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Design of Solar Desiccant Clothes Dryer

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Abstract:

The system design uses solar energy as power source for a clothes dryer attached to a room. The device has two processes which is Dehumidified Air Inlet Process and Humid Air Outlet Process, consisting of heat exchangers, fans and a desiccant wheel.

In the Dehumidified Air Inlet Process, the outside air is suctioned and dehumidified, acting as the working substance that removes moisture from the drying room. In the Humid Air Outlet Process, humid air from the drying room is removed and its moisture content is reduced by the second heat exchanger of the system. The air is then used as the working substance to regenerate the desiccant.

The system can remove 1.7439 kg of moisture within 9.65 minutes. This calculation is based on assumptions and computation based on thermodynamic principles and equations. The purpose in the long term would be to reduce the consumption of electricity used for clothes dryer.

Keywords — **Desiccant, Air Dryer, Solar Flat Plate Collector, Solar Water Heater**

I. INTRODUCTION

From the last few decades, the system of solar desiccant air conditioner has been attained. It is further developed to serve the necessity to conserve energy and reduce harmful emission. Several project for solar cooling, heating and drying has been analysed within the scope of "SACE project (Solar air conditioning in Europe)" to testing environmentally friendly air conditioning for the use with solar thermal system.

The experimental analysis of solar desiccant air conditioning is created to achieve the great result without using the compressor. Without using the compressor we can reduce the electricity which is required in the conventional air conditioning. The solar energy is used to heat the water and flows through the condenser to reduce the moisture. (Kongre et.al, 2014)

This study is based from the project published last May 1, 2014 by Dr. U. V. Kongre, C. M. Singh, and A. B. Biswas of the Dept. of Mechanical Engineering, Jawaharlal Darda Institute of Engineering and Technology / Amravati University, Yavatmal, Maharashtra, India entitled "Experimental Analysis on Solar Desiccant Air Conditioner".

II. SYSTEM DESCRIPTION

The solar desiccant air dryer system has two processes which is dehumidified air inlet process and humid air outlet process.

In the dehumidified air inlet process, the outside air is suctioned and passes through the desiccant wheel. The air is dehumidified by the desiccant (silica gel) and it goes to a heat exchanger.

In the heat exchanger the air passes through coils with hot water from the solar water heater. The air is dehumidified to some extent by the heat transfer and its temperature increases. The air then is finally diffused to the drying room.

In the humid air outlet process, the system takes humid air from the drying room which passes through the second heat exchanger of the system. By passing the humid air through the condenser, moisture in the air reduces to some extent. The air then passes through the desiccant wheel, in which it serves as the working substance that regenerates the desiccant.

The water coming from the heat exchangers is re-used at the solar water heater (Fig. 1).

III. SYSTEM COMPONENTS

1. Solar flat plate collectors - As shown in Fig.1 the system have a flat plate collector that serves as energy source for the Solar Water Heater

2. Solar Water Heater (SWH) – this is the mixing and storage vessel for the hot water that is used by the heat exchangers.

3. Desiccant wheel - The desiccant wheel contains silica gel that serves as the air dehumidifier

4. Condenser - The system contains two heat exchangers, one per process

5. Fans - The system contains three fans. Suction of outside air; diffusion of dehumidified air to the room and suction of humid from the room

IV. SYSTEM CALCULATION

1. Outside Air Condition

Dry Bulb (T_{db}) of the outside air is taken as 22°C. This is the average low temperature for Metro Manila, Philippines (Fig. 2) taken from Pag-Asa data based on the historical records from 1974 to 2012. Earlier records are either unavailable or unreliable.

The temperature was chosen based on the condition where the weather is a bit humid to test if the system can still operate on desired conditions.

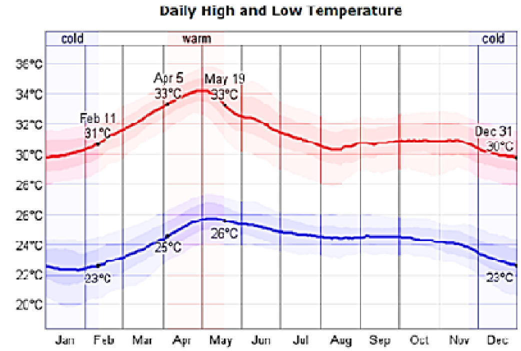

Figure 2: Manila Philippines Daily High and Low Temperature Graph

Over the course of a year, the dew point typically varies from 19°C (muggy) to 26°C (oppressive) and is rarely below 17°C (mildly humid) or above 27°C (very oppressive), as shown in Fig. 3. For the system computation, the condition is taken to as muggy.

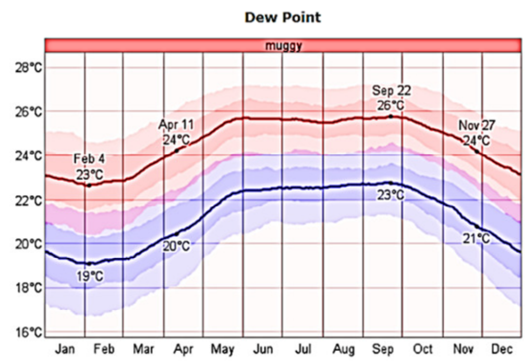

Fig. 3: Manila Philippines Daily Dew Point Temperature Graph

The Relative Humidity (RH) was computed using the formula:

$$RH = \frac{P_v}{P_{sat}} \qquad \text{(Eq. 1)}$$

wherePv is the partial pressure of the water vapour and Psat is the pressure at dry bulb temperature.

The Mass flow rate of dry air (m_a) and vapour (m_v) were computed using the following formula:

$$ma = \frac{V_f}{\upsilon} \qquad \text{(Eq. 2)}$$

$$w = \frac{m_v}{m_a} \qquad \text{(Eq. 3)}$$

where V_f is the volume flowrate of the fan, (see Fan Capacity); υ is the Specific Volume of the air and ω is the Humidity Ratio.

Table 1: Outside Air Condition Properties

Property	Unit	Value
Dry Bulb (T_{dp})	°C	22
Dew Point (T_{dp})	°C	19
Relative Humidity (RH)	---	0.828
Humidity Ration (ω)[a]	g moisture / kg dry air	14
Specific Volume (υ)[a]	m3/ kg dry air	0.854
Dry Air Massflow (m_a)	kg of dry air/sec	0.2763
Moist Air Massflow (m_v)	g of moisture/sec	3.8682

aValues from Psychrometric Chart

2. Fan Capacity

This design uses Centrifugal Backward Inclined fan. Wheel diameter and air flow are from the Mechanical Engineering Handbook.

Table 2: Fan Capacity

Property	STD Range	Unit	Value
Wheel Diameter (d)	10 – 75 in	cm	25.4[a]
Air Flow (V_f)	500 – 125,000 ft3/min	m3/sec	0.23597[a]

aAssumed Value converted to SI Unit

3. Desiccant Wheel

The desiccant wheel diameter is twice the fan diameter, as illustrated by Fig.1. Since silica gel can absorb up to 40% moisture at one pass, the volume of the silica gel inside the desiccant wheel is half the volume of the wheel.

Volume of Silica Gel = (0.5)(Volume of the desiccant wheel) (Eq. 4)

Commercially, 15 grams of silica gel is under a ¾ in by 1 7/16 in by ¼ pack which is equivalent to 4.4168 cm^3. To estimate the mass of the silica gel in the wheel, ratio and proportion was used.

$$\text{Mass of Silica Gel} = \left(\frac{\text{Mass of Pack}}{\text{Volume of the Pack}}\right)(\text{Volume of Silica Gel}) \quad \text{(Eq. 5)}$$

The desiccant wheel absorption rate was estimated using Fig. 4.

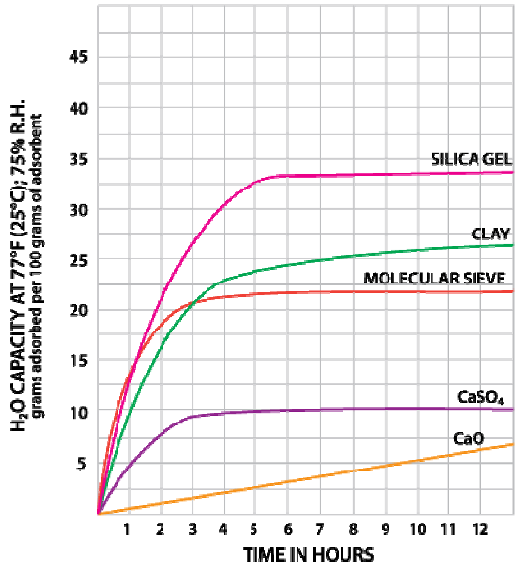

Figure 4: Water Absorption Chart of Desiccants

Since the data given on Fig. 4 shows a less humid air with RH = 75% compared to the outside air with RH = 82%, we take the data from the graph given above to estimate vapour absorption: 12.5 grams of vapour per 100 grams of silica gel is absorbed in 1 hour.

So, Absorption is at 0.00034722 grams of vapour / gram of silica gel / sec.

Table 3: Desiccant Wheel Properties

Property	Unit	Value
Wheel Diameter	cm	50
Wheel Thickness	in/cm	1.5/3.81
Wheel Volume	cm^3	7,480.918
Volume of Silica Gel	cm^3	3,740.459
Total Weight of Silica Gel	grams	12,722.649
Desiccant Moisture Absorption Rate	grams of vapour / gram of silica gel / sec	0.00034722

4. Desiccant Wheel Air Inflow

This is the first part of the dehumidified air inlet process. Outside air is suctioned by the fan and it passes through the desiccant wheel which dehumidifies the air.

Half of the desiccant wheel is exposed for dehumidification. It is estimated that half the silica gel is used for moisture removal, 6,361.324 grams of silica gel.

Vapour Absorption Rate (VAR) = (Desiccant Moisture Absorption Rate)(Silica Gel Mass) (Eq. 6).

Since, mv is coming in at 3.8682 grams of moisture / sec, the vapour mass after the wheel is:

$m_v = m_v\,(in) - VAR$ (Eq. 7)

while, ma = ma of outside air = 0.2763 kg of dry air/sec.

Table 4: Desiccant Wheel Air Outflow Properties

Property	Unit	Value
Moist Air Massflow (m_v)	g of moisture / sec	1.6592
Dry Air Massflow (m_a)	kg of dry air/sec	0.2763
Humidity Ration (ϖ)	g moisture / kg dry air	6
Relative Humidity (RH)	---	0.25[a]
Enthalpy (h)	kJ / kg of dry air	33[a]

aValues from Psychrometric Chart

5. Heat Exchanger 1

After the air passes through the desiccant wheel it passes through the first heat exchanger of the system for heating and further dehumidification.

The calculation of the properties for Heat Exchanger 1 use the following assumptions:

1. Flat-plate collectors are the most common solar collector for solar water-heating systems in homes and solar space heating. A typical flat-plate collector is an insulated metal box with a glass or plastic cover (called glazing) and a dark-coloured absorber plate. These collectors heat liquid or air at temperatures less than 180°F or 82.22°C

Use: 80°C as water inlet temperature

2. Water outlet temperature is 73°C
3. Dry air mass does not change as it passes the heat exchanger but the vapour mass decreases
4. Desired outflow RH = 20% and Humidity Ratio (ϖ) = 4

Since, the dry air flow is assumed to be the same, Eq. 3 is used to solve for the vapour mass flow of air. Mass-Energy balance is used to get the mass flow of water in the heat exchanger.

Mass- Energy Balance:

Energy In = Energy Out

$m_{a1}h_{a1} + m_{w1}h_{w1} = m_{a2}h_{a2} + m_{w2}h_{w2}$ (Eq. 8)

Table 5: Heat Exchanger 1 Properties

Property	Unit	Value
Relative Humidity (RH)	---	0.20
Humidity Ration (ϖ)	g moisture / kg dry air	4
Dry Bulb (T_{db})	°C	25[a]
Enthalpy (h)	kJ / kg of dry air	35[a]
Dry Air Massflow (m_a)	kg of dry air/sec	0.2763
Moist Air Massflow (m_v)	g of moisture / sec	1.1052
Water Inlet Temperature	°C	80
Water Outlet Temperature	°C	73
Water Inlet Enthalpy (h)	kJ / kg	334.91[b]
Water Outlet Enthalpy (h)	kJ / kg	305.55[b]

a Values from the Psychrometric Chart
b Values from Steam Table
All air properties are outflow

6. Drying Room Condition

The drying room have the following assumptions:

1. Room Volume: 3m by 4m by 7m = $84m^3$
2. Room RH = 95% and dry bulb temperature is 24°C

The dry air mass inside the room is computed using the formula:

$$m_a = \frac{\text{Room Volume}}{\text{Air Specific Volume}} \quad \text{(Eq. 9)}$$

while, the vapour content uses Eq. 3.

Table 6: Drying Room Properties

Property	Unit	Value
Room Volume	m^3	84
Relative Humidity (RH)	---	0.95
Dry Bulb (T_{db})	°C	24
Humidity Ration (ω)	g moisture / kg dry air	18[a]
Specific Volume (υ)	m^3/ kg dry air	0.867[a]
Enthalpy (h)	kJ / kg of dry air	70[a]
Dry Air Mass (m_a)	kg dry air	96.8858
Moist Air Mass (m_v)	kg of moisture	1.744

aValues from Psychrometric Chart

7. Drying Room Air Outflow

The drying room air outflow have the following assumptions:
1. Desired Air Outflow RH = 50%
2. Desired Air Outflow Humidity Ratio (w) = 11

Since the humid air from the room is being suctioned by a fan, the dry air mass uses Eq.2. And to solve for the moist air mass, use Eq. 3.

Table 7: Drying Room Air Outflow Properties

Property	Unit	Value
Moist Air Massflow (m_v)	g of moisture / sec	3.0107
Dry Air Massflow (m_a)	kg of dry air/sec	0.2737
Humidity Ration (ω)	g moisture / kg dry air	11
Relative Humidity (RH)	---	0.50
Specific Volume (υ)	m3/ kg dry air	0.862[a]
Enthalpy (h)	kJ / kg of dry air	53[a]

aValues from the Psychrometric Chart

8. Heat Exchanger 2

After the air passes through the second heat exchanger, it will then pass the heat exchanger 2 where the air is slightly dehumidified by the heat of the coils.

The calculation of the properties for Heat Exchanger 2 use the following assumptions:

1. Flat-plate collectors are the most common solar collector for solar water-heating systems in homes and solar space heating. A typical flat-plate collector is an insulated metal box with a glass or plastic cover (called glazing) and a dark-coloured absorber plate. These collectors heat liquid or air at temperatures less than 180°F or 82.22°C

Use: 80□C as water inlet temperature

2. Dry air mass does not change as it passes the heat exchanger but the vapour mass decreases

3. Desired outflow RH = 20% and Humidity Ratio (ω) = 8

Since, the dry air flow is assumed to be the same Eq. 3 is used to solve for the vapour mass flow of air. Mass-Energy balance (Eq. 8) is used to get the mass flow of water in the heat exchanger.

Table 5: Heat Exchanger 2 Properties

Property	Unit	Value
Relative Humidity (RH)	---	0.20
Humidity Ration (ω)	g moisture / kg dry air	8
Dry Bulb (T_{db})	°C	36[a]
Enthalpy (h)	kJ / kg of dry air	56[a]
Dry Air Massflow (m_a)	kg of dry air/sec	0.2737
Moist Air Massflow (m_v)	g of moisture / sec	2.19
Water Inlet Temperature	°C	80
Water Outlet Temperature	°C	73
Water Inlet Enthalpy (h)	kJ / kg	334.91[b]
Water Outlet Enthalpy (h)	kJ / kg	305.55[b]

a Values from the Psychrometric Chart
b Values from Steam Table
All air properties are outflow

V. CONCLUSION AND RECOMMENDATION

If the given conditions and assumptions can hold true with the solar desiccant clothes dryer; 1.7439 kg of moisture can be removed from the room within 9.65 minutes with a rate of 3.0107 grams of moisture/sec removal. Since, the outlet water temperature of the heat exchangers is ranging from 70°C - 78°C, recycling of hot water is possible.

The power requirement of the system and water recycling calculation is taken to be part of the future improvement for this study.

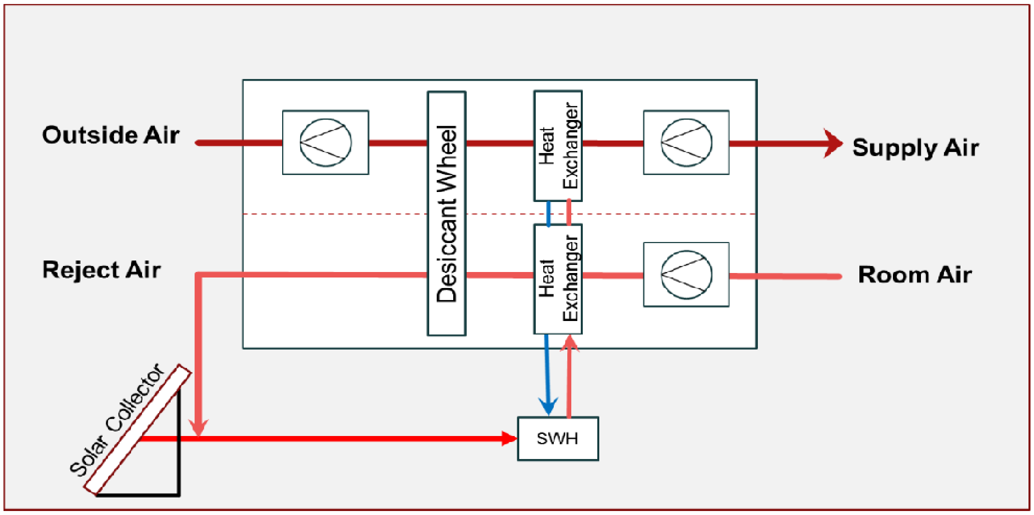

Figure 1: Solar Desiccant Clothes Dryer System Diagram

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