A Review on Desiccant Dehumidification Assisted Air-Conditioning System

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Abstract— The current article describes about construction and working of desiccant assisted various cooling technologies. The contribution of the building sector to the above problem so as to maintain indoor environment providing human thermal comfort is prone area for the future research. In the present review, the alternative cooling methods for the provision of the human thermal comfort through desiccant dehumidification and cooling technologies are discussed. These technologies are potential alternatives to the conventionally used mechanical vapor compression cooling technologies in the provision of human thermal comfort conditions. However, the development and application is mostly in developed and advanced developing countries. For a global scale solution to the problem of energy and environment contributed by the building air-conditioning sector for the maintenance of comfortable conditions, dissemination of ideas and technologies to the developing countries enhances the applicability and practicability of these technologies in building cooling sector.

Key words: Desiccant Cooling, Desiccant Material, Rotary Desiccant Dehumidifier, Regeneration Temperature

I. Introduction

The global environmental problem is a serious worldwide issue. The depleting conventional energy resources are other major issues that threat to the developing world. The world population is increasing day by day. The human demand for better and comfortable condition is getting exponential rise. Urbanization is happening around the world. Industrialization is taking place in every part of the world. The above problems are complex as there are many parameters and considerations to be deeply looked into. These situations have become globally political, economic, and technological issues that concern to everyone this planet. Hand in hand solutions for these problems are a must to attain a common goal. Hence these issues of energy, environment, and technology are interrelated to each other and must be treated with interconnectivity if we have to attain clean and greener environmental conditions for humanity's survival (Fig. 1).

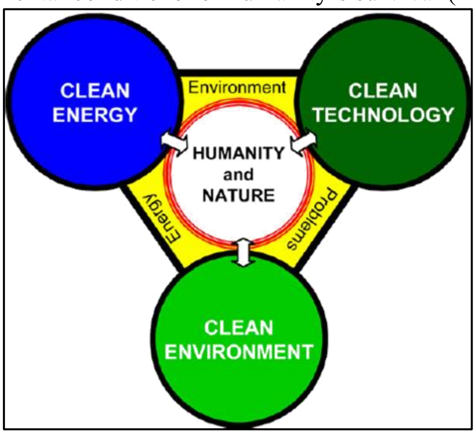

Fig. 1: Chart Shows Relation between Technology, Energy and Environment

The technological innovation is needed for better future and sustainable energy systems. From this, greenhouse gases emission such as CO_2 can be reduced or maintained. This will involve both political and technological will in tackling the issue is carbon-based energy sources. Example, developed countries have cut the carbon dioxide emission by 27% in less than 10 years despite increasing overall energy consumption. The present environmental condition is complex due to the problems of greenhouse gases emission, ozone layer depleting substances, particulate matters in the air, heavy metals, air borne chemical and biological contents due to industrialization. Furthermore, the increasing greenhouse gases in the air. These large scale emissions of gases and matters in the air due to human activities have detrimental effects to human health and to the civilization sustainability. In the case of air particulate matter such as biological and chemical compounds, they cause human health hazard directly. Studies show that the global warming and climate change is really due to the large amount of greenhouse gases present in the atmosphere by use of conventionally used vapor compression based air conditioners. Since the start of industrial revolution, large amount of greenhouse gases were deposited in the atmosphere. Hence, the increase of global pollutants is due to human activities (urbanization, industrialization, and others). Greenhouse gases are the primary cause of global warming. The ozone layer depleting substance is the cause of ozone layer thinning. Hence, all of these have consequences to the increase of global temperature which has serious effect to climate pattern–flooding, cyclones, and other weather disturbances in major part of the world. The above situation has serious effect to global sustainability as concluded by numerous modern environmental studies have been carried out by the different researchers in many part of the world. With this aim, alternative approach is needed in confronting massive energy consumption and, large scale greenhouse and pollutant gases emissions in the environment. Alternative approach such as utilization of alternative energy resources are one of the most prospects. Development of efficient and clean or green technologies solves the issue of large gases emissions (greenhouse gases and ozone layer depleting substances). Policies on energy conservation and environmental protections such as use of renewable energy or industrial waste heat etc. portfolios are one of the best start-up for tackling this global problem [1-5].

As building air conditioning sector is one of the primary energy consumers accounted to more than 60% inclusive of commercial and industrial buildings. The sector energy consumption is used to support electrical appliances, thermal comfort produced by use of traditional air conditioners and others such as lighting. As global population grows, urbanization taking place, and standard of living becoming higher, it is expected that the building sector energy consumption will increase furthermore. The past study showed that population size and age structure may effect on energy consumption in building in residential or industrial applications. The sector electric energy consumption will increase by 122% from 2002 to 2030. The residential sector including the agriculture consumed 58.7% in 2006 compared to 46.2% in 1975 in electric energy consumption [6-8].

II. WORKING PRINCIPLE OF DESICCANT COOLING

The desiccant assisted air-conditioning system utilizes the capability of desiccant materials in removing the air moisture content by natural process—the sorption process. The sorption process (adsorption and absorption) is an interaction between the sorbent and sorbate molecules through intermolecular interaction to dehumidify the air. Since desiccant materials have low concentration of water vapor content, the air moisture content is attracted to the surface of the desiccant materials due to the moisture vapor pressure difference between the air and the desiccant surface in channel of matrix in rotary dehumidifier. In order for the desiccant material to be used again, application of thermal energy is necessary to remove the moisture from the desiccant materials if known as desiccant regeneration. Fig. 2 shows the basic concept and diagram of the thermally activated desiccant cooling technologies [9].

The process of attracting moisture from the air is either by adsorption or by absorption: the adsorption process is a physical process in which the property of the desiccant material remains the same (Surface phenomenon); while in the absorption process, upon attracting moisture, the physical characteristic of the material changes (Body phenomenon). The desiccant materials are of basically two types either solid or liquid: the solid desiccant and hydrophilic adsorbents are the silica gel, activated alumina, zeolites and except for the calcium chloride which is absorbent. The commercial hydrophobic solid adsorbents are the activated carbons, metal oxides, specially developed porous metal hydrides and other composite adsorbents.

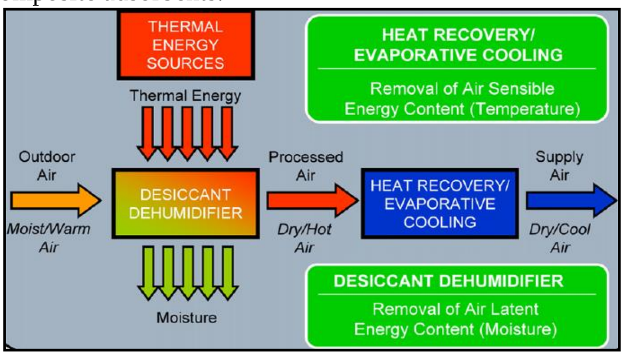

Fig. 2: Working Principle of Desiccant Assisted Cooling and Dehumidification System

Generally the desiccant materials are combinations of absorbent and adsorbent to enhance its physical properties and sorption capacity called composites desiccant materials. The basic mechanism in the sorption of moisture between the air moisture and of the desiccant material is the difference in the water vapor pressure in the surface of the desiccant and of the material. The uptake of moisture from the air to the desiccant is when the vapor pressure in the air is high; the removal of vapor or moisture from the desiccant material is done when the vapor pressure in the air is lower than on the desiccant material. When the vapor pressure is the same both in the air and in the desiccant material, the equilibrium condition is reached and sorption process stopped. The only means to make the adsorption process proceed is by using outside forces such as by increasing the air pressure, decreasing the temperature or by artificial electromotive force. The same procedure is applied for the removal of moisture from the desiccant material which is done in opposite way during the regeneration process to restore the wheel operation for the next cycle [10].

The desiccant assisted evaporative cooling is sustainable, economical and cleaner space cooling technique possibly the better option over traditional vapor-compression system based conventional cooling for maintaining required thermal comfort because vapor-compression based cooling have many limitation like it consumes more electricity and increases the CFC level which is responsible for depleting the ozone layer. The desiccant assisted evaporative cooling can also be used coupled with free energy source such as solar energy and waste heat resulting in the reduction of the operating cost and increase the accessibility to the air conditioning for the population of urban areas. The desiccants are natural or synthetic substances which are capable of absorbing or adsorbing large amount of water vapor due the difference of water vapor pressure between the surrounding due to its natural affinity with water vapor. The desiccants are natural or synthetic substances which are capable of absorbing or adsorbing water vapor due the difference of water vapor pressure between the surrounding air and the desiccant matrix surface lined inside desiccant dehumidifier. The desiccants could be in both liquid and solid states. Each of liquid and solid desiccant systems has its own advantages and disadvantages based on applications. Some commonly used desiccant materials include lithium chloride, tri-ethylene glycol, silica gels, aluminium silicates (zeolite or molecular sieves), aluminium oxides, lithium bromide solution and lithium chloride solution with water, etc. In addition of having lower regeneration temperature and flexibility in utilization, liquid desiccant have lower pressure drop on air side. Solid desiccant are compact, less subject to corrosion and carry over [11-12].

In the two stage dehumidification process, two desiccant wheels are employed (Fig. 3). The main purpose of the double stage dehumidification is to reduce the air moisture content in the case of humid air with lower regeneration temperature requirements. It shows it has lower regeneration temperature requirements with higher COP. It depicted that the four wheel cycles (two desiccant wheels and two heat wheel) can be used for the hot and humid climatic condition. In addition, the 3-wheel cycle (desiccant wheel, 1 heat wheel and 1 total heat exchanger) is better than the 4-wheel cycle [13].

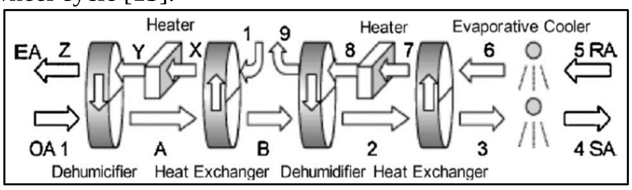

Fig. 3: Two Stage Desiccants Assisted Evaporative Cooling

The desiccant cooling system is highly energy efficient, it can supply the required fresh air to the building resulting to the good indoor air quality and ventilation effectiveness. The application of the desiccant dehumidification integrated with chilled ceiling and displacement ventilation. It shows it is feasible to be applied in the hot and humid climate due to its capability to respond consistently to cooling demand. In addition it reduces building energy consumption to 87.2% compared to conventional system. The main application of the desiccant assisted dehumidification by desiccant wheel with chilled-ceiling (Fig. 4). The aim of the installation is for the desiccant to reduce the air moisture content and thus avoid the condensation of moisture in the ceiling panel and at the same time cool the air by means of the chilled-ceiling for space cooling purpose [14].

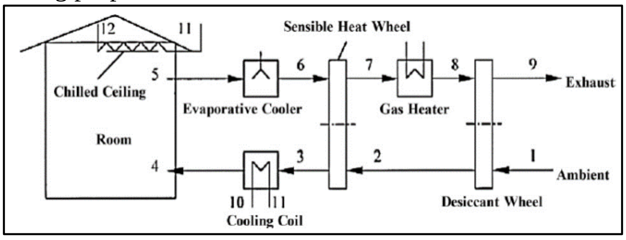

Fig. 4: Desiccants Integrated Chilled-Ceiling Cooling

Another application of the solid desiccant wheel in the automobile air-conditioning system is shown in Fig. 5. It shows that the system is energy efficient compared to the conventional vapor compression based automobile air-conditioning system. One of the problems encountered is the difficult control of the air humidity and temperature due to the heat exchange and coolant flow to the evaporator [15].

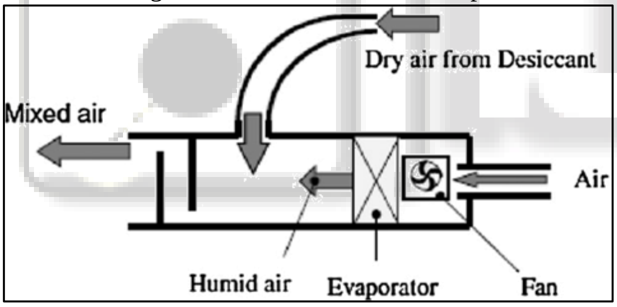

Fig. 5: Desiccants Integrated Automobile Air-Conditioning

A single-stage solar powered hybrid desiccant cooling system was shown in the schematic diagram in Fig. 6. The system mainly consists of a desiccant wheel, a heat exchanger, an evaporative cooler, flat plate solar collector, two backup heaters, and a vapor compression cooling unit. The cooling load for the building was with a maximum during the summer period will have at the same time for cooling available [16-18].

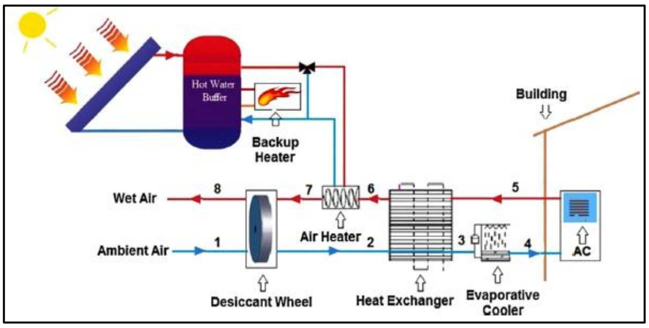

Fig. 6: Working of Solar Powered Desiccant Cooling and Dehumidification System

The desiccant dehumidifier is regenerated using reactivation heat available from freely available solar renewable. Free energy sources can be utilized for the regeneration process such as solar (Table-1).

Technology	Temperature (°C)
Flat plate collector	30–100
Solar pond	170–90
Solar chimney	20–80
Evacuated tube collector	90–200
Non imaging trough	90–200
Linear Fresnel reflector technology	260–400
Parabolic trough	260–400
Heliostat field + Central receiver	500–800
Dish concentrators	500–1200

Table 1: Typical Regeneration Temperature Achieved by Use of Different Types of Solar Collector

The liquid desiccant cooling system as shown in Fig. 7 depends mainly on the liquid desiccant in controlling air humidity content. The process of liquid desiccant control of moisture is by means of absorption process. One of the main advantages of the liquid desiccant cooling system is the lower reactivation temperature requirements and lower thermal and chemical storage. The advantage of the hybrid desiccant cooling system is the complete operation of the system using electric energy at higher performance. Means, for small applications, hybrid desiccant cooling system will prevail more than the pure or dedicated/standalone desiccant evaporative cooling [19].

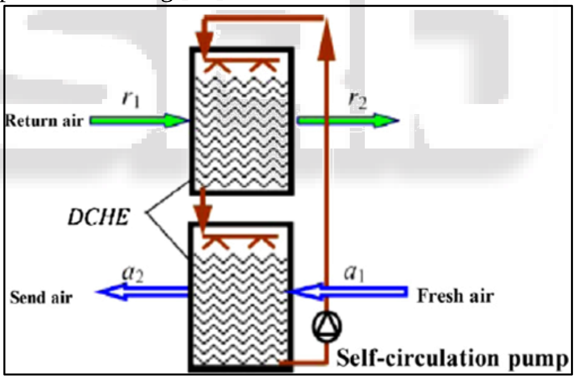

Fig. 7: Working of Liquid Desiccant Cooling System

The application of liquid desiccant cooling in thermal storage is shown in Fig. 8. The important factors for efficient absorption process are the inlet concentration of the liquid desiccant and the temperature during the absorption process. For a high energy storage capacity, high ratio of air to solution is required to achieve great difference between the solution inlet and outlet concentration ratio [20].

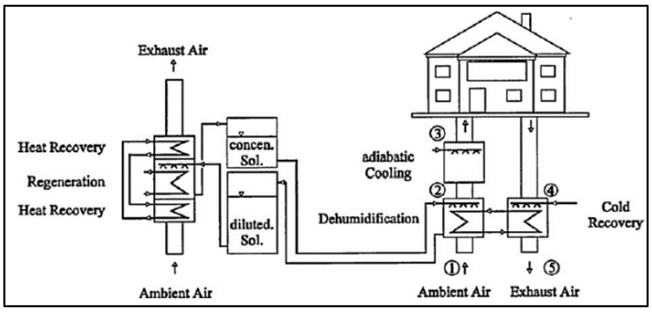

Fig. 8: The Liquid Desiccant Cooling System Integrated Thermal Storage System

Desiccant materials are used for air-conditioning applications with advantages in condition when:

1) The latent load is large in comparison to the sensible load.
2) The cost of energy to regenerate the desiccant is low when compared with the cost of energy to dehumidify the air by chilling it below its dew point.
3) The moisture control level required in the space would require chilling the air to subfreezing dew points if compression refrigeration alone were used to dehumidify the air.
4) The temperature control level required by the space or process requires continuous delivery of air at subfreezing temperatures.

III. COMPARISON OF SOLID DESICCANT COOLING WITH LIQUID DESICCANT COOLING SYSTEM

Regarding operational flexibility and ability to absorb pollutants and bacteria, the liquid desiccants are more attractive than solid desiccants. Liquid desiccants are usually regenerated at a lower temperature (less than 82°C) and equally create lower airside pressure drops. Furthermore, that also gives an opportunity to utilize solar or low-grade waste heat. It can also result in 40% in energy savings compared to conventional vapour compression systems due to regeneration extracted from the renewable source. Some advantages of extra features offered by liquid desiccant conditioners are: (i) high moisture removal capacity with low regeneration temperature requirement, (ii) the materials are typically very efficient antifreeze; lithium chloride/ water solution can cool air to temperature as low as −55°C, (iii) liquid desiccant conditioners usually possess high contact efficiency; air keeps almost the same temperature and humidity ratio from the inlet to the outlet, and (iv) the cost of energy for regeneration is lower in comparison to air dehumidification by chilling below the dew point.

The results showed in Fig. 9 liquid desiccant systems are able to provide supply air at 26°C at lower temperatures, but have a lower COP due to their size and would therefore require more energy usage at low capacities. The distribution of the annual COP of both systems in hot and humid is presented in Fig. 9 according to the frequency or the number of hour's application. From the results it can be concluded that liquid desiccant has a lower COP compared to solid desiccant. It was also reported that solid desiccant systems for all types' climates have the advantage of lower energy and water consumption. However, a drawback in use of this system is that it has limited accuracy and applicability within a limited range of conditions making the models impractical for other climates and conditions [21-22].

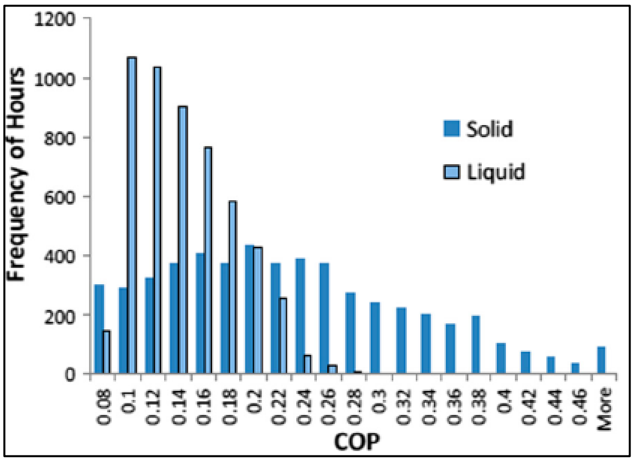

Fig. 9: Comparison of Performance between Solid and Liquid Desiccant Cooling Systems

IV. CONCLUSIONS

It has been seen that the standalone DAC can be operated by solar thermal energy for moderate humid climates for substantial reduction in operating cost of the same. The system performance increases with higher regeneration temperature. A dedicated DAC system for a given operating condition can obtain a certain level of performance and the design needs to be modified to achieve higher performance and economic feasibility. The present study reviewed on many kind of modifications namely VAC assisted hybrid system and multi-stage dehumidification. It has been found that multi-stage DAC system can be operated at lower regeneration temperature as compared to single-stage cycle delivering the same dehumidification amount. The moisture removal capacity in the two-stage dehumidification is found to be higher than single-stage with constant flow rate which helps to improve the system COP. Feasibility studies show that the potential of DAC in dry conditions is limited but there the evaporative cooling will become an optimum solution rather than conventional vapor compression system. Most of the earlier studies show that payback period of less than five years can be obtained by utilizing the DAC system intelligently and thus significantly contribute in ameliorating energy and cost saving and environmental protection.

V. NOMENCLATURES

- COP: Coefficient of performance
- T_{wb}: Wet Bulb Temperature [K]
- T_{db}: Dry Bulb Temperature [K]
- IEC: Indirect Evaporative Cooling
- DEC: Direct Evaporative Cooling
- DW: Desiccant wheel
- HE: Heat Exchanger
- HX: Heat Exchanger
- HS: Heating system
- CFC: Chloro Floro Carbon
- SA: Conditioned supply air
- RA: Return air
- EA: Exhaust air
- AA: Ambient air

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