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Desiccant-based air dehumidifier and cooling system

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Desiccant-based air dehumidifier and cooling system

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Abstract. Air conditioning system plays a vital role in providing convenient environment for human. Many studies conducted on the efficiencies of the air conditioners operating under vapor compression cycle (VCC), however, only few recent studies conducted to analyse the indoor humidity efficiencies. In this research, silica gel, zeolite, and molecular sieve as solid desiccants were experimented to observe their adsorption ability to identify the suitable desiccant material for dehumidification for air conditioner. It was noted that silica gel adsorbs 48% of water during the experiment making it to be the best adsorbent. The highest water adsorption capability by silica gel motivated this research to conduct numerical method to analyse its performance in the desiccant wheel system. The density, thermal conductivity, and specific heat capacity of silica gel used at the desiccant channel region on the geometry. The numerical results showed that the suitable regeneration temperature to reactivate silica gel is 35 °C with thermal effectiveness of 0.375. Silica gel has dehumidification efficiency of 85% and moisture removal capacity of 2.571×10^{-4} g/s. This system can be a potential trademark for HVAC industries to innovate pollutant-free systems because SDCS does not release any harmful coolants such as chlorofluorocarbon and hydrochlorofluorocarbon to environment.

1. Introduction

The increase in Earth population has made energies to become more demanding for many applications. As growth rate increases, high volume of energy is required to operate more machines for humans and industrial application for daily lives utilization. Busy lifestyle has made nations to be more competitive and several tasks are expected to be performed at the same time. Tiredness and sweat cause people to be uncomfortable and the only thing that comes into their mind is to turn on air conditioners. Therefore, it is imperative that the cooling framework of air conditioner should be analysed, whilst also taking the thermal comfort into concern. Air conditioner has become one widely used innovation by humans in local and modern location to obtain good thermal comfort. The fact that air conditioners have been serving well for humans to provide proper indoor air quality cannot be denied but there are some critical problems that must be taken more concern by Heating, Ventilation, Air Conditioning (HVAC) industries to make them more viable.

Based on American Society for Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), good indoor air quality refers to air without contaminants and when more than 80% of people exposed to that air do not feel dissatisfaction [1]. Good indoor air quality safeguards the health of the building occupants and contributes to their comfort and well-being. The Industry Code of Practice has been set up to ensure occupants are protected from poor indoor air quality that could adversely affect their health and well-being [1].

One of the problems is that the air conditioners could not rely on fossil fuels anymore to obtain power source in the next few decades due to the declining trend of fossil fuel availability [2]. This can be a potential reason for the drop of air conditioners production in the upcoming years. Based on Load and Household Profiles Analysis for Air Conditioning and Total Electricity in Malaysia, 50% of the total electrical sources are used only for air conditioners which is operating under vapor compression cycle (VCC) [3, 4]. The operating cost of vapor compression cycle (VCC) is expensive as the power source are from limiting source of fossil fuels. According to Malaysian Air Conditioning and Refrigerant Association (MARCA), air conditioners market gains an average of RM 150 million on monthly sales [4, 5]. Therefore, air conditioners are facing high competition being in this profitable industry for the past decades. This scenario become worse when most of air conditioners sector nowadays are spoilt by the different type of brands and less concern were taken to analyse the power consumption of its system.

There are some limitations in the vapor compression cycle (VCC) which urge the researchers to find a better replacement for cooling system. One of the problems in vapor compression cycle is that its system has been consuming high volume of electrical energy to operate air conditioners [6, 7]. This is because VCC could not reduce the cooling load by dehumidification, instead it only uses up power to cool down surroundings by coolants. Besides that, VCC system has also been a major factor for the discharge of carbon dioxide (CO_2), and ozone depletion substances such as Chlorinated Fluorocarbon Compounds (CFCs) and hydro chlorofluorocarbons (HCFCs) which is considered as potential ozone draining gases [8, 9]. These ozone depletion coolants can indirectly cause skin diseases and asthma for users over long term. High concentration of these coolants is potential to lower the quality of indoor air. A part of it, VCC has caused some major loss for air conditioner users due to rotting on surrounding furniture especially when surrounding relative humidity exceeds 60% [10, 11]. This happens because the system could not control the environment's humidity and temperature separately. High humidity causes high amount of water vapor in the air which promotes the growth of mold on furniture and cause user's furniture to rot because VCC could not control the indoor humidity and temperature separately [12, 13].

The aim of this research paper is to propose an economical cooling framework for indoor environment purposes. This can be done by innovating a cooling system which has the capabilities to reduce the indoor humidity and temperature at the same time. One promising idea came up by researchers to provide better cooling quality is by using Solid Desiccant Cooling System (SDCS) [14, 15]. SDCS requires the use of solid desiccant materials to adsorb the indoor moisture to keep indoor humidity under control by dehumidification process [16, 17]. Dehumidified air can provide dry and cool air to indoor surrounding and at the same time, reducing the risk of rotting the indoor furniture [11]. SDCS is also able to reduce the energy cost by air conditioners because this system will be operated only under thermal heat which is from the processed ambient air [18]. As the dehumidification done by SDCS will remove moisture, it will also be able to cool down the surrounding air to a certain extent. This will reduce the need of cooling because the indoor will be more comfortable than usual condition. This will reduce the workload of the air conditioner to run than the usual. So, the air conditioner will be able to reduce power consumption by cutting the running cost. This research also aims to investigate the performance of different desiccant material in the solid desiccant cooling system framework and propose the best desiccant for this cooling system by conducting simulation. In addition to that, SDCS does not require refrigerant which is another bright side of this system. Therefore, high energy is not required to compress any refrigerant to the system for cooling purposes.

2. Literature Review

Figure 1 shows a solid desiccant cooling system with desiccant wheel which is used to dehumidify the air. The wheel consists of desiccant material that rotates in a slow speed, a heater and drive motor [19]. Ambient air(humid) flows through the process air section during which the moisture content of the air will be adsorbed by the desiccant material. In this process, the temperature of air rises slightly since the adsorption process on the wheel releases heat [20, 21]. As results, this causes the process air leaves the wheel with lower humidity. The hot reactivation air from the heater flows through the air channel in the wheel in opposite direction of the ambient air [22]. The purpose of regeneration air in the system is to regenerate the desiccant material overtime for continuous adsorption process to occur. In conjunction with this scenario, the water vapor that exist on the desiccant surface is absorbed by the hot air stream which involves heat transfer [23]. Therefore, the regeneration air exists the wheel with higher humidity and slightly lower temperature. This will allow the desiccant material to be dry and ready for new process of adsorption [23, 24]. The above sequence is repeated since the wheel is rotating slowly. There is a small compressor in the system to compress the water vapor from the ambient air into the condenser. The condenser acts as a heat exchanger to convert the ambient air into liquid by condensation before transferring it to the desiccant wheel for dehumidification process.

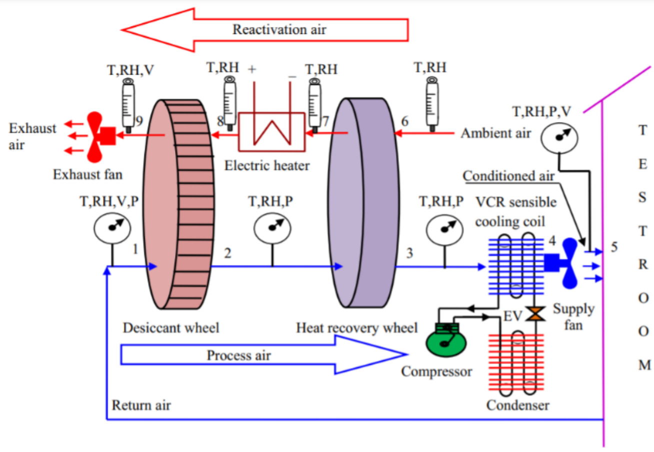

Figure 1. Solid Desiccant Cooling System (SDCS) viewed in detail from household units [12].

There were significant progresses that have been made along the investigation on the efficiency and cost effectiveness of SDCS, but still there are some limitations in this research which need to be addressed. It was noticeable that the thermal sensation of solid desiccant cooling system users was not investigated deeply. Thermal sensation is the condition of mind that expresses personal satisfaction of users with thermal environment. Accessing thermal sensation level from this technology towards users could help to improve the reliability of this research [18, 19]. This could help this research further in studying users' physiological changes with different temperature. Besides that, more experiments should be carried out on solid desiccant products which has special characteristics in giving better moisture absorption capability. This is to improve the activity of solid desiccant materials in air conditioning system [17, 18]. For example, innovation of desiccant products with smaller surface tension will improve the wetting process on the surface which is in contact with the desiccant wheel during the cooling framework by air conditioners.

High liabilities problems that have been arisen from large scale industries has motivated this research paper. Based on Load and House Profile Analysis for Air Conditioning and Total Electricity in Malaysia, many owners recently faced problems paying their electricity utilities due to low overall income by families especially during this pandemic [3]. Therefore, this system can be a potential trademark for users who are looking to get a better cooling quality with low electricity consumptions. This dehumidification system supported by the desiccant products can be a potential method to save electrical cost for heavy scale industries in production line who need air conditioner operating for long hours.

3. Research Methodology

The methodology of the research mainly focuses on experiments. There are few defsiccant materials chosen for experimental purpose in this research which are silica gel, zeolite, and molecular sieve. These desiccant materials were chosen because it has good consistency in water adsorption process based on literature reviewed. In addition to the experiments, the current research involves experiments and numerical simulations to analyse the performance of the solid desiccant materials for dehumidification purposes.

3.1. Experiment Conductions

The purpose of the experiment is to analyse the water adsorption of silica gel, zeolite, and molecular sieve before proposing one best material for air conditioner to achieve proper dehumidification. The environmental temperature and humidity factor were taken into consideration during this experiment. The experiment was conducted in room temperature (25 °C) and relative humidity of 45%.

3.1.1. Materials

The apparatus and materials that were utilized for this experiment are distilled water (50 mL), beaker (100 mL), digital analytical balance, meshed filter, box, cloth. Silica gel (98.9 g, 1-2mm, CHEMSOLN), zeolite (98.9 g,3-6mm, CHEMSOLN), molecular sieve (98.9 g, 2-5mm, CHEMSOLN) was purchased from Synertec Enterprise. 50mL of distilled water was considered as an optimum volume for the silica gel, zeolite, and molecular sieve to adsorb enough water throughout the experiment.

3.1.2. Procedures

There are few important procedures that was taken during the experiments to obtain the most reliable results for this research. The silica gel was chosen as the first sample to be tested in this experiment. Firstly, the weight of the petri dish was measured by using the digital analytical balance. Secondly, 50mL of distilled water was poured into the beaker and its weight was measured again by using the analytical balance. The amount of distilled water used to test the adsorption process of the desiccant materials remained the constant variable in this experiment. Thirdly, the weighted silica gel was place on the mesh filter. Fourthly, the beaker filled with distilled water was placed beneath the silica gel which was on the filter for adsorption process to take place. The weight of the distilled water was recorded for 45 minutes with 5 minutes of time interval. Lastly, the percentage of water adsorbed by the silica gel through the adsorption process has been calculated. Those procedures were repeated for zeolite and molecular sieve. Figure 2 shows the experimental setup for this research when experimenting silica gel.

Figure 2. The experimental setup of the research for silica gel.

3.1.3. Findings

The amount of water adsorbed by silica gel, zeolite, and molecular sieve from the experiment are shown in Table 1, Table 2, and Table 3 respectively.

Table 1. Percentage of water adsorbed by silica gel.

Time (minutes)	Weight of distilled water with beaker(g)	Amount of water loss(g)	Percentage of water loss (%)
5	110.382	0.360	36.0
10	110.363	0.379	37.9
15	110.342	0.400	40.0
20	110.326	0.416	41.6
25	110.311	0.431	43.1
30	110.297	0.445	44.5
35	110.285	0.457	45.7
40	110.273	0.469	46.9
45	110.258	0.484	48.4

Table 2. Percentage of water adsorbed by zeolite.

Time (minutes)	Weight of distilled water with beaker(g)	Amount of water loss (g)	Percentage of water loss (%)
5	110.636	0.109	10.9
10	110.522	0.220	22.0
15	110.507	0.235	23.5
20	110.393	0.349	34.9
25	110.378	0.364	36.4
30	110.367	0.375	37.5
35	110.352	0.390	39.0
40	110.338	0.404	40.4
45	110.323	0.419	41.9

Table 3. Percentage of water adsorbed by molecular sieve.

Time (minutes)	Weight of distilled water with beaker(g)	Amount of water loss (g)	Percentage of water loss (%)
5	110.494	0.248	24.8
10	110.432	0.310	31.0
15	110.411	0.331	33.1
20	110.391	0.351	35.1
25	110.375	0.367	36.7
30	110.354	0.388	38.8
35	110.334	0.408	40.8
40	110.313	0.429	42.9
45	110.293	0.449	44.9

The performance of silica gel, zeolite and molecular sieve experimented in this research were analysed by the water adsorption capability. The percentage of water adsorbed by silica gel, zeolite, and molecular sieve throughout the experiment was investigated and discussed on Figure 3. The figure shows the amount of water adsorbed by the desiccant materials from the experiment.

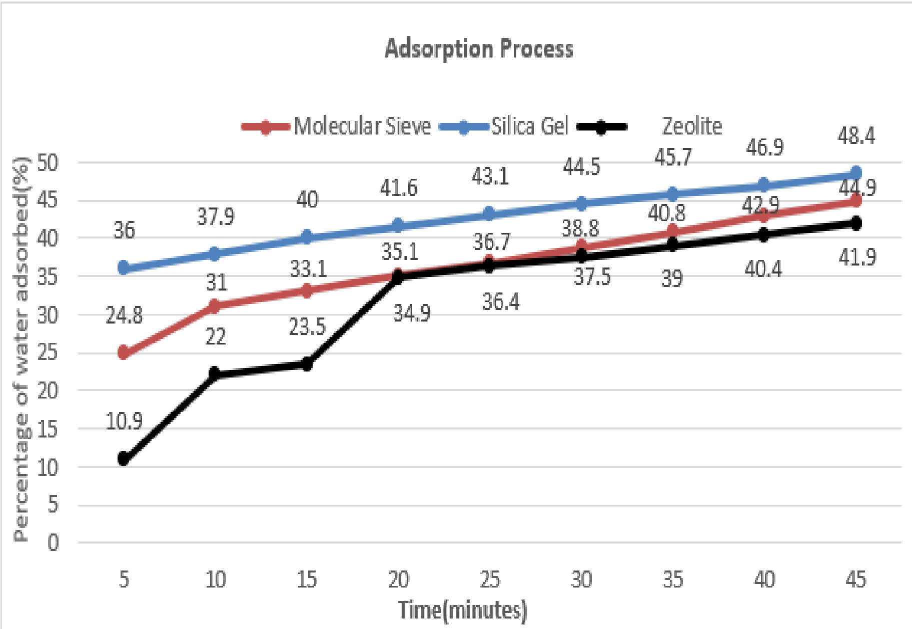

Figure 3. Amount of water adsorbed by desiccant materials.

Based on Figure 3, silica gel adsorbed the highest amount of water over the 45 minutes ,48.4% from the initial mass of water throughout the experiment. There is significant increase in the percentage of water adsorbed by the silica gel in the first 10 minutes of the experiment. It can clearly be seen that water adsorption rate of the silica gel is constant throughout the experiment because of its smooth line of curve. Molecular sieve had adsorbed 44.9% of water throughout the experiment at the end of 45 minutes. Based on Figure 3, molecular sieve had adsorbed higher amount of water compared to silica gel at higher rate between the 5^{th} -10^{th} minute interval. The line increases with the constant rate overtime. However, the final amount of water adsorbed by molecular sieve is still lowfer than silica gel at the end of 45 minutes. Zeolite also has significant increase in the amount of water adsorbed at the 5^{th} to 10^{th} minutes interval with higher rate compared to silica gel and molecular sieve. The line of water adsorption of zeolite is inconsistent at the first 20 minutes of the experiment. The adsorption process stabilizes from the 20^{th} minutes onwards. Zeolite has the lowest amount of water adsorb over 45 minutes, 41.9%. Therefore, based on the analysis made from Figure 3, it is clearly proven that silica gel is the best performing adsorbent for dehumidification purpose by achieving higher water adsorption capacity compared to molecular sieve and zeolite. Silica gel is the best product for dehumidification because it is made up from the synthesis of sodium silicate which is processed to produce gel. Silica gel is coated with a vapor-permeable plastic which results in a versatile dehumidifying agent.

3.1.4. Physical Properties

Based on the observations made from experimenting silica gel, zeolite, and molecular sieve, there are some physical differences occurred on these materials after adsorption process takes place. Figure 4 shows the silica gel, zeolite, and molecular sieve respectively after adsorption process has taken place. Based on Figure 4, silica gel turns its colour from dark blue to light blue and pinkish for some particles. This happens because the silica gel absorbed water into its surface through adsorption. Meanwhile, there is almost no changes on the physical properties of zeolite and molecular sieve as depicts in Figure 4.

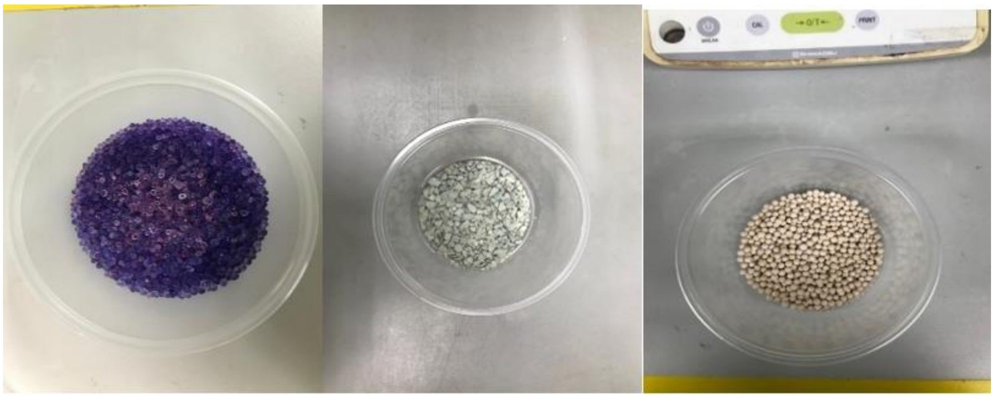

Figure 4. Physical properties of silica gel, zeolite, and molecular sieve after adsorption process.

3.2. Numerical Method

Silica gel is chosen to perform numerical solution because it has the highest water adsorption based on the experiment conducted and is believed that it could provide good performance in dehumidification. A 2D CAD model of air channel from the desiccant wheel in the solid desiccant cooling system is constructed using Design Modular in ANSYS software. Air channels represent the cross section of the desiccant wheel where the dehumidification process takes place. The purpose of numerical solution is to investigate on the performance of silica gel on the wheel with different regeneration temperature. The dimensions used for this air channel was considered based on Zhang and Niu's theory [24]. Table 4 shows the properties of silica gel that was used in the numerical method. There were 4 assumptions made during the simulation process (1) Dry air and water vapor are treated as ideal gases, (2) The kinetic and potential energy are assumed to be negligible, (3) The entire process is one-dimensional flow, and (4) The desiccant wheel is a steady flow process, therefore mass flow rate of dry air remains constant throughout the entire process.

Table 4. Properties of silica gel used in numerical solution [13].

Properties	Specification
Density (kg/m^3)	790
Thermal Conductivity (kWm^{-1}K)	1.98×10^{-4}
Specific Heat Capacity (kJ kg^{-1}K)	0.921
Porosity, ε	0.5
Adsorption Heat(kJ/kg)	2362
Maximum water uptake of desiccant(kg/kg)	0.40
Constant in adsorption curve, C	1.1

3.2.1. Geometry

The length of the air channel is 100 mm, thickness of desiccant wall which is at the upper and lower boundary of the model is 0.15 mm, and height of the air channel is 1.8 mm [24]. The geometry of the air channel was made according to dimensions provided by Zhang et al. In this reseacrh paper, the top and bottom wall of the air channel was assigned as the silica gel region, in which the properties of silica gel was included under that region in the ANSYS Fluent software. There is an inlet air flow of 1 m/s at the inlet of the air channel. After the air channel geometry was constructed, the boundaries were named as inlet and outlet with the upper and lower boundary(desiccant channel) assigned as wall. Figure 5 shows the geometry of the air channel contructed using Design Modular under the geometry section of the schematic. Figure 6 shows the screenshot of geometry's dimension details.

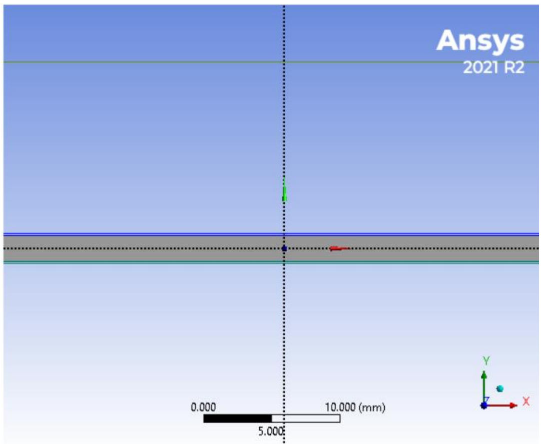

Figure 5. Air channel of desiccant wheel.

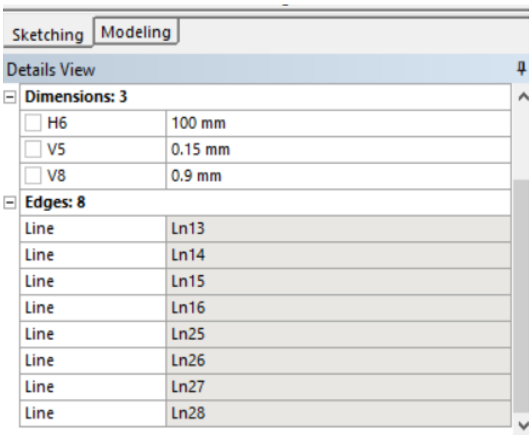

Figure 6. Screenshot of dimension used for the air channel.

3.2.2. Meshing Method

The chosen mesh method was triangle method with body sizing of 6.5×10^{-5} mm. Default mesh size is set at 3.25×10^{-5} mm, the desiccant channel, which is the upper and lower boundary of the air channel underwent refinement with inflation growth rate of 1.2. 6.5×10^{-5} mm of body sizing for the air channel is chosen after conducting the grid independent test (GIT). The purpose of conducting GIT is to establish the number of elements that can minimize the effect of meshing on the simulation results. The mesh size was made as small as possible to increase the resolution. Figure 7 shows the 2D CAD model of the air channel geometry that was constructed for this research. Figure 8 shows the geometry of the air channel after performing triangular meshing method with 6.5×10^{-5} mm of body sizing.

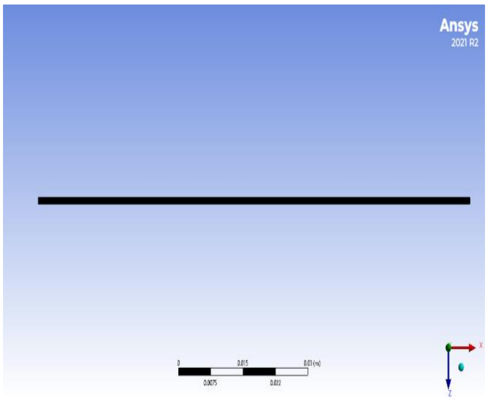

Figure 7. 2D CAD model of the air channel.

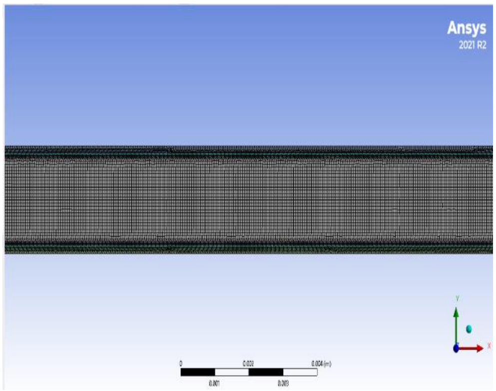

Figure 8. Meshing view for the air channel.

3.2.3. Boundary Conditions

The indoor temperature is set to be 30°C(300K) when it is warm. The inlet moisture content is 23.25 g/kg of dry air, and its velocity of process air is also assumed with 1 m/s based on Zhang et al. theory. Figures 9 and 10 show the inlet and outlet boundaries assigned on the air channel geometry respectively. Figure 11 and Figure 12 show the process air region and desiccant region assigned on the air channel geometry respectively. Table 5 shows the inlet boundary condition set for the numerical solutions.

Table 5. Boundary condition assigned at the air channel.

Parameters	Specification
Process air inlet temperature, $T_{a\ inlet}$ (K)	300
Process air inlet velocity, u (m/s)	1
Process air inlet moisture content, ω_1(g/kg)	23.25

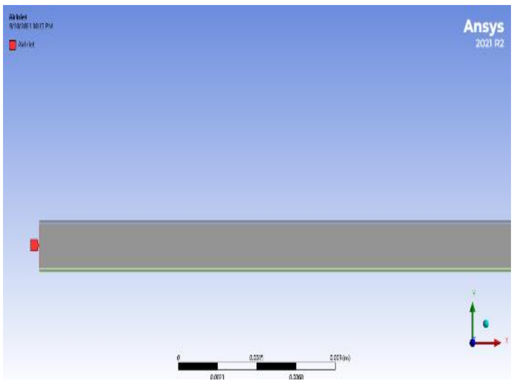

Figure 9. Inlet process air region.

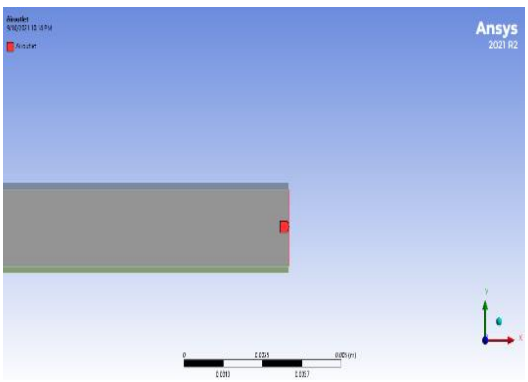

Figure 10. Outlet Process air region.

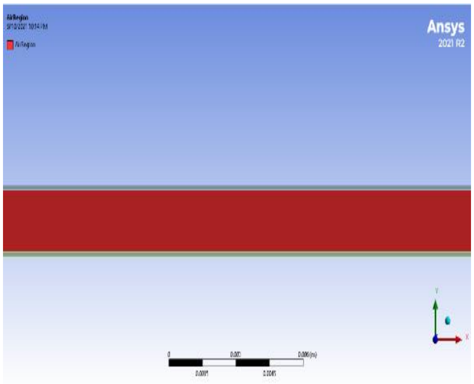

Figure 11. Process air region geometry.

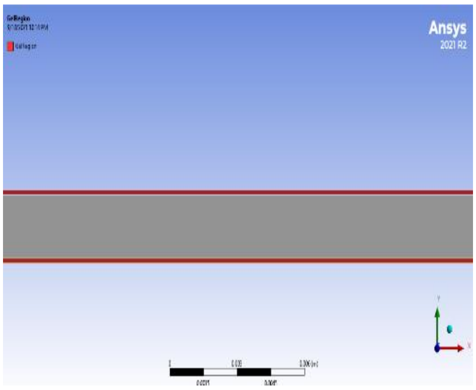

Figure 12. Desiccant region geometry.

4. Results and Discussions

There are three main factors that were accessed to evaluate the performance of the solid desiccant cooling system, which are thermal effectiveness, ε_t dehumidification efficiencies, η_{Dh} and moisture removal rate, $\dot{m}_w$ of the silica gel. Equation (1) shows the thermal effectiveness of the system [24]. Equation 2 shows the dehumidification efficiencies of the system [24]. Equation 3 shows the moisture removal capacity of the system [24]. T_1 is the dry bulb temperature, 300K that was set as inlet temperature and T_2' is outlet temperature which is obtained from the numerical solution. T_3 refers to regeneration temperature for the system to reactivate the silica gel for continuous water adsorption process, to be precise dehumidification. Since regeneration is not being considered in the simulation, therefore the benchmark of the minimum regeneration temperature, T_3 that was set is from 35°C to 50°C. ω_1 is the moisture content that was assigned as boundary condition at the inlet of the air channel geometry. The ω_2' is the moisture content obtained at the outlet from the numerical solution. The $\omega_{2,ideal}$ is the ideal moisture content required by the system in a certain indoor temperature. Therefore, $\omega_{2,ideal}$ is taken from psychometric chart according to the dry bulb temperature, T_1(300K) and ideal relative humidity as 45% based on Daikin Malaysia.

$$\varepsilon_t = \frac{(T_2' - T_1)}{(T_3 - T_1)} \ldots \quad (1)$$

$$\eta_{Dh} = \frac{(\omega_1 - \omega_2')}{(\omega_1 - \omega_{2,ideal})} \times 100 \ldots \quad (2)$$

$$\dot{m}_w = \dot{m}_a (\omega_1 - \omega_2') \ldots \quad (3)$$

$$\dot{m}_w = \rho V A (\omega_1 - \omega_2') \quad (4)$$

4.1. Thermal Effectiveness of system

Figure 13 shows the humidity obtained near the outlet end of the air channel. Figure 13 shows the temperature obtained near the outlet end of the air channel. The air temperature is higher, 303 K at the silica gel region because heat is released through the adsorption process as can be seen in Figure 13.

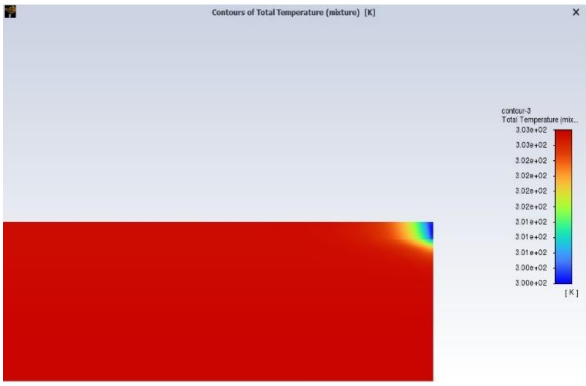

Figure 13. Thermal effectiveness of silica gel.

Table 6 shows the data calculated to analyse the performance of silica gel in the system. The thermal effectiveness was calculated using equation (3). Thermal effectiveness is the ability of the air in the dehumidifier unit in the system to remove the sensible heat from the incoming process air. Figure 14 shows the effect of regeneration temperature (°C) against the system's thermal effectiveness (%) that we plotted using the calculated values shown in Table 6. Based on Figure 14, the thermal effectiveness decreases as the regeneration air temperature increases. This process is totally depending on the temperature difference between the silica gel in the desiccant wheel and the process air. When the regeneration air temperature increases, the temperature difference available in the system is smaller. Therefore, the thermal effect of the regeneration temperature (°C) against the system's thermal effectiveness of the unit drops. Based on the numerical method performed for regeneration temperature of 35°C: T_1 = Dry bulb temperature, T_2' = Outlet temperature, which is obtained from the numerical solution, and T_3 = Regeneration temperature for the system, then

$$\varepsilon_t = \frac{(303-300)}{(308-300)} = 0.375$$

Thermal effectiveness analysis was performed by using different regeneration temperature (40 °C, 45 °C, 50 °C):

Table 6. Thermal Effectiveness assessment.

T_3 (°C)	Thermal effectiveness, ε_t
35	0.3750
40	0.2308
45	0.1667
50	0.1304

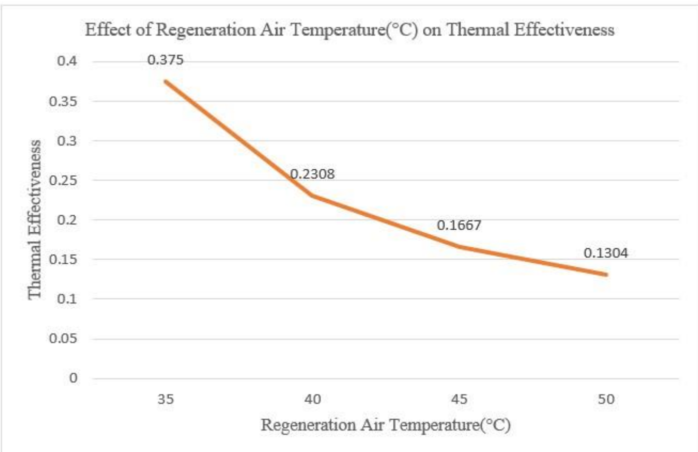

Figure 14. Thermal Effectiveness of solid desiccant cooling system.

4.2. Dehumidification Efficiency of system

Dehumidification efficiencies is the measure on the ability of silica gel to remove moisture from the process air that passes through it in this research paper. It's ability to dehumidify air is affected by the temperature difference between the silica gel and the process air. It will be effective to implement a dehumidifier unit with high dehumidification efficiency in an air conditioning system to reduce the latent heat load of the system. This will be an economical cooling framework whereby it will help to save energy when it operates.

The values of ω_2' was directly taken from the numerical solution performed. Figure 15 shows that the silica gel has 14.1g/kg at the outlet end of the air channel geometry. This shows that silica gel has worked effectively in removing moisture from the inlet by adsorption process. The mass fraction of water vapor(humidity) in the process air region (blue region) is low, 2.6 g/kg because the moistures were adsorbed by the silica gel in the air channel which had made the mass fraction of silica gel (red region) to be higher,14.1g/kg. This analysis has proven that silica gel is able to adsorb significant amount of moisture in this system by reducing the mass of water vapor in the indoor environment. $\Omega_{2,ideal}$, 6.666 g/kg which was taken from psychometric chart using the boundary condition set, T (300 K) and its ideal relative humidity, 45% as suggested by Daikin Malaysia. Therefore, these values are used to evaluate the dehumidification efficiency, η_{Dh}, of the system using equation (2).

$$\eta_{Dh} = \frac{(\omega 1 - \omega 2')}{(\omega_1 - \omega_{2,ideal})} \times 100 = \frac{(14.1)}{(23.25 - 6.666)} \times 100 = 85\%$$

where ω_1=Inlet specific humidity, $\omega_{2,ideal}$= Ideal humidity for proper cooling, (RH=45%).
(Note: ω_1 - ω_2' = Amount of water adsorbed at the desiccant channel obtained from numerical solution)
The calculation shows the silica gel has the dehumidification efficiency of 85%. This means that silica gel can dehumidify 85% of the outdoor moisture content effectively.

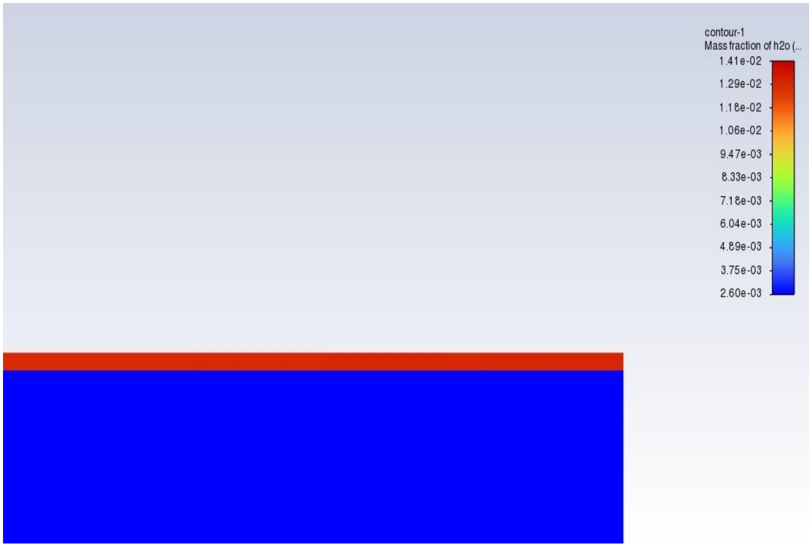

Figure 15. Amount of water adsorbed by silica gel.

4.3. Moisture Removal Capacity (MRC)

Based on Figure 16, the pressure is relatively lower on the desiccant region, -1.97×10^{-1} because the adsorbed water vapor from the process air region is still embedded on the surface of the silica gel. Therefore, the temperature on the silica gel region is expected to be lower because of high moisture concentration on that region. However, the temperature raises due to the released heat by silica gel during the adsorption process.

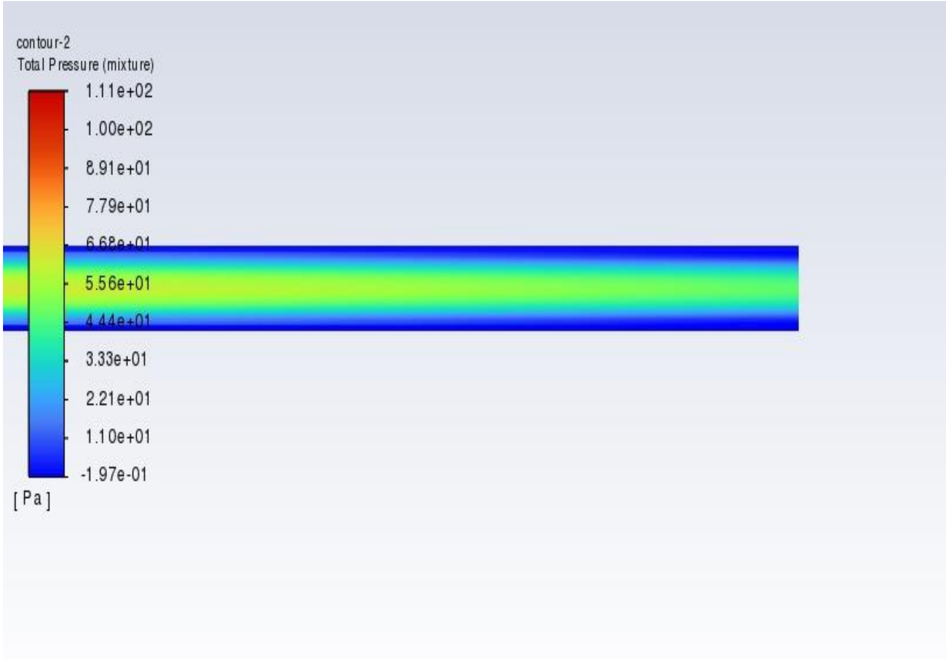

Figure 16. Pressure on the air channel geometry.

The moisture removal capacity (MRC) is also calculated as it is considered an important parameter to access the performance of silica gel in the desiccant system. The moisture removal rate is calculated as shown below:

$$MRC=\rho VA\ (\omega_1 - \omega_2') = (1.225)\ (6.5)\ (2.29\times10^{-6})\ (14.1) = 2.571\times10^{-4}\ \text{g/s}$$

where ρ = Density of air, kg/m^3, V=Velocity of air, m/s, A=Cross sectional area of air channel geometry, m^2
(Note: $\omega_1 - \omega_2'$ = Amount of water adsorbed at the desiccant channel obtained from numerical solution)

4.4. Validation of Numerical Method

The numerical model was validated by comparing the air temperature at the end of the air channel with the numerical solution performed by Zhang and Niu [24]. For this purpose, the dimension of the air channel, inlet moisture content, the properties of silica gel were set same as suggested by Zhang et al. This numerical solution in this research was only done for adsorption process. Theoretical assumptions were made for the regeneration temperature, T_3 by the heater in the system to calculate the thermal effectiveness of SDCS. Although the outlet temperature obtained from the numerical solution in this research are slightly different [24], however the trend of the results is the same which proves the numerical solution results were acceptable.

5. Conclusion and Future Works

As a conclusion, it is proven the silica gel is the best performing desiccant in term of removing water vapor for in the indoor environment based on experiment conducted. Silica gel can reduce the humidity by lowering the mass fraction of water vapor at the outlet of the desiccant wheel from 23.25g/kg to 14.1g/kg by adsorption process. Based on the analysis conducted from the numerical method, it can be concluded that as the regeneration temperature for silica gel decreases, the thermal effectiveness of the system increases. The lower the humidity achieved by silica gel at the outlet of the air channel geometry, the higher the dehumidification efficiency that can be achieved by the system. Even though this silica gel has proven to be the best material in adsorbing water from the experiment, more initiative will be taken to perform numerical method for zeolite and molecular sieve to make a more accurate comparison on their performance on the air channel.

There are some improvements that can be made in future to make sure this system achieves a good business value in market. One prominent method is by insulating the desiccant wheel to reduce the heating effect inside the system [9]. This is important because the rotating desiccant wheel will release heat over long run. Therefore, fixing insulation around the wheel can prevent the heat from escaping and cause short circuit on the other components in the system such as the compressor and the heater which play an important role for the air conditioner to serve cooling and dehumidification purposes.

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