

Thermodynamic investigation of M-cycle assisted open-cycle desiccant air conditioning systems

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Abstract. There is a necessity of low cost air conditioning (AC) systems for the agricultural sector of Pakistan e.g. product storage/preservation, greenhouse growing and thermal comfort of animals etc. Solid desiccant air-conditioning (DAC) system can be a handy solution in this regard. The present study gives a detail overview of DAC assisted with the Maisotsenko cycle (M-cycle) system and its applicability for the agriculture sector and livestock applications. Ideal humidity and temperature requirements for the agricultural and livestock applications have been represented on psychometric charts. Comparison between M-cycle assisted DAC and conventional DAC systems has been given which shows the significance of DAC technology in the AC sciences and also represented this difference as graphically. Desiccant AC systems are getting lots of attention in order to control the humidity in various air conditioning applications e.g. product storage, greenhouses and thermal comfort for the livestock. Different materials and arrangements of the desiccant air conditioning system are checked whether which arrangement is suitable for Pakistan situation. Additionally, some analysis has been made to investigate the DAC system assisted with M-cycle and checked the feasibility of system for ambient conditions of Multan. Results show that the DAC system can be low cost heat driven air conditioning system for the human comfort as well as agricultural sector of Pakistan.

Keywords: desiccant; air-conditioning; M-cycle; agriculture; product storage; Pakistan.

1. Introduction

Desiccant air conditioning (DAC) will be a definite solution for air conditioning instead of vapor compression air conditioning (VAC) as it has no effect on global warming (GW) and has zero ozone depletion potential (ODP) due to non-appearance of harmful refrigerants used [1]. Furthermore, individual evaporating cooling systems cannot be used individually for the regions where the controlled temperature as well as relative humidity is required [2, 3]. DAC system can handle the both temperature as well as relative humidity at the same time discretely. Desiccants are used to control relative humidity and evaporative coolers are used for control of temperature and these can be operated at low regeneration temperatures or low grade heat sources [4, 5]. For need of the humidity and temperature control, desiccant air conditioning systems and desiccants are becoming eye catching technology for human as well as non-human thermal comfort mostly in humid and hot climates [1, 4, 6, 7]. System schematics are shown in Figure 1, which show the system with integration of any evaporative cooler (M-cycle) and the system without integration of evaporative cooling system (M-cycle). M-cycle (advance indirect evaporative cooling system) is innovative thermodynamic conception in the field of evaporative cooling systems that can lower down temperature up to dew point [8, 9]. Therefore, a set of equations are used for the analysis of desiccant wheel and performance evaluation of M-cycle which are developed by Sultan et al. and Jurinak et al., respectively [9, 10].



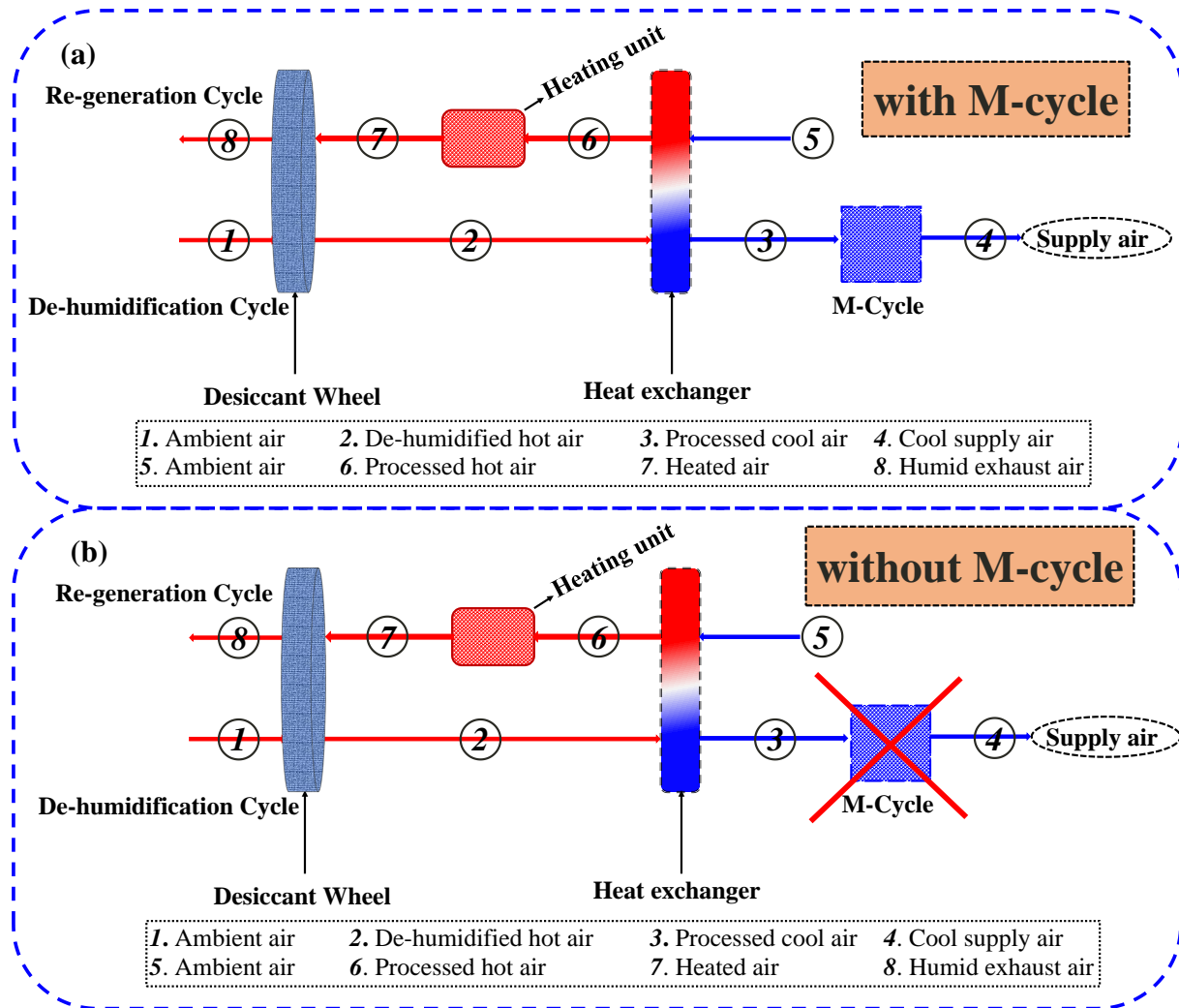


Figure 1: Typical desiccant air conditioning systems: (a) Desiccant air conditioning system with integration of M-cycle; (b) Desiccant air conditioning system without integration of M-cycle.

2. Research methodology

For the analysis of DAC system, grain type silica gel is used in desiccant wheel. Silica gel is cheap, easily available material and has a high capability of water uptake [2, 7, 11, 12]. Desiccant wheel is evaluated under static conditions. Unit mass flow rate is considered for system analysis. The schematics of the systems have shown in Figure 1. The systems mainly contain a desiccant wheel, flat plate heat exchanger, heating unit and M-cycle unit. The effectiveness of the heat exchanger is considered as 0.90, the outdoor air is passed through the system from 1 to 4 to be air conditioned for required space. Therefore, conditions of air associated with DAC, HX and M-cycle are estimated for same flow rate (unit mass flow rate) using the following equations (1) to (4). Equation (1) and (2) are used for the desiccant wheel performance [7, 12] and equation (3) and (4) are for the heat exchanger and M-cycle performance calculations [9, 13], respectively. Furthermore, COP of the system is calculated by using equation (5) [14].

$$F_{1,ip} = \frac{-2865}{(T_{ip} + 273.15)^{1.49}} + 4.344 \left(\frac{w_{ip}}{1000} \right)^{0.8624} \quad (1.1)$$

$$F_{2,ip} = \frac{(T_{ip} + 273.15)^{1.49}}{6360} - 1.127 \left(\frac{w_{ip}}{1000} \right)^{0.07969} \quad (1.2)$$

$$\eta_{F1} = \frac{F_{1,2} - F_{1,1}}{F_{1,8} - F_{1,1}} \quad (2.1)$$

$$\eta_{F2} = \frac{F_{2,2} - F_{2,1}}{F_{2,8} - F_{2,1}} \quad (2.2)$$

where F_1 and F_2 are combined potentials, η_{F1} , η_{F2} are the efficiencies in terms of the combined potentials and $(\eta_{F1}, \eta_{F2}) = (0.05, 0.95)$ for high performance desiccant wheel and '*ip*' indicates the state of air in the system (1, 2, and 8).

$$T_3 = T_{2,db} - \varepsilon_{hx}(T_{2,db} - T_{1,db}) \quad (3)$$

where ' ε ' is the efficiency of the HX whose value is considered as 0.9

$$T_{out} = 6.70 + 0.2630 (T_{in}) + 0.5298 (w_{in}) \quad (4)$$

$$COP = \frac{\text{Cooling capacity}}{\text{Heat input}} = \frac{|h_1 - h_4|}{|h_7 - h_6|} \quad (5.1)$$

Thermal COP can be calculated in terms of enthalpy at different stages.

$$h = 1.006T + w(2501 + 1.86T) \quad (5.2)$$

T is temperature in °C, w is humidity ratio in g/kg-DA.

3. Results and discussions

In this study, performance of desiccant wheel is evaluated for ambient conditions of Multan. Moreover, analysis based on monthly and hourly data as shown in Figure 2 and **Error! Reference source not found.**, respectively. The results show the feasibility of material for air conditioning purpose as relative humidity and temperature are concerned. A very low amount of temperature and relative humidity can be obtained by using both systems discussed in above headings, whereas M-cycle assisted DAC system shows better results in terms of controlled relative humidity and temperature requirement for the air conditioning space. Furthermore, the temperature and relative humidity requirements for fruits, vegetables, buildings, livestock and product's storage can also be obtained by DAC system while the size of the desiccant wheel will be changed [2, 6, 11]. Analysis of monthly data shows that DAC system is valid for tropical regions and also for subtropical regions in winter or monsoon season when the relative humidity is very much high. Whereas analysis of hourly data shows that DAC system works better in night conditions rather than day conditions because of higher relative humidity.

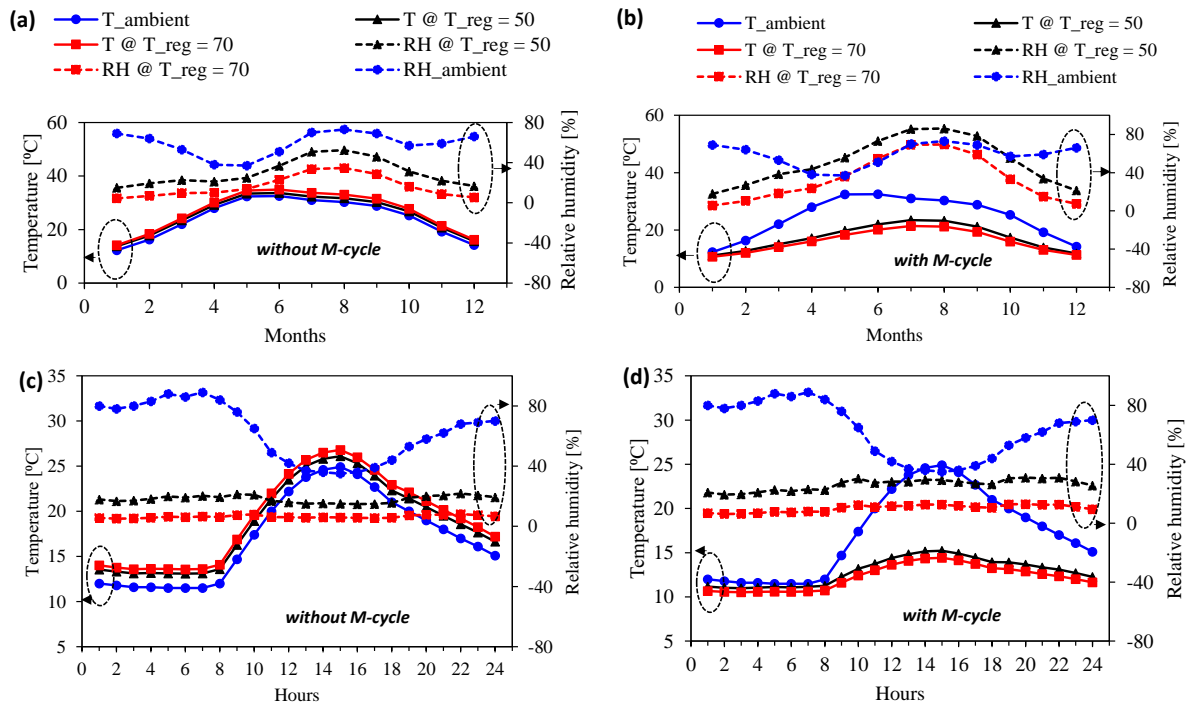


Figure 2: Monthly and hourly data of ambient air conditions which are at $T_{reg}=70\text{ }^{\circ}\text{C}$ and $T_{reg}=50\text{ }^{\circ}\text{C}$ for Multan: (a) monthly data for system without M-cycle; (b) monthly data for system with M-cycle; (c) hourly data for system without M-cycle and (d) hourly data for system with M-cycle.

Data analysis shows that DAC system integrated with M-cycle provides better air conditions than that of system without M-cycle in both monthly conditions and also in hourly conditions as shown in the Figure .

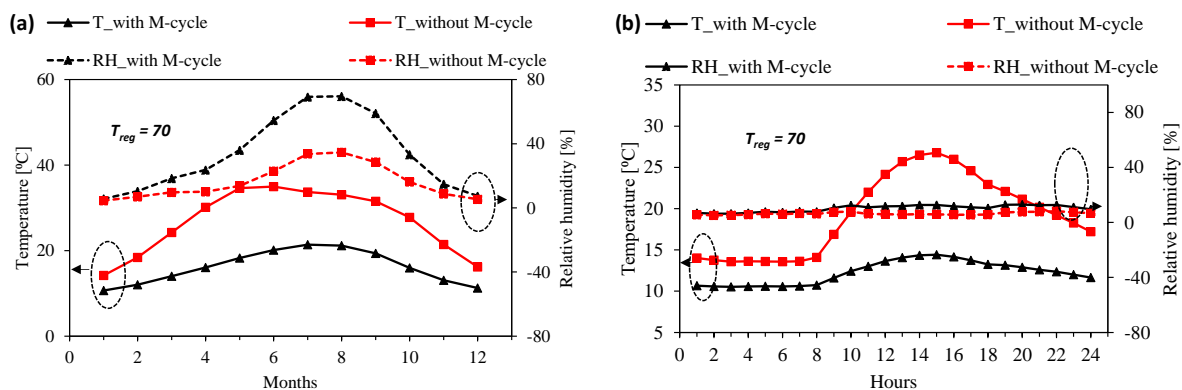


Figure 3: Comparison of systems at $T_{reg}=70\text{ }^{\circ}\text{C}$ for Multan condition: (a) comparison on monthly basis and (b) comparison on hourly basis.

Furthermore, there are no. of parameters involved in the performance evaluation of DAC system [2, 4, 5, 11] such as;

- Air flow rate of supply air and exhaust air.
- Rotational speed of the desiccant wheel.
- The regeneration temperature of the desiccant wheel.

These parameters have a great influence on the performance of the desiccant wheel. If regeneration temperature is increased to a high level, the COP of the system decreased. Results show that how regeneration temperature influences on the COP and how the trend line moves with the temperature variation as shown in the Figure 4.

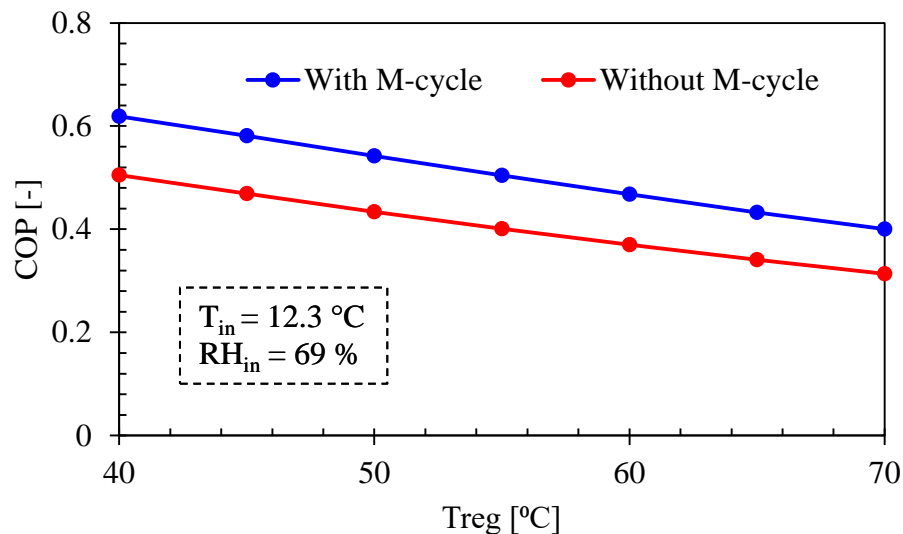


Figure 4: Calculation of COP of the DAC system (with and without integration of M-cycle) by changing the regeneration temperature at specific ambient conditions for the month of January

As the regeneration temperature decreases, the value of COP of the DAC system is increases due to less ambient temperature. Results also shows that the system assisted with M-cycle has better COP than that of the system without the integration of M-cycle. Furthermore, both systems are applicable depends upon the ambient conditions of the space need to be air conditioned. As the regeneration temperature will be increased, the COP of the system will be decreased. So, regeneration temperature depends upon the material properties. Every material has an optimum regeneration value at which the system has maximum COP [2, 4].

4. Conclusions

The aim of this study is to check the feasibility of the desiccant air conditioning system with and without integration of M-cycle. DAC system without integration of M-cycle can be used for the climatic conditions where the temperature is low or controlled relative humidity is required e.g. northern areas in Pakistan, while DAC system with integration of M-cycle can be used where both temperature and relative humidity control is required. A set of equations are used for the analysis and performance evaluation of DAC system as well as M-cycle developed in the literature. Analysis have shown the validity of the systems to satisfy the actual cooling loads for different applications such as; product storage, greenhouses and thermal comfort for the livestock. The air flow rate, regeneration temperatures and the size of the desiccant wheel depends upon the cooling load requirements which vary for different applications and also for different climatic conditions. A considerable working range is achieved by using M-cycle assisted DAC system for different agricultural applications. Furthermore, DAC system can be designed for any specific purpose by using analysis and set of equations used in this study.

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