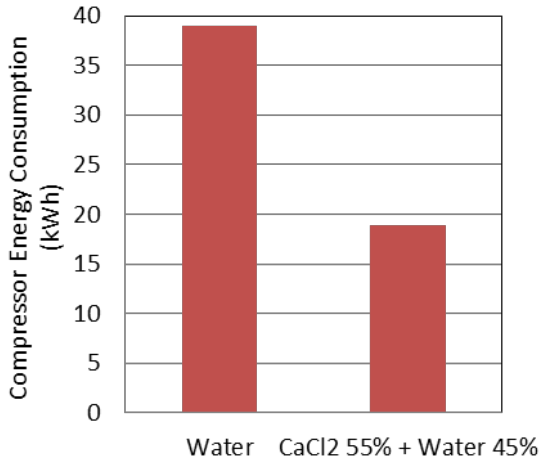

Figure 7. Energy consumption of compressor

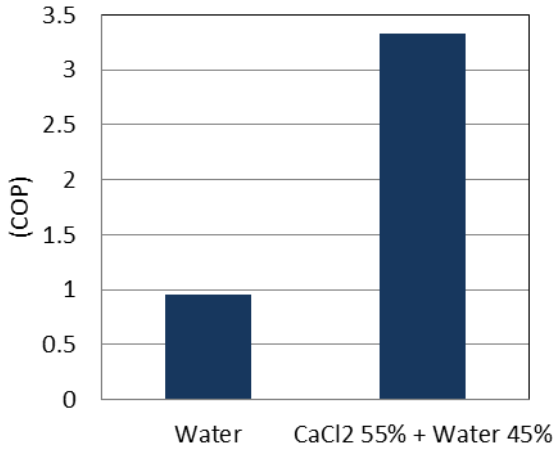

Figure 8. COP of chiller

Daily COP of chiller has been increase for the use of salt hydrates from calcium chloride as a secondary refrigerant as shown in Figure 8. This improved is due to the reduction of energy

consumption compressor chiller, and increasing of cooling capacity. With the partly of energy is stored in the form of latent heat, the cooling capacity can be increased compared to water.

4. Conclusion

The use of calcium chloride in the form $CaCl_2.2H_2O$ that is dissolved in water with a composition of 55%: 45% can be used as a thermal energy storage air conditioning system as a secondary refrigerant replaced of water. This material has a high latent heat, and it can reduce the energy consumption of the compressor. In addition, the use of salt hydrates did not significantly affect the increase in electricity consumption of pumps. With the availability of many materials at low prices, and can decrease energy consumption of the air conditioning system makes this material very prospect to be developed.

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