APPLICATION OF PHASE CHANGE MATERIAL TO SAVE AIR CONDITIONING ENERGY IN BUILDING

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Abstract

Energy saving in Air Conditioning (AC) system is quite important for climate-change mitigation, since AC system consumes around 60% of building electricity. Air conditioning technology also deals with ozone depletion problem. Chilled-water AC system needs smaller amount of primary refrigerant, so it can minimize possible CFC or HCFC (Ozone Depleting Substances) emission into the atmosphere. Latent heat transportation system applied in chilled-water system open opportunity to save energy. In the second aspect, integration of Phase Change Material (PCM) in building wall can increase heat capacity of the wall and reduce and stabilize indoor temperature. Both technologies can mutually contribute in reducing AC energy consumption. In this paper, application of some PCMs in chilled water system and wall model are reported.

Keywords: Air conditioning, Concrete block, Energy saving, Phase change material

Introduction

Air conditioning technology is strongly related with two prominent environmental issues in this decade, i.e. global warming and ozone layer depletion problems. All improvements in air conditioning technology are directed to produce air conditioning system with high energy-efficiency, and uses refrigerant with zero ODP (Ozone Depleting Potential) and low GWP (Global Warming Potential). Air conditioning system consumes large amount of building electricity; in Indonesia, the figure is around 60% for commercial building. The comparable situation is also occurred in USA, Japan, and China [1,2,3]. It is mean that energy saving in air conditioning system is strategic effort to reduce building energy consumption.

PCM Application in Chilled Water System

One kind of technology to reduce refrigerant consumption in a big-capacity air conditioning system is indirect refrigeration system. Secondary refrigerant, such as chilled water, is circulated through building to absorb thermal load from Air Handling Unit (AHU) or directly from rooms. To increase heat transfer and thermal capacity of the secondary refrigerant, some researchers used phase change material (PCM) / latent heat transportation system. They usually use ice slurry as PCM. Inaba [4] pointed out that the latent heat transportation system has significant improvement in down-sizing of piping network equipment, reduce heat loss, increase heat capacity and enhance heat transfer coefficient in heat exchanger. However, ice slurry usage needs lower temperature of the evaporator. This sacrifices chiller performance. To avoid that condition, PCM with higher solidification-temperature should be used. In this paper, that kind of PCMs is used.

Trimethylolethane (TME) slurry is a good candidate to replace chilled water in a cooling system. Crystallization temperature of TME can be adjusted by control its concentration in water. The crystallization temperature of TME is higher compared with that of ice, i.e. about 9 and 13^{o}C for TME 23 and 27.5 wt%, respectively [5].

TME slurry is also non-flammable and non-corrosive against metals [6]. TME is considered as non-hazard and non-toxic material. However, compared with the high latent heat of ice, i.e. about 334 kJ/kg at 0^oC, TME hydrate has a lower value, i.e. 218 kJ/kg (at 29.8^oC for TME 62.5 wt%) [6]. To reduce the pressure drop of TME slurry, additives consist of cationic surfactant (oleyl bishydroxyethyl methyl ammonium chloride, trade name: Ethoquad O/12) and sodium salicylate (NaSal) are used as drag-reducing agent.

The second PCM used in chilled-water system reported in this paper is vegetable oil mixture. TME represents inorganic substance, while vegetable oil is organic substance. Organic substance generally has lower latent heat value compared with inorganic substance. However, organic substance has advantage on non-corrosiveness, chemical and thermal stability [7]. Organic substance such as vegetable oil is highly available in tropical country like Indonesia at reasonable price. On the other hand, TME is imported with relatively high price. Heat balance in phase-change fluid can be calculated by following equation:

$$q = \dot{m}_{mix} c_{p,mix} (T_{in} - T_{out})_{mix} + \dot{m}_{pc} \Delta h_{latent} \qquad (1)$$

In the above equation, q is heat transfer of fluid containing phase change material, $\dot{m}_{mix}$ is mixture flow rate, $c_{p,mix}$ is specific heat at constant pressure of the mixture, T_{in}& T_{out} are inlet and outlet fluid temperature, respectively, $\dot{m}_{pc}$ is flow rate of substance which experiences phase-changed, and Δh_{latent} is latent heat of the phase-changed material. It can be seen from Equation 1 that latent heat transportation has higher heat capacity than that of single phase fluid.

PCM Application in Building Wall

Integrating PCM into building wall give some advantageous, such as thermal stabilizer, energy storage, reduction and/or shifting of peak cooling-load. Those mechanisms are possible since PCM wall has higher thermal capacity than conventional wall because of latent heat-storage capability of the PCM. Pasupathy et al. [8] clearly show that PCM roof used in their study stabilize indoor temperature. Diaconu and Cruceru [9] reported that their composite PCM wall reduce peak cooling load up to 35.4%. Zalba et al. [10] design and test their “free-cooling” system by using PCM ability to store energy during day and release it at night. Many studies in this area confirm the capability of PCM wall to save AC energy.

Baetensa et al. [11] classify PCM usage in building into three types: PCM enhanced wall board, PCM enhanced concrete, and PCM enhanced building insulation material. Latent heat storage substances typically can be classified as organics and inorganics. Main advantage of inorganics substances over the organics is its higher latent heat, while organics substance has advantage on non-corrosiveness, low or non-undercooling, also chemical and thermal stability [12]. Organic substances can be classified further as paraffin and fatty acid. Based on contact between PCM and wall material, basically there are two types of PCM integration in building wall: direct and indirect contact. In indirect contact type, PCM is covered by other substance. Microencapsulated phase change material (MEPCM) is composed of PCM as core and a polymer or inorganic shell to maintain the shape and prevent PCM from leakage during the phase change process [13]. Özonur et al. [14] explain some advantageous of MECPCM, i.e. leak prevention of the PCM, and avoid change of salt hydrates number especially in humid air. They found that coacervaction technique by using mixture of gelatin and gum arabic is suitable to microencapsulate coco fatty acid.

In this paper, preliminary experiment on MEPCM integration in concrete block model is reported.

Experiment

PCM Application in Chilled Water System

Substances

Two types of PCM is used in this study, i.e. inorganic and organic PCM. Commercial-grade Trimethylolethane (TME) trihydrate is used as inorganic substance, while mixture of vegetable oil is used as organic substance. To compensate high pressure drop resulted from TME slurry flow in pipe, certain drag-reducer additive is used. The additives used in this experiment are cationic surfactant (Ethoquad O/12) 2000 ppm and counter-ion (sodium salicylate) with molar ratio between surfactant and counter ion is 1:1.5. The PCM is mixed directly into chilled water.

PCM is mixed with water in certain composition as secondary refrigerant in indirect refrigeration. Picture of indirect refrigeration installation is shown in Figure 1. This installation is located at Thermodynamics Laboratory, Institut Teknologi Bandung (ITB), Indonesia. Chiller performance, in term of daily COP, was calculated by measuring secondary fluid flow rate, inlet/outlet temperature at evaporator, and electricity consumed by compressor for 8-12 hours.

Equipment

Experiment on chilled water system performance was done in Thermodynamics Laboratory, Institut Teknologi Bandung (ITB). Schematic figure of AC installation is shown in Figure 1. Chiller used in this experiment is RCU15Y from Hitachi, with cooling capacity of 8,700 – 96,500 W and compressor power of 10.8 kW. R-22 is default refrigerant of this chiller. Voltage-output, integrated circuit temperature sensor LM35DZ from National Semiconductor Inc., were placed at inlets and outlets of evaporator and condenser of the refrigeration machine. The sensors were connected to data acquisition unit (NI 4340/4351 from National Instrument) and computer to store the data. For vegetable oil experiments, temperature measurement was done by using thermocouple and data acquisition (TC-08) from Omega Engineering, because the NI 4340/4351 was not available at that time. However, both devices were calibrated carefully.

Compressor power consumption was monitored by using 3-phase kWh meter. The meter records electric usage by the compressor during 8-12 hours per-day. The compressor automatically shut-down when temperature of secondary refrigerant is below 6.4^{o}C. Bourdon tube pressure gages were used to monitor suction and discharge pressure in the refrigeration machine. In the secondary loop, flow rate of the fluid was measured by rotameter with maximum capacity of 1.4 L/s. Pump power consumption was measured by using single phase Wh (Watt-hour) meter. Cooling fluid was circulated through 3 room air terminals (RATs) in 3 working rooms. The RAT consists of compact heat exchanger with circular tube and continuous fin. Temperature and humidity in each room were measured by K-type thermocouple and humidity meter.

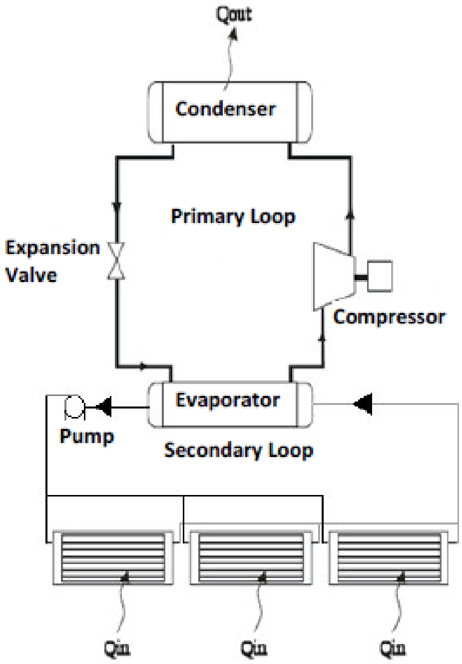

Figure 1. Chilled water system in thermodynamics laboratory ITB

PCM Application in Building Wall

Substance

Materials used to produce MEPCM are common Virgin Coconut Oil (VCO) as PCM, gelatin, gum-arabic, Sodium Hydroxide (NaOH), 98% acetic acid (CH_3COOH), 96% ethanol, and formaldehyde. All substances were available in local market. Model of concrete block is composed from cement and premixed mortar (mixture of sand, cement, and additive).

Microencapsulation

Similar with Özonur et al. [14] work, microencapsulation method used in this research is complex coacervaction. Initially, aqueous gelation solution was made by mixing gelatin and water (1:20 mass basis) while keep water at 55^{o}C and stirred it at 500 rpm. Coconut oil then was poured in the solution and the stirrer speed was increased to 1,500 rpm for 5 minutes. Gum-arabic powder was added slowly until the mixture became light-brown colored and more viscous. Mass ratio between gelatin, water, coconut oil, and gum arabic used in this experiment is 1:20:2:3.

Next process was addition of acetic acid to reduce pH until 4; then the stirrer was stopped and the mixture was cooled slowly to room temperature. It took almost one and half hour before microcapsules' wall is hardened. Wall hardening is facilitated by formaldehyde as cross-linking agent. To avoid microcapsules stick each other, water was added and the stirrer was set at 300 rpm. This hardening process can take place at least for 16 hours, but the process can be shortened by adding few milliliters of NaOH 5 molar to adjust the pH to 11. The solid granules then were separated from the excess water and placed in the cooling water-bath at 2^{o}C for 2 days. Finally, the capsules were washed by using ethanol, filtered, and dried. Final product of MEPCM is shown in Figure 2.

Concrete Block Manufacturing

Two types of concrete blocks were manufactured, i.e. conventional concrete block and concrete block with MEPCM. Conventional concrete block was manufactured from cement and premixed mortar with volume ratio of 3:7. While concrete block with MEPCM is composed from MEPCM, cement, and premixed mortar with volume ratio of 2:1:2; resulting 40% (mass basis) of MEPCM contained in the concrete. Picture of concrete blocks with and without MEPCM can be seen in Figure 3.

Figure 2. Microencapsulation phase change Material (MEPCM)

Figure 3. Conventional concrete block (right) and concrete block with MEPCM (left)

K-type thermocouples are placed on concrete blocks and in the room. Temperature measurement was done for 7-8 hours and was repeated to assure data validity. Surface of concrete block with MEPCM is covered with same material as another concrete, to assure that both blocks receive and absorb same energy.

Result and Discussion

PCM Application in Chilled Water System

Result of this experimental work informs that compressor energy consumption is smaller when TME 30% is added into chilled-water. During phase change, heat transfer coefficient is usually high. Small particle formed during crystallization also can contribute to turbulence flow and produce higher heat transfer coefficient. This high heat transfer coefficient may responsible for shorter compressor work and reduce its energy consumption. On the other hand, for TME-surfactant system, compressor work is slightly higher (compared with TME only) since surfactant may inhibit heat transfer on pipe surface.

As it can be predicted from Equation 1, this experimental study confirms heat transfer improvement of water & TME 30% (mass basis) mixture in evaporator. This increase is caused by higher heat capacity of phase change mixture. Surfactant addition into the mixture reduces friction drag or increases flow rate. That is the reason why surfactant addition also increases heat transfer to the evaporator.

As result, COP of chiller using mixture of water and TME is higher compared with water only (see Figure 4). Since surfactant addition increases compressor power, COP of water-TME-Surfactant is slightly lower than that of water-TME. The similar experiment was conducted for vegetable oil (VO) mixture. COP of the chiller when vegetable oil is used as secondary refrigerant can be seen in Figure 5.

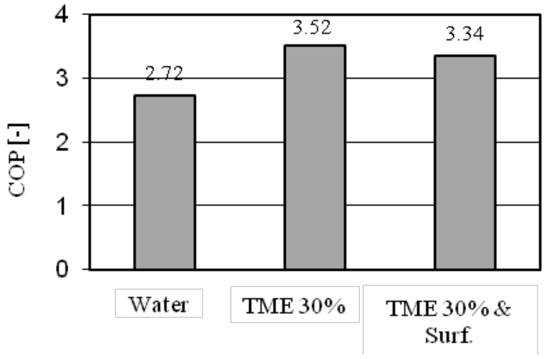

Figure 4. COP of chiller as a function of secondary refrigerant

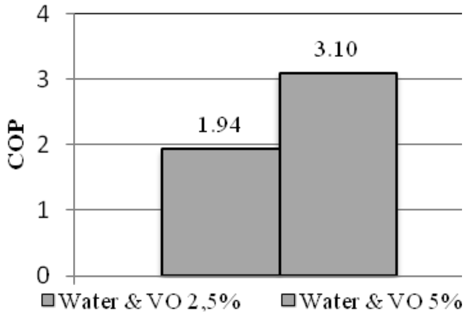

Figure 5. COP of chiller as a function of secondary refrigerant

PCM Application in Building Wall

To assure that MEPCM has phase change temperature similar with that of coconut oil, it is important to measure the MEPCM in the DSC. Measurement was done by heating the MEPCM. Result of the measurement can be seen in Figure 6.

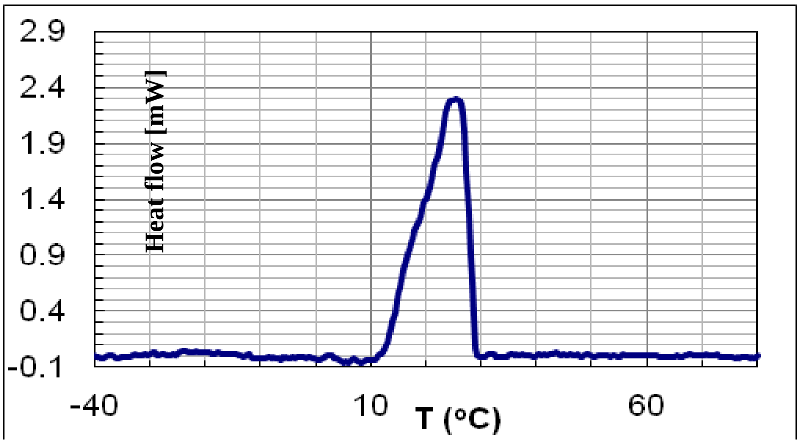

Figure 6. Phase change temperature of the MEPCM

Triangle curve shown in Figure 6 indicates phase change phenomenon occurred in the material. Özonur et al. [13] explain that coconut oil has melting temperature range of 22-24°C. Figure 6 shows first melting indication of MEPCM take place at 16°C, peak at 24°C, and complete at 28°C. This measurement assures that MEPCM used in the concrete block model has similar behaviour with the core material.

Two day measurements (see Figure 7) confirm that wall/MEPCM inner-side has lower temperature than wall without MEPCM. Both figures show stability of wall/MEPCM temperature compared with wall without MEPCM. Those temperature-profiles difference are caused by higher thermal capacity of the wall/MEPCM. Lower temperature of surrounding after 10:00-11:00 is caused by cloudy situation at the time of measurement.

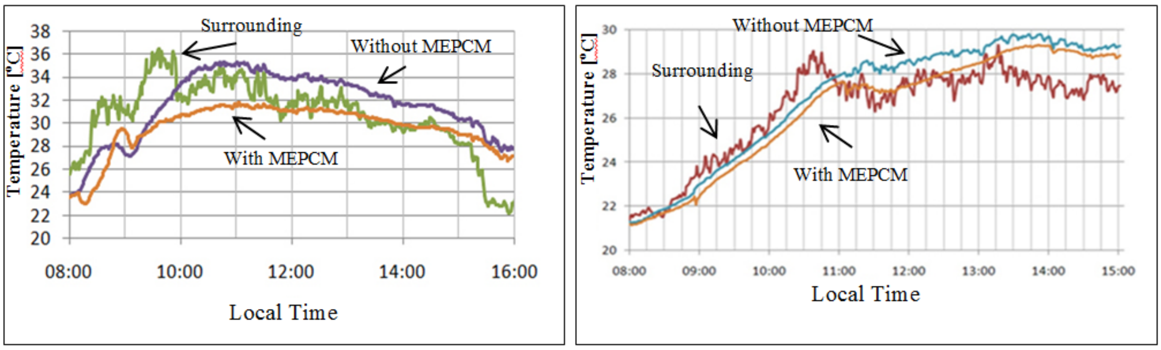

Figure 7. Inner-side temperature of wall (2 day measurement)

Figure 7 shows that there is temperature-coupling between wall and surrounding from 08:00 until 10:00-11:00. After that time, surrounding temperature goes down since cloudy situation. This decoupling nature is cause by thermal-storage characteristic of concrete block. At Figure 8 (left) it can be seen that wall/MEPCM temperature is slightly higher compared with that of wall without MEPCM. This situation occurred because there was abrupt decrease of surrounding temperature. Since thermal capacity/inertia of wall/MEPCM is larger compared with that of wall without MEPCM, wall/MEPCM temperature continued its journey before it also goes down; following the surrounding. In general, we can see time-lag of wall/MEPCM temperature compared with that of wall without MEPCM. The time-lag causes lower wall/MEPCM temperature compared with that of wall without MEPCM. This lower inner surface temperature can contribute in reducing room temperature. Lower cooling load and AC energy consumption can be expected from this kind of technology.

Conclusions

Two types of PCMs application to save AC energy in building are discussed in this paper. First application of the PCMs is as component of secondary refrigerant (chilled water), while at the second application, PCM is used to increase thermal capacity of wall. PCMs used in this study are Trimethylolethane (TME) Triydrate and vegetable oil (VO). Mixtures of PCM and water are used as secondary refrigerant in chilled-water system installation. COP of chiller was calculated by measuring temperatures and flow rate of secondary refrigerant, and electricity consumed by compressor. While in the second experiment, PCM is integrated in wall model. Temperature of wall with and without MEPCM was measured for 7-8 hours (day time).

Mixture between water and both PCMs shows higher COP compared with that of water. Heat transfer improvement and thermal capacity increasing are responsible for the higher COP. Since TME is expensive, VO is good candidate to be used in agricultural country like Indonesia. However, more experiments are needed to ensure suitability of VO usage as PCM in chilled-water system. Preliminary study on MEPCM integration into wall model shows that the MEPCM contribute to suppress inner side temperature of the wall. This lower temperature may reduce cooling load and then AC energy of building. Both technologies can mutually contribute to save AC energy of a building.

Acknowledgement

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