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Implementation of a Solar Powered Desiccant Air Conditioning System

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Abstract

At present, the increasing use of conventional air conditioning system has led to more stress on power grids. Moreover the system requires components which are hardly economically feasible. These reasons elucidate the need of a financially viable air conditioning system which utilizes renewable energy. This paper describes the implementation of a proposed solar powered desiccant air conditioning system for residential and commercial applications. The system differs from the conventional thermal cooling systems in the sense that it requires inexpensive regenerative desiccant (i.e. Calcium Chloride) and low-temperature solar thermal collector. A flat plate solar collector absorbs sun's radiation and vaporizes the water from the salt solution leaving a concentrated solution behind which simultaneously works as a low cost energy reservoir. The desiccant solution is then kept in a container till cooling is required. A cooling unit comprised of three optimal heat exchangers materializes the dehumidification and cooling from the phase change phenomenon of the liquid desiccant and supplied water accordingly. In case of the lack of sunlight, off-peak electricity and natural gas can be used as alternative heat sources. The implementation of an economically feasible air conditioning system is the sole objective of this study.

Keywords: *Flat Plate Solar Collector, Regenerative Desiccant, Heat Exchanger, Absorption Air Conditioning*

1. Introduction

Ever since the industrial revolution in the 18th century, the emission of greenhouse gases has increased abruptly resulting in global warming. The impact of this temperature rise is nevertheless detrimental to our communities, our health, and our climate. More frequent and intensified heat waves have been observed throughout the world than the last 60 years, specially in South Asian countries .These increased heat waves create critical health risks, and can lead to heat exhaustion, heat stroke, and deteriorate existing medical conditions. .In June, 2015 death tolls rose over two thousand in Pakistan due to severe heat waves .The widespread usage of air conditioning units is the only imaginable solution to this unavoidable circumstance. Air conditioning facilitates the optimum humidity and maintains suitable temperature for human comfort. The conventional air-conditioning systems are subjected to high cost manufacturing and consumes extensive amount of power. In developing countries like Bangladesh these conventional systems are not affordable for the general people. In these circumstances implementation of an economically feasible air-conditioning system is essential. The power grid crisis in Bangladesh is evident and the utilization of alternative power resources is essential to mitigate this crisis and at the same time prevent environment pollution. Air conditioning units powered by solar energy is quite implementable in this scenario. On the average the amount of solar energy that reaches the earth is 1700 Btu/ft^2 or 5300 Wh/m^2 in a moderately radiant day. This paper describes the mechanism and working principle of an air conditioning system which utilizes this solar energy and ensures economic feasibility by using inexpensive flat plate solar collector and a low-cost desiccant.

2. Vapor Compression Refrigeration System

The flow of refrigerant through the compressor raises the refrigerant's pressure. Then the refrigerant flows through the condenser which causes a phase change from vapor to liquid and subsequently gives off heat. In the third stage, the refrigerant passes the expansion valve and experiences a pressure drop. Finally the refrigerant enters the evaporator where it is vaporized again. The evaporator receives heat from the region that requires cooling. The vaporized refrigerant then flows back to the compressor which initiates the cycle again.

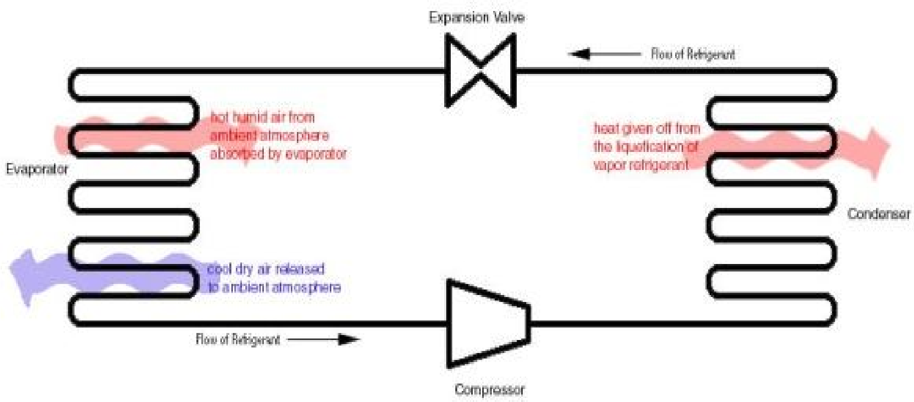
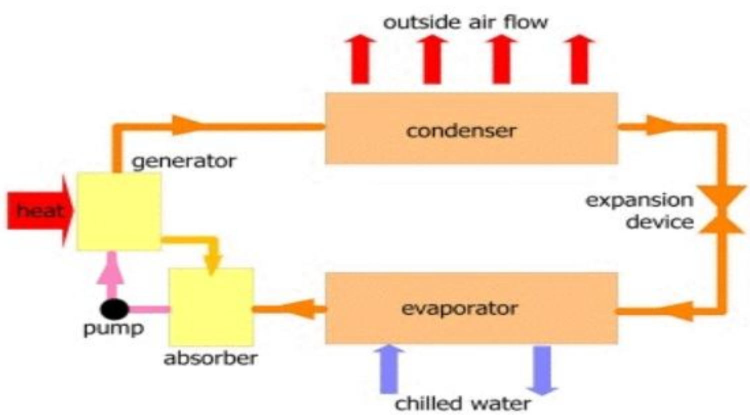


Fig. 1. Vapor compression refrigeration system.

3. Absorption Refrigeration System

This system differs from the vapor compression system in the sense that this operates on heat energy rather than mechanical energy. The condenser and evaporator are similar to the other system. However, a generator, pump and absorber are used instead of the compressor. The heat source causes the vapor refrigerant to boil and raises it's pressure. The highly pressurized vapor is condensed at a higher temperature and pressure compared to it's surrounding. Thus the heat is gets rejected from the condenser to the surrounding. The highly pressurized liquid then flows through the expansion valve which results in a pressure drop. The boiling point temperature subsequently falls and then it's passed through an evaporator. The liquid absorbs heat from the conditioned air which results in it's evaporation. This causes the air to be cooled. The vapor is then flown through the absorber where it turns into liquid desiccant solution. Then the solution is pumped back into the generator by the pump. The heat separates the absorbent from the water. The water vapor enters the condenser while the desiccant goes to the absorber. This process is repeated continuously and results in cooling of the supplied air.



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4. Solar Air Conditioning

Photovoltaic solar cooling

This system requires photovoltaic (PV) cells which are ten times more expensive than the conventional air reconditioning systems and requires a large space for the supply of sufficient electrical power to operate an air condition.

Passive solar cooling

This system requires the overall transformation of the structure of the buildings. The building materials are to be specified , the airflow needs to be controlled to ensure the removal of unwanted heat.

Solar A/C using desiccants

The basic idea is to use regenerative desiccant to dehumidify the incoming outside air and provide a cooled air stream into the space that requires cooling. Silica gel, zeolites, lithium chlorides are commonly used desiccants but prove to be rather expensive.

5. Methodology

The proposed solar powered desiccant air conditioning system's schematic diagram is shown in Fig.3.The working fluid is a desiccant liquid (preferably Calcium Chloride solution) which provides cooling and dehumidification to the air. The mechanism of the system requires further explanations. The system is driven by a force generated by the temperature difference between a water surface and the working fluid surface in contact with an air flow. The temperature of the water surface nearly corresponds to the wet-bulb temperature of the air while the desiccant surface's temperature corresponds to a comparatively high temperature. The temperature difference between the concentrated desiccant equilibrium temperature and the wet-bulb temperature is approximately 15-20°F.The system efficiently utilizes a comparatively weak desiccant to ensure cooling. A total of three counter flow heat exchangers are used in the system to transfer thermal energy from the air that enters the system from the outside to the exhaust air. From the top, the first heat exchanger causes evaporation of water into exhaust air. The second heat exchanger(liquid to liquid) that cools the water by exchanging heat with the desiccant solution. The third heat exchanger is direct contact type that works between the incoming outside air and the chilled desiccant solution resulting in the dehumidification of the air. A flat plate solar collector utilizes solar thermal energy to banish the water from the solution which increases its concentration. The concentrated desiccant solution also plays the role of a storage medium in case of the scarcity of sunlight (night hours and cloudy weather). The concentrated solution is further stored in a container for continuous supply. An external source of water is also introduced to the system for the continuous circulation of water. The proposed system consists of the heat-exchangers and internal piping systems made out of plastic materials which can be modified and improvised for obtaining a relatively higher rate of heat transfer. An external source of electrical energy can be implemented and adjunct to the flat plate solar collector to ensure continuous cooling.

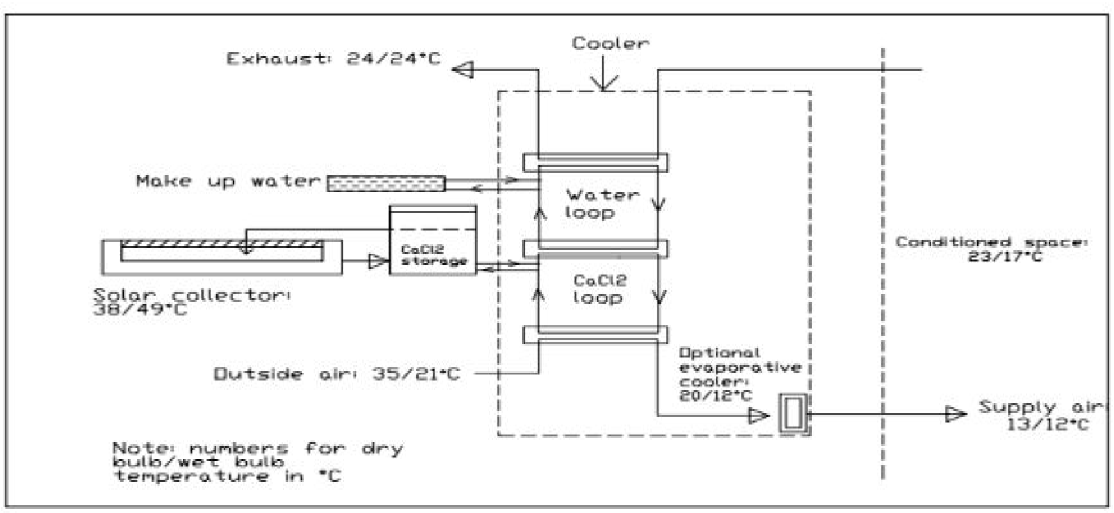

Fig. 3. Method of solar air cooling.

6. Desiccants

A desiccant may be defined as a dehumidifying substance which can remove water vapor or moisture from the air. Desiccants can come in solid or liquid states depending on its use. Normally, compressed air is passed over a desiccant to dry the air. They are regenerative type so they are recyclable. Some common desiccants' properties are discussed below:

Silica gel

SiO_2 is commonly known as silica gel. It comes in round shaped little components of solid state. Pure silica gel is a rare type of desiccant which can be kept near food.

Indicating silica gel

Indicating silica gel is a mixture of silica gel and cobalt chloride. The $CoCl_2$ will change its color from blue to light pink when it is saturated with water. For this "sign" it is called indicating silica gel. As $CoCl_2$ is a heavy metal salt, it is not safe to keep it near food.

Calcium chloride

$CaCl_2$ is a vastly available desiccant material which comes both in solid powder and liquid solution form. It has corrosive properties over metal object. As a result, it has to be kept in plastic or glass jar.

Calcium oxide and calcium sulfate

CaO and $CaSO_4$ are commonly known as quicklime and gypsum respectively. They are alkaline and erosive in nature so special precautions are necessary for handling them.

Sodium chloride

Pure NaCl and its solution can be used as a desiccant. It is highly available in nature as well as in market. But it becomes saturated very fast in the presence of little water vapor.

Table 1. Desiccants and their price analysis

Desiccants	Price (tk.) per kg
Silica gel	2000
Indicating silica gel	2500
Calcium chloride	120
Calcium oxide	120
Calcium sulfate	125
Sodium chloride	70

7. Construction costing

The costs of the various components of required for the system are enlisted below. The list has been prepared after proper market analysis and certainty of the availability.

Table 2. Construction costing of solar air cooling system.

Quantity	Units	Cost per unit (tk.)	Total cost (tk.)
Liquid-air heat exchanger	2	850	1700
Liquid-liquid heat exchanger	1	550	550
Collector	1	850	850
Storage (water)	1	110	110
$CaCl_2$ (kg)	3	120	360
Fan	2	300	600
Pump	1	1050	1050
Piping, connections, construction			1800
Overhead			250
Glass plate (ft^2)	3	30	90
		Grand total	7360

Market analysis of conventional air conditioners

The price and cooling capacity analysis of some of the air conditioners which are available in the market are given below:

Table 2. Price and cooling capacity of conventional air conditioners

Brand	Size	Price(tk.)	Cooling capacity(kW)
Sample no. 1	0.75 ton	31500	2.5-2.6
Sample no. 2	1 ton	36000	3.4-3.5
Sample no. 3	1 ton	40000	3.5-3.6
Sample no. 4	1.5 ton	48200	5.1-5.5
Sample no. 5	1.5 ton	55000	5.2-5.4
Sample no. 6	2 ton	57600	6.3-6.6
Sample no. 7	2 ton	65000	6.9-7.0

8. Limitations

In case of cloudy weather and during night hours the system can't work properly if there is no external source of energy provided. The desiccant properties of $CaCl_2$ has some limitations at 25° C as it shows some crystallization property at a concentration around 50%.In dry conditions $CaCl_2$ is unable to dehumidify because of the absence of moisture. Scale formation may occur due to the excess use of $CaCl_2$. The working process is comparatively slow due to less moving parts. Efficiency is relatively lower due to the non-uniform solar thermal radiation and the properties of $CaCl_2$.

9. Application

Desiccant technology now-a-days has become the most effective intermittent solution for the industry to ensure space -conditioning .It is more effective than vapor compression and absorption system .We can use this system for the conditioning of a large area. This system utilizes solar energy which is free from the detrimental effects on the environment. The low cost of the system plays a role in it's widespread application in developing countries like Bangladesh.

10. Conclusion

As per the proposed plan of the project we have successfully analyzed the mechanism, effectiveness and construction cost of the air conditioner operating on solar radiation and produces cooling effect based on the dehumidifying property of the calcium chloride desiccant. The conclusions observed are: It dehumidifies the atmospheric humid air present in our surroundings successfully, provides cooling effect by absorbing the heat of air and it is cost effective as the whole cost of the project comes around Tk. 7360.00 only which is inexpensive compared to the conventional air conditioning units.

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