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Experimental analysis on solid desiccant used in an air conditioning Ekadewi Anggraini Handoyo*, and Andriano Slamet Mechanical Engineering Dept., Petra Christian University - Surabaya, Indonesia Abstract. Garden by The Bay in Singapore is the world's largest coolest conservatories. Although it is located in tropics and uses so many glasses, its electricity consumption is as much as a commercial building. The key of this low consumption is in the air cooling technology. Air used for cooling the conservatories is dehumidified first using liquid desiccants before cooled. The same technology was implemented to a single-split air conditioner (AC) that works on a vapor-compression refrigeration cycle. The experiments were conducted in a room with opened – and – closed door. Instead of using liquid desiccant, the experiment used solid desiccant, i.e. silica gel which thickness were 6 mm and 8 mm with density equals to 1.27 gr/cm³. From the experiment, it is found that (a) the thicker the silica gel, the higher outlet air temperature from silica gel, (b) less condensate will be produced when the silica gel used is thicker, (c) silica gel is suitable for reducing humidity of outdoor/fresh air, and (d) the electricity consumption saving for inserting 8-mm silica gel is only 4% when the door is closed and 31% when the door is opened. Key words: silica gel, air conditioning in tropics, air conditioning process

1 Introduction As a country located in tropics, the weather in Indonesia is humid and hot. Global warming makes it worse. Nowadays, air conditioning is required in almost all building and houses in densely populated cities in Indonesia. A principal purpose of air conditioning system is to provide conditions for human thermal comfort. "Thermal comfort is that condition of mind that expresses satisfaction with the thermal environment." In general, comfort occurs when air temperature is maintained at 22°C – 26°C and its relative humidity (RH) is lower than 60% [1]. This comfort condition was available long time ago, but it is not any more now. For example, the air temperature and RH in Surabaya could reach 75 – 93°F (24 – 34°C) and 4 – 96%, respectively [2]. Since this condition can not meet the comfort criteria, an air conditioning is required. Another country in tropics that has the same climate is Singapore. One well known icon of the city available since 2012 is Garden by the Bay. This Singapore superstructures are the world's largest coolest conservatories. These conservatories are Flower Dome and Cloud * Corresponding author: ekadewi@petra.ac.id Forest. Building two cooled conservatories in a place that is so close to the equator and where fuel resources are limited was considered madness [3]. Yet, its electrical consumption is not more than a modern office building in Singapore. Air used for cooling is dehumidified first using liquid desiccants. Then, this less moisture air is cooled with chilled water. The desiccants are regenerated using a combination of waste heat from a biomass system and solar energy [4]. An air-conditioning system with

silica gel bed was evaluated in an experimental investigation in India. From the experiment, it was found that the electricity saving was about 19% [5]. Combining conventional vapor-compression system with liquid desiccant cycles become hybrid solar space-conditioning system. From the research, it was found that 80% of energy savings can be achieved under the condition of 90% of latent heat load [6]. The use of solar energy to drive air-conditioning is attractive since the cooling load has a high coincidence with the availability of solar irradiation. A simulation with Mediterranean Region data was conducted to compare a solar desiccant solid system (DEC), an absorption refrigerant chillers, and a conventional vapor compression refrigerator. It is found out that the DEC system can achieve a primary energy saving of around 40%, compared to an absorption refrigerant and of around 150% compared to a conventional vapor compressor refrigerator [7]. Performance study of solid desiccant vapor compression hybrid air- conditioning system has been experimentally carried out for typical hot and humid weather of Roorkee. The present system has ensured 61.7% reduction in process air humidity ratio at the outlet of desiccant wheel as compared to outdoor humidity ratio [8]. A two-dimensional heat and mass transfer theoretical model of cross flow dehumidifier for household split air conditioner has been established [9]. A simulation with TRNSYS model was conducted to investigate the feasibility of using

desiccant cooling system combined with the heat wheel and heat source

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as an alternative HVAC in buildings. An

experimental study has been performed in Tohoku University in Japan
to compare the **model. The**

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results

show that such system is feasible for cooling building in hot-humid climates,

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especially when

solar energy is used to regenerate the desiccant wheel

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[10]. A desiccant air-conditioning (DAC) can be operated by solar thermal energy for moderate humid climates. The performance of the DAC system improves with higher regeneration temperature until its threshold. This threshold regeneration temperature depends on several parameter such as the desiccant material, its flow rate, and air velocity. A multi-stage DAC system can be operated at lower regeneration temperature as compare to single-stage cycle with the same dehumidification amount [11]. Rotary DAC system combines desiccant dehumidification and evaporative cooling. This air conditioning system is advantageous because it is free from CFCs refrigerant and able to use low grade heat source (such as solar energy and waste heat). Compared with conventional vapor compression air conditioning system, it gives

advantage of environment-friendly, energy saving, healthy, comfortable [12]. Liquid desiccant was successfully used in a central air conditioning system in Garden by the Bay. Many researchers also reported that the desiccant can be used in air conditioning [5 – 10]. Some experiment was conducted to know the effect of solid desiccant, which is silica gel, on a small air conditioning. Almost all of the previous research was conducted with evaporative cooler with silica gel. In this research, the solid desiccant, i.e. silica gel, will be used with a vapor-compression refrigeration or single-split air conditioner (AC) system. The electric consumption and process of air flowing thru silica gel and air conditioner will be analyzed.

2 Methode The solid desiccant, silica gel, was installed above the return grille of the single-split AC. The air will be drawn by the fan to flow thru silica gel first before being cooled with evaporator pipe of the AC. The schema of experiment apparatus and position of measurement device is shown in Fig. 1. While the equipment used is shown in Fig. 2. Fig. 1 shows measurement of air temperature include dry bulb – DB and web bulb – WB. It was measured at supply of AC, return of AC, and after silica gel before being cooled. Six thermocouples type K was used with a KRN100 logger to record the air temperature. The air flow is measured using digital anemometer which accuracy is ± 0.1 m/s. The wood box in Fig. 2 was used as a channel of the air flow thru silica gel. The thickness of silica gel bed used were 6 mm and 8 mm with density 1.27 gr/cm^3 . Fig. 1. Schema of experiment apparatus and position of measurement device. Fig. 2. Device used in experiment of this research

The water condensat resulted in the AC was measured during experiment to be used to analyze the air humidity as a result of silica gel usage. A digital kWh-meter was also installed to obtain electric consumption of the AC. First, the experiment was conducted only on the single-split AC with no silica gel. Then, silica gel was inserted before air flow enter the AC with thickness of 6-mm and 8-mm. So, there were three sets of experiment conducted. These experiment was conducted with door closed or air circulated inside the testing room. To investigate the effect of using silica gel in AC when outdoor or fresh air was used, the experiment was repeated with door opened.

3 Result and Discussion The temperature of supply and return air of the AC with and without silica gel are shown in Fig. 3 (a) and (b) for door closed and opened, respectively. The temperature of the air after passed thru silica gel (SG) are also shown in Fig. 3 (a) and (b) as SG_DB. Fig. 3 (a) and (b) show that the air temperature increased as it passed thru the silica gel either 6 mm or 8 mm thickness. During closed-door experiment without silica gel, the supply air could be as low as 10.45°C while the return air was 20.95°C at steady condition. Six-mm silica gel decreased the air flow and made the room or return air was higher slightly, i.e. 23.25°C . Flowing thru silica gel, the air temperature increased to be 24.15°C . Being cooled in evaporator, its temperature reached 9.95°C . For a eight-mm silica gel, return air was 24.25°C and after silica gel reached 26.05°C . Being cooled, the supply air was 10.8°C . Thus, the air temperature difference between in and out was 10.5°C for air flow without silica gel, and 13.3°C and 13.45°C for 6 mm and 8 mm silica gel bed. The thicker the silica gel, the higher the outlet air temperature from silica gel. These condition were found whether the door closed or opened. This happens because silica gel works by adsorption process.

35 door closed 30 temperature (C) 25 20 15 10 5 0 100 200 300 400 500 time (s) 600 700 (a) Experiment with door closed 35 door opened 5 0 100 200 300 400 500 600 700 time (s) (b) Experiment with door opened Fig. 3. Temperature measured during experiment return DB, no SG supply, no SG return DB, 6 mm SG_DB, 6 mm supply DB, 6 mm return DB, 8 mm SG_DB, 8 mm supply DB, 8 mm return DB, no SG supply DB, no SG return DB, 6 mm SG_DB, 6 mm supply DB, 6 mm return DB, 8 mm SG_DB, 8 mm supply DB, 8 mm

The water in the air will be absorbed by the silica gel as it passes thru them. This adsorption process is exothermic and makes air temperature increasing. Yet, the air humidity becomes less. This adsorption process experienced by the air is shown in Fig. 4. Data in Fig. 4 is an example for air passed thru (a) 8-mm silica gel when the door closed and (b) 6-mm silica gel when the door opened. The same trend will happen for other condition. The humidity ratio of the “return air” will decrease when it passes thru the silica gel and its dry-bulb temperature increase. Then, this “after-SG air” will flow thru cooling coil of the evaporator. It is cooled and becomes “supply air”. The

cooling process of the after-SG air to be supply air will produce less dew or condensate compare to cooling process from the return air to be supply air. When the door is opened during experiment, the humidity of the return PSYCHROMETRIC CHART air is higher than when the door is closed. The cooling coil works harder in Fig. 4 (b) than Fig. 4 (a). The condensate produced when the silica gel used is thicker, i.e. 8 mm. Thick silica gel that can absorb more water vapor. The cooling coil during experiment, the humidity ratio of the return air is shown in Fig. 5. When the door is opened, humid air enters the cooling coil and produce more condensate than when it is closed. Silica gel reduces the condensate because some of

water vapor in the air is already absorbed before reach **the**

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cooling coil. Less condensate produced when the silica gel used is thicker, i.e. 8 mm. Thick silica gel that can absorb more water vapor. The cooling coil during experiment, the humidity ratio of the return air is shown in Fig. 5. When the door is opened, humid air enters the cooling coil and produce more condensate than when it is closed. Silica gel reduces the condensate because some of

HUMIDITY RATIO - KILOGRAMS MOISTURE PER KILOGRAM DRY AIR

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10 after-SG air humidity ratio 0.08 supply air 0.15, 0.08% humidity ratio

HUMIDITY RATIO (or Specific Humidity) GRAMS OF MOISTURE PER KILOGRAM OF DRY AIR

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Example: 10 after-SG air humidity ratio 0.08 supply air 0.15, 0.08% humidity ratio. The cooling coil during experiment, the humidity ratio of the return air is shown in Fig. 5. When the door is opened, humid air enters the cooling coil and produce more condensate than when it is closed. Silica gel reduces the condensate because some of

properties and enthalpy deviation lines are for ice. Chart by: **HANDS** DaOffWerN-SSOGFTaWirARE, www.handsdownsoftware.com

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HUMIDITY RATIO (or Specific Humidity) GRAMS OF MOISTURE PER

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KILOGRAM OF DRY AIR

Factor E 20 ETB 60% -0,6 J M k E - C W 10 supply air , -08 U BIC 8 .008

HUMIDITY RATIO - KILOGRAMS MOISTURE PER KILOGRAM DRY AIR

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508,04% M E T E R P 1 E 0 6 .006 5 Fig. 4. The state of the air flowing in 0,8A2C with silica gel (b) 6-mm silica gel when the door is opened. Wet-Bulb 0 0,3 kJ 5 10% RELATIVE HUMIDITY 2 Dewpoint or Saturation ? ,76 0,4 kJ Temperature °C Dry-Bulb 4 0 -10 -5 0 5 10 15 20 25 30 35 40 ,000 Temperature °C Below 0°C,

properties and enthalpy deviation lines are for ice. condensate (liter) 3

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Chart by: HANDS DOWN SOFTWARE, www.handsdownsoftware.com

2 1 0 door closed door opened no SG 6 mm 8 mm Fig. 5. The condensate produced by cooling coil of the evaporator of the AC for two-hour experiment Fig. 6 (a) and (b) show the room dry-bulb temperature and its relative humidity (RH) when it returns to the AC from the room for door closed and opened, respectively. When the door was closed, the room temperature reached lowest when no silica gel used and the highest when 8-mm silica gel inserted in the AC. Opposite to that, room RH was the lowest when 8- mm silica gel used. Fig. 5 shows that the condensate produced when 8-mm silica gel used is the least. Silica gel used in this experiment had good performance, i.e. dry air, less condensate but higher air temperature. The same phenomenon also happened when the door was opened. Air temperature was the lowest when no silica gel used and RH was the lowest when 8-mm silica gel used before the cooling coil. The room conditions could be very different if the door is opened or closed. From Fig. 6 (a), the room DB temperature and relative humidity could be 21.0°C and 69%, respectively when the door was closed and no silica gel used. From Fig. 6 (b), it could be 27.4°C and 67.5% RH. The room DB temperature increased around 30% because of opening the door when no silica gel. When silica gel used, the room DB increased 16% and 14% for thickness of 6 mm and 8 mm, respectively. Room DB temperature in Fig. 6 (b) looks change rapidly. It is because outdoor air affects the room temperature. Opening the door could be considered equal to letting some fresh or outdoor air entering the room. From Fig. 6, it is found that silica gel affected the room temperature when the door was closed, but did not affect when the door was opened. The room temperature at steady condition changes 10.7% and 14.5% when 6-mm silica gel, and 8-mm silica gel used, respectively. While for opened-door condition, the room temperature changes only 1.2% and 1.1% for having 6-mm and 8-mm silica gel. door closed 29 90 27 85 room DB T (C) 25 80 23 21 RH 75 RH (%) 19 70 17 65 15 60 0 100 200 300 400 500 600 700 time (s) room DB, no SG room DB, 6 mm room DB, 8 mm RH, no SG RH, 6 mm RH, 8 mm (a) Experiment with door closed door opened 28 90 27 85 room, DB T (C) 80 26 RH 75 25 70 RH (%) 65 24 60 23 55 0 100 200 300 400 time (s) 500 600 700 room DB, no SG RH, no SG room DB, 6 mm RH, 6 mm room DB, 8 mm RH, 8 mm (b) Experiment with door closed Fig. 6. Comparison of room temperature when the AC with and without silica gel Though silica gel has a lot benefit, it has some disadvantage, too. Silica gel is easy to find and economically friendly. It is only Rp 45,000/kg with density around 700 kg/m³. The silica gel absorbs the water vapor in the air coming to the AC. The air flow rate decreases because the silica gel makes high pressure drop as shown in Fig. 7. The room DB temperature reduced much quickly when no silica gel used as shown in Fig. 6 (a). The low air flow rate produced by AC

makes the room temperature decreasing very slowly. It is a disadvantage of adding silica gel. Yet, the air relative humidity is lower when silica gel used is thicker. So, there is advantage and disadvantage of adding silica gel. Fig. 7. The effect of silica gel on air flow rate returning and supplying in AC As in Garden by The Bay, the electricity consumption for the AC with silica gel is also 3 return supply air flow (m/s) 2 1 2 0 electric consumption (kWh) no silica 6 mm 8 mclmlosed door 1.5 opened door 1 0.5 0 no silica 6 mm 8 mm less. Fig. 8 shows that the energy used to pump heat transfer from the air in the AC is less when the thick silica gel is used. For a closed-door experiment, the energy required is much less than for an opened-door experiment. When the door is opened, then fresh air will enter the evaporator. The fresh air is usually warmer than circulated air. Higher temperature entering the AC will make higher electricity consumption. The electricity consumption saving for inserting 8-mm silica gel is only 4% when the door is closed and 31% when the door is opened. Fig. 8. Comparison of electricity consumption for two-hour experiment The application of the result is that silica gel or other adsorbent can be inserted in fresh air grille before cooling coil of an Air Handling Unit (AHU) of a central air conditioning system. The silica gel or adsorbent will reduce the water vapor in the fresh air that is usually humid. Then, the air will transfer only sensible heat to the cooling coil. It will save electricity consumption for running the AC or AHU and chiller. Other suggestion is that the silica gel used combined with an absorption chiller [12]. When the air is humid and warm, silica gel can be used with an evaporative cooler (direct or indirect) to produce cool and dry air [11].

4 Conclusion

From the experiments conducted, the result are: ? The air humidity decreased and its temperature increased as it passed thru the silica gel either 6 mm or 8 mm thickness. The thicker the silica gel, the higher outlet air temperature from silica gel. This result were found during experiment both when the door closed or opened. ? Silica gel reduces the condensate because some of

water vapor in the air is already **absorbed** before reach **the**

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cooling coil. Less condensate produced when the silica gel used is thicker. ? Room temperature was the lowest when no silica gel used and the RH was the lowest when 8-mm silica gel used before the cooling coil. ? The room temperature changes only 1.2% and 1.1% for having 6-mm and 8-mm silica gel during opened-door experiment. Silica gel is suitable for reducing humidity of outdoor air. ? The electricity consumption saving for inserting 8-mm silica gel is only 4% when the door is closed and 31% when the door is opened.

References [1] ASHRAE, Fundamentals, ASHRAE (2001). [2] "WEATHER SPARK," Cedar Lake Inc., [Online]. Available: <https://weatherspark.com/y/124626/Average-Weather-in-Surabaya-Indonesia-Year-Round>. [Accessed on 19 July 2018] [3] ATELIER ONE, "Gardens by The Bay, Singapore "Cooled Conservatories, Supertrees & Aerial Walkways", Singapore (2013). [4] Patrick Bellew RDI FEng, "Singapore's Supertrees," INGENIA ISSUE 58, pp. 25- 31 (March 2014). [5] V. MITTAL and B. K. KHAN, "Experimental investigation on desiccant air-conditioning system in India," Front. Energy Power Eng. China 2010, 4(2), p. 161– 165 (2010). [6] Y. Yadav, " system for energy conservation," Renewable Energy, vol. 6, no. 7, p. 719–723 (1995). [7] A. GAGLIANO, F. PATANIA,, F. NOCERA and A. GALESÌ, "Performance Assessment Of A Solar Assisted Desiccant Cooling System," Thermal Science, vol. 18, no. 2, pp. 563-576 (2014). [8] D. Jani, M. Mishra and P. Sahoo, "Experimental investigation on solid desiccant - vapor compression hybrid air-conditioning system in hot and humid weather," Applied Thermal Engineering, vol. 104, p. 556–564 (2016). [9] G. Ding, X. Chen, Z. Huang, Y. Ji and Y. Li, "Study on model of household split air conditioning solution dehumidifier," Applied Thermal Engineering, vol. 139, p. 376– 386 (2018). [10] M. Khoukhi, "A Study of Desiccant-Based Cooling and Dehumidifying System in Hot-Humid Climate," International Journal of Materials, Mechanics and Manufacturing, vol. 1, no. 2, pp. 191 - 194 (2013). [11] M. Sultan, I. I. El-Sharkawy, T. Miyazaki, B. B. Saha and S. Koyama, "An overview of solid desiccant

dehumidification and air conditioning systems,” *Renewable and Sustainable Energy Reviews*, vol. 46, p. 16–29 (2015). [12] D. La, Y. Dai, Y. Li, R. Wang and T. Ge, “Technical development of rotary desiccant dehumidification and air conditioning: A Review,” *Renewable and Sustainable Energy Reviews*, vol. 14, p. 130–147 (2010).