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Design of solid desiccant air conditioning system

by Dendi Adi Saputra

Design of solid desiccant air conditioning system

Design of solid desiccant air conditioning system

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Abstract. Currently, solid desiccant air conditioning system (SDACS) is an alternative to utilize solar energy to resolve environmental and energy issues resulting from the use of conventional vapor compression of air conditioning systems. SDACS can maintain the thermal comfort of a room with optimization of solar thermal energy and minimal use of electrical power. Present work in this paper is to design a solid desiccant air conditioning system of a closed room with 18 m^3 of total volume. The desiccant wheel is used to dehumidify air in the room, and evaporative cooling will be decreasing the temperature of the air. The result shows the lower temperature can be reached 24^0C.

1. Introduction

Indoor work trend increases at this time. The elevations of information technology utilization make people can do their work without leaving their room/house. It causes an increased requirement for indoor thermal comfort standards for workers/employees who perform activities. Thermal comfort standards are met by using the air conditioning machine (AC) which is one of the widely used solutions.

Currently, the use of air conditioning machine still uses vapor compression refrigeration system which requires significant electrical energy consumption. Energy requirements for air conditioning machines are predicted increase due to the rising standard of comfort and global warming issues. Isaac et al. [1] have predicted energy requirements for cooling systems in the world building, which will increase energy requirement about 4000 TWh in 2050 and will continue to 10,000 TWh in 2100. Thus, the renewable energy utilization to fulfill the energy requirement for cooling/air conditioning system needs to be done.

From several alternatives of renewable energy that can be harnessed, solar energy is the best alternative renewable energy that can be used. Solar energy can be used as a source of energy for air conditioning systems in two ways: through the process of converting solar energy into electrical energy and process for direct utilization of the solar energy. In the first process, the use of photovoltaic cells in solar energy utilization will convert solar energy into electrical energy, and then electricity will be used to operate the conventional vapor compression system in air conditioning system. With this system, simple construction and high efficiency are the main advantages. However, high investment

costs for equipment and energy storage media (battery) and limited cooling during the day cause lack of technology implementation.

In the cooling system driven by solar heat, the solar heat is collected through a solar collector which is used to produce mechanical energy to compress the refrigerant vapor in a conventional vapor compression system or as a heat source for the generator to the cooling system of the sorption (absorption). The utilization of solar energy through thermal processes provide greater economic returns than the use of solar energy through solar cells (photovoltaic). It is because of the ability to provide the maximum cooling effect when the maximum input of solar radiation occurs at the same time. When the moment of the small size of solar radiation so the cooling load will be low, and thus no requirement for a large thermal storage tank to overcome the influence of the season. [1]

2. Literature Review

2.1. Solid desiccant air conditioning systems

The solid desiccant cooling system operates based on the open sorption cycle with adsorption working principles by absorbing water vapor contained in the air, and then the dry air is lowered to room temperature by using a sensible heat exchanger and cooling coil. The air conditioning system required a desiccant wheel to carry out an absorption process which consists of small hexagonal channels to form honeycomb formation. The desiccant wheel is continuously spinning very slowly through two separate airflows [5]. The first stream is air flow process which dehumidifiers by desiccant and the second flow are air flow regeneration or reactivation. Air temperature reactivation of silica gel rang from 50 - 160 °C. In the visualization, the principle of the solid desiccant cooling system is shown in Figure 1.

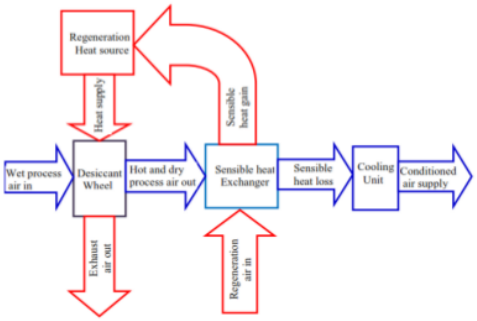

Figure 1. Working principle of solid desiccant cooling system [2]

2.2. The Cycle of Desikan

All desiccant function is in the same way by movement of water vapor. It caused by the difference between the surface pressure of water vapor and the around water pressure. When the vapor pressure at the surface is lower than air, the desiccant will bind moisture. When the surface pressure of water vapor is higher than the surrounding air, the desiccant will release water vapor.

After desiccant is dried (reactivated) with the heat, the vapor pressure becomes high, so the ability to absorb water vapor becomes small. When the desiccant is cooling down, it will reduce surface pressure so that it can absorb more water vapor. The full cycle is shown in Figure 2.

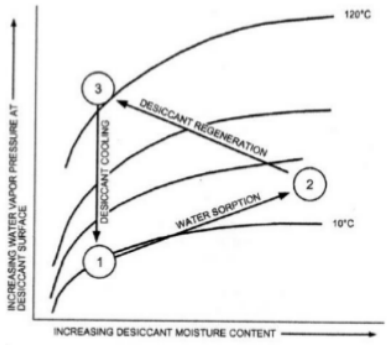

Figure 2. Desiccant regeneration cycle [6]

2.3. Heat Exchanger

The heat exchanger is a device for transfer energy due to temperature changes that can function as a heater or cooler. The heat exchanger is designed to perform heat transfer functions between fluid can take place efficiently. Heat transfer occurs due to direct or indirect contact.

2.4. Evaporative Cooler

Evaporative cooling process occurs when water vapor is added to the air which has a relative humidity below 100%. The relative humidity is a quantity that depends on the temperature of the dry and wet ball from the air. If the relative humidity is going low, so the potential for evaporative cooling will be greater. Evaporative cooling process can be seen in Figure 3.

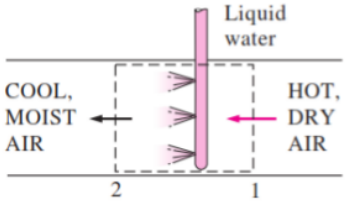

Figure 3. Evaporative cooler [7]

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As described in the introduction, this study aims to (1) design solar power solid desiccant air conditioning system based on the criteria of thermal comfort in indoor, (2) determining empirically operational conditions optimum for the system designed and (3) technical evaluation prototype based on the requirements of thermal comfort. For the second purposes a test will be carried out, and the information from test result is used to determine the optimal operating conditions.

This study begins by determining the design concept of solar power solid desiccant air conditioning systems, design specifications, the components characteristics, layout, analysis (using heat transfer concept and thermodynamics), component determination obtain the results of the design of air conditioning system. After getting design results, the design of the system is carried out.

3.1. Design

3.1.1 The Design Concept

The design concept of an air conditioning system is to utilize solar heat as an energy source to perform the function of decreasing temperature in a room — the air conditioning system that will be designed using a solid desiccant as a moisture absorber. Also, some equipment to aid air circulation and cooling processes will be integrated into this prototype.

3.1.2 Design Specifications

As a limitation (constraints) in the design of solar power solid desiccant air conditioning systems, the following design specifications are determined as follows:

A. Dimensions workspace
- Long : 3 m
- Wide: 2 m
- High : 3 m

B. Air conditioning systems
- Environmental temperature (max) : 38^0C
- Temperatures to be achieved: 16^0C - 25^0C
- The capacity of workers in the workspace: 2 (max)
- Using a solid desiccant wheel
- The desiccant material used is silica gel which main material is SiO_2 solid wheel and transparent.

3.2. Determinations of Components

At this stage, the component characteristics are determined by the design specifications that have been set. It aims to identify the main components and auxiliary air conditioning system in the room.

3.2.1. Layout

In the process of determining the components of the air conditioning system, it is divided into two types of components, namely standard components and specialized components. For the type of standard components will be determined by using an existing catalog, such as the evaporator component, condenser, expansion valve, and pump. For determination, the specific component is done using the basic calculation in advance as a way to know the dimensions of the components that are designed, such as the cooling load of the room, generator tubes, absorber, and solar collectors. After the air conditioning system component is set, it will determine the ideal component location. The layout plan for the prototype component can be seen in Figure 5.

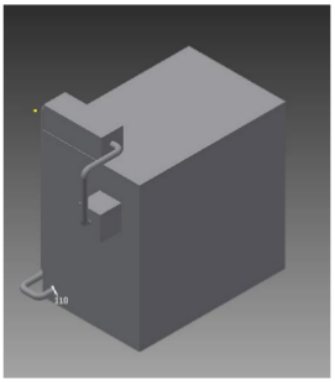

Figure 4. The layout design of air conditioning engine components

3.2.2. Determination of Dimension or Cooling System Component Selection
In the process of determining the component dimensions. The system is done with basic calculations in advance as a way to know the dimensions of the components that are designed, then the result of the calculation are adjusted to the catalog or easily found in the market as a way to obtain additional data regarding the dimensions of cooling system components.

3.2.3. Detailed Design
After the design process is done, then the results of the design are expressed in technical drawings. The result of the cooling system design will be drawn using Autodesk Inventor 2013 Student Version. Technical drawings will serve to simplify the process of making the cooling system.

3.3. Manufacture Cooling System
After the design and drawing design completed, the manufacture of the cooling system will be made. The preparation is carried out by several stages:

1. The first stage
   Creating a test room that resembles a box room area of 6 m^2. It is used to test the circumstances or air temperature in the room.
2. The second stage
   Manufacture of desiccant wheel, heater, pump selection, and fan selection suitable for the solar power solid desiccant cooling system. The entire manufacturing process was carried out in the manufacturing workshop and the related laboratories in the Department of Mechanical Engineering and Industrial Engineering, Andalas University.
3. The third stage
   The assembly process of cooling system components. After all, components have been selected and made. The assembly process is carried out, both the installation of desiccant wheels, fans, pumps, solar collectors, and heater.

3.4. Experiment
Implementation of experiments was conducted with the following stages [11]:

1. Formulation of the problem
   Technical and economic evaluation of design results requires empirical validation. As well as to obtain optimum operating conditions, the empirical approach is treated considering the limitations of mathematical models on real prototypes.
2. Goal setting
   For purpose determination, identify the characteristics of the output must be done. In this study, the output is the yield of oil separation. Whereas, the purpose of the experiment was to evaluate the effect of desiccant wheel rotation on the performance of the air conditioning system made. It is based on the hypothesis of the relationship between rotation and performance of the prototype.

3.5. Testing and Data Collection
The tests to be performed are:

- Testing the lowest temperature that can be achieved by the system.
- Testing the chamber room temperature changing and components cooling engine.
- Humidity measurement of the test room during the test

4. Result and Discussion

4.1. Performance of the Test Chamber Cooling System
Experiments carried out useful for testing the performance of the cooling system with the first step of measuring the temperature of the dry ball (T_{db}) and relative humidity (ϕ) At the input and output desiccant wheel as well as direct evaporative cooling. At the desiccant wheel input, the measured temperature is the environmental temperature while the output temperature is in the system that is the

air temperature after passing the desiccant wheel, then for evaporative cooling temperature measured inside the system is the air temperature before it entering the evaporative cooler while the output temperature is measured in the test room. Results of temperature testing and relative humidity are used to find the value of a humidity specific air, which uses a psychrometric diagram.

Table 1. The thermodynamic properties of air before and after passing desiccant

Time	Before Entering Desiccant			After Entering Desiccant			*m*	MRC
	Tdb1	RH1	W1	Tdb2	RH2	W2		
0	28	69	16	35	54	19	0.447	-1.341
15	29	70	18	34	54	18	0.447	0
30	31	74	21.5	33	57	17.5	0.447	1.788
45	30	73	20.5	33	35	11.3	0.447	4.1124
60	31	74	21.4	32	35	11	0.447	4.6488

The psychrometric diagram is used to find the value of specific humidity, which is this specific humidity is useful for searching for desiccant dryer performance value by calculating the moisture removal rate (MRC), which can be determined by the following equation:

$$\dot{m} = \rho \cdot v \cdot A \tag{1}$$

$$\dot{m} = 1{,}2\ {}^{kg}/_{m^3} \bullet 0{,}08\ m^2 \bullet 4{,}66\ {}^{m}/_{s}$$

$$\dot{m} = 0{,}447\ {}^{kg}/_{s}$$

$$MRC = \dot{m}(\omega_{inlet} - \omega_{outlet}) \tag{2}$$

$$MRC = 0{,}447\ {}^{kg}/_{s}\ (16-19)$$

$$MRC = -1{,}341$$

Table 2. The thermodynamic properties of air before and after passing through an evaporative cooler

Time	Before Entering The Cooler			After Entering The Cooler			*m*	QC
	Tdb3	RH3	W3	Tdb4	RH4	W4		
0	32	54	16	26	85	19	0.447	2.6954
15	31	54	15.2	26	84	17	0.447	2.2462
30	32	57	16.1	26	84	17	0.447	2.6954
45	33	35	11.3	25	82	16.5	0.447	3.5939
60	31	35	9.2	24	76	16	0.447	3.1446

From the temperature difference of dry ball before entering and after entering the cooling, the cooling capacity can be found using the equation:

$$Q_c = \dot{m} \bullet cp \bullet \left(T_{db3} - T_{db4}\right) \quad (3)$$
$$Q_c = 0,447 \, {kg}/{s} \bullet 1,005 \, {kj}/{kg \, ^\circ C} \bullet \left(32 - 26\right)^\circ C$$
$$Q_c = 2,6954 \, kW$$

4.2. Wheels Desiccant System Performance

In the design desiccant cooling system, the air from the environment enters the desiccant wheel in stage 1 to 2. In stage 1-2, there is a reduction in the water content of the incoming air or dehumidifying process. At stage 2-3, the dehumidifying process is still being processed through a heat rotary wheel. The output in this process, The air humidity decreases and followed by the decrease in temperature. In the 3-4 stage, dry air will be cooled by evaporative cooling. The lowest temperature that can be achieved by the system is 24°C.

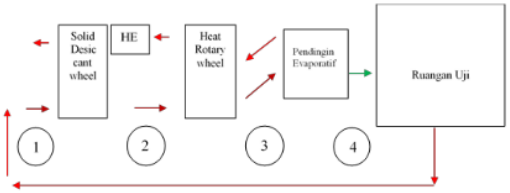

Figure 5. The cycle process of solid desiccant

5. Conclusions And Recommendations

Based on research that has been done obtained some conclusions as follows:

1. The desiccant cooling system has been made with a volume of 18 m^3.
2. The solid desiccant system has been able to work, have been able to reduce the input air humidity by reducing the rate of water/moisture removal rate (MRC): -1.341.
3. The designed cooling capacity is 2.6954 kW, rounded up to 2.7 kW.

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Design of solid desiccant air conditioning system

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Abstract. Currently, solid desiccant air conditioning system (SDACS) is an alternative to utilize solar energy to resolve environmental and energy issues resulting from the use of conventional vapor compression of air conditioning systems. SDACS can maintain the thermal comfort of a room with optimization of solar thermal energy and minimal use of electrical power. Present work in this paper is to design a solid desiccant air conditioning system of a closed room with 18 m^3 of total volume. The desiccant wheel is used to dehumidify air in the room, and evaporative cooling will be decreasing the temperature of the air. The result shows the lower temperature can be reached 24^0C.

1. Introduction

Indoor work trend increases at this time. The elevations of information technology utilization make people can do their work without leaving their room/house. It causes an increased requirement for indoor thermal comfort standards for workers/employees who perform activities. Thermal comfort standards are met by using the air conditioning machine (AC) which is one of the widely used solutions.

Currently, the use of air conditioning machine still uses vapor compression refrigeration system which requires significant electrical energy consumption. Energy requirements for air conditioning machines are predicted increase due to the rising standard of comfort and global warming issues. Isaac et al. [1] have predicted energy requirements for cooling systems in the world building, which will increase energy requirement about 4000 TWh in 2050 and will continue to 10,000 TWh in 2100. Thus, the renewable energy utilization to fulfill the energy requirement for cooling/air conditioning system needs to be done.

From several alternatives of renewable energy that can be harnessed, solar energy is the best alternative renewable energy that can be used. Solar energy can be used as a source of energy for air conditioning systems in two ways: through the process of converting solar energy into electrical energy and process for direct utilization of the solar energy. In the first process, the use of photovoltaic cells in solar energy utilization will convert solar energy into electrical energy, and then electricity will be used to operate the conventional vapor compression system in air conditioning system. With this system, simple construction and high efficiency are the main advantages. However, high investment

costs for equipment and energy storage media (battery) and limited cooling during the day cause lack of technology implementation.

In the cooling system driven by solar heat, the solar heat is collected through a solar collector which is used to produce mechanical energy to compress the refrigerant vapor in a conventional vapor compression system or as a heat source for the generator to the cooling system of the sorption (absorption). The utilization of solar energy through thermal processes provide greater economic returns than the use of solar energy through solar cells (photovoltaic). It is because of the ability to provide the maximum cooling effect when the maximum input of solar radiation occurs at the same time. When the moment of the small size of solar radiation so the cooling load will be low, and thus no requirement for a large thermal storage tank to overcome the influence of the season. [1]

2. Literature Review

2.1. Solid desiccant air conditioning systems

The solid desiccant cooling system operates based on the open sorption cycle with adsorption working principles by absorbing water vapor contained in the air, and then the dry air is lowered to room temperature by using a sensible heat exchanger and cooling coil. The air conditioning system required a desiccant wheel to carry out an absorption process which consists of small hexagonal channels to form honeycomb formation. The desiccant wheel is continuously spinning very slowly through two separate airflows [5]. The first stream is air flow process which dehumidifiers by desiccant and the second flow are air flow regeneration or reactivation. Air temperature reactivation of silica gel ranges from 50 - 160 °C. In the visualization, the principle of the solid desiccant cooling system is shown in Figure 1.

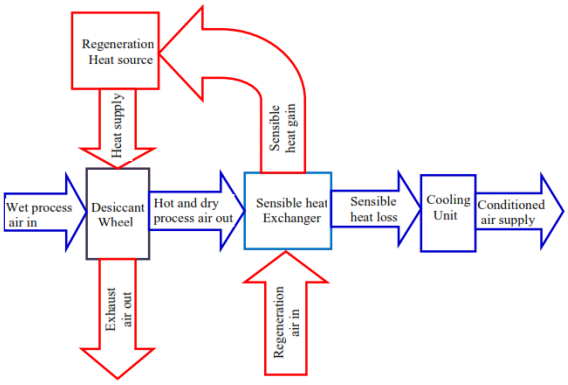

Figure 1. Working principle of solid desiccant cooling system [2]

2.2. The Cycle of Desikan

All desiccant function is in the same way by movement of water vapor. It caused by the difference between the surface pressure of water vapor and the around water pressure. When the vapor pressure at the surface is lower than air, the desiccant will bind moisture. When the surface pressure of water vapor is higher than the surrounding air, the desiccant will release water vapor.

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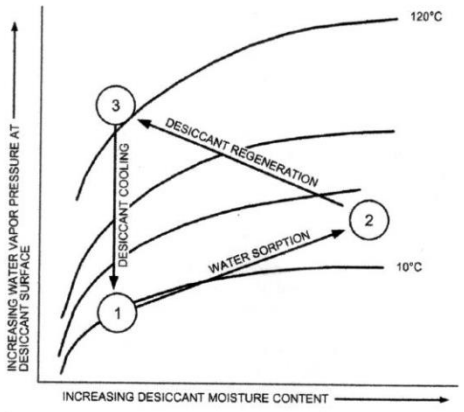

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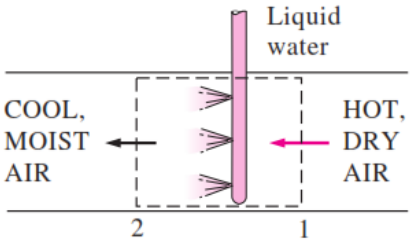

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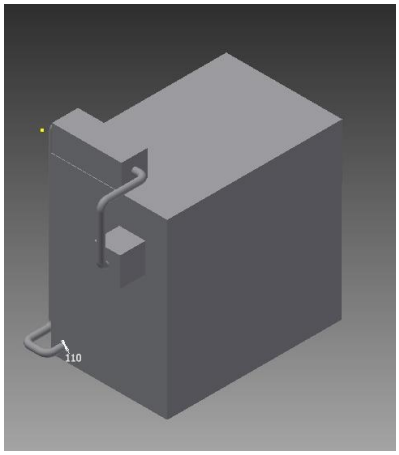

Figure 4. The layout design of air conditioning engine components

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   Technical and economic evaluation of design results requires empirical validation. As well as to obtain optimum operating conditions, the empirical approach is treated considering the limitations of mathematical models on real prototypes.
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The tests to be performed are:

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Experiments carried out useful for testing the performance of the cooling system with the first step of measuring the temperature of the dry ball (T_{db}) and relative humidity (ϕ) At the input and output desiccant wheel as well as direct evaporative cooling. At the desiccant wheel input, the measured temperature is the environmental temperature while the output temperature is in the system that is the

air temperature after passing the desiccant wheel, then for evaporative cooling temperature measured inside the system is the air temperature before it entering the evaporative cooler while the output temperature is measured in the test room. Results of temperature testing and relative humidity are used to find the value of a humidity specific air, which uses a psychrometric diagram.

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Time	Before Entering Desiccant			After Entering Desiccant			*m*	MRC
	Tdb1	RH1	W1	Tdb2	RH2	W2		
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The psychrometric diagram is used to find the value of specific humidity, which is this specific humidity is useful for searching for desiccant dryer performance value by calculating the moisture removal rate (MRC), which can be determined by the following equation:

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$$\dot{m} = 1,2 \, {kg}/{m^3} \bullet 0,08 \, m^2 \bullet 4,66 \, {m}/{s}$$

$$\dot{m} = 0,447 \, {kg}/{s}$$

$$MRC = \dot{m}(\omega_{inlet} - \omega_{outlet}) \tag{2}$$

$$MRC = 0,447 \, {kg}/{s} \, (16-19)$$

$$MRC = -1,341$$

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Time	Before Entering The Cooler			After Entering The Cooler			*m*	QC
	Tdb3	RH3	W3	Tdb4	RH4	W4		
0	32	54	16	26	85	19	0.447	2.6954
15	31	54	15.2	26	84	17	0.447	2.2462
30	32	57	16.1	26	84	17	0.447	2.6954
45	33	35	11.3	25	82	16.5	0.447	3.5939
60	31	35	9.2	24	76	16	0.447	3.1446

From the temperature difference of dry ball before entering and after entering the cooling, the cooling capacity can be found using the equation:

$$Q_c = \dot{m} \bullet cp \bullet \left(T_{db3} - T_{db4}\right) \tag{3}$$
$$Q_c = 0,447\, {kg}/{s} \bullet 1,005\, {kj}/{kg\,^\circ C} \bullet (32-26)\,^\circ C$$
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In the design desiccant cooling system, the air from the environment enters the desiccant wheel in stage 1 to 2. In stage 1-2, there is a reduction in the water content of the incoming air or dehumidifying process. At stage 2-3, the dehumidifying process is still being processed through a heat rotary wheel. The output in this process, The air humidity decreases and followed by the decrease in temperature. In the 3-4 stage, dry air will be cooled by evaporative cooling. The lowest temperature that can be achieved by the system is 24°C.

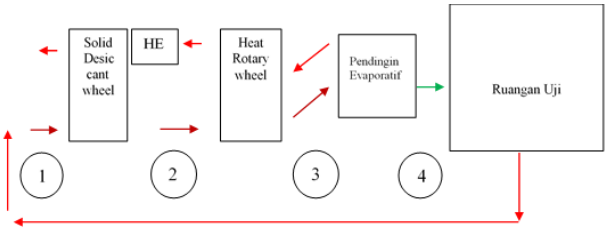

Figure 5. The cycle process of solid desiccant

5. Conclusions And Recommendations

Based on research that has been done obtained some conclusions as follows:

1. The desiccant cooling system has been made with a volume of 18 m^3.
2. The solid desiccant system has been able to work, have been able to reduce the input air humidity by reducing the rate of water/moisture removal rate (MRC): -1.341.
3. The designed cooling capacity is 2.6954 kW, rounded up to 2.7 kW.

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