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Research Paper

# Experimental analysis of an improved Maisotsenko cycle design under low velocity conditions

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## HIGHLIGHTS

- Improved structure of Maisotsenko cycle is experimentally investigated.
- Experiments are conducted in three different operating conditions.
- Supply air temperature depression is accounted for different inlet velocities.
- The improved design resulted 5% more efficient than the previous designs.

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## ABSTRACT

In this paper performance of an indirect evaporative cooler is experimentally analyzed in terms of its thermal effectiveness. A heat and mass exchanger (HMX) using a cross-flow pattern incorporating Maisotsenko cycle (M-cycle) is designed and fabricated having an improved channel width to height ratio and more efficient moisture absorbing material (felt) on the wet channel. Experimental investigations are conducted under various operating conditions of inlet air including its humidity, temperature and velocity along with water temperature. The experimental results indicate that the dew point effectiveness and the wet bulb effectiveness vary in the range of 62–85% and 92–120%, respectively with inlet air temperature variation from 25 to 45 °C at different humidity ratio ranging from 11 g/kg to 19g/kg. Moreover, the overall performance of the improved design is found 5% more efficient in terms of wet bulb effectiveness compared to the previous systems.



## 1. Introduction

The total energy consumed by buildings across the world is 30–40% [1]. The major portion around 50% of this energy is utilized by buildings for air-conditioning purposes [2]. The demand for air-conditioning appliances is constantly increasing throughout the world due to installation of heavy heat generating machineries. Almost 95% of air-conditioning appliances utilizes vapor-compression systems for cooling purposes [3]. These systems consumes substantial amount of energy. To make the air conditioning systems more energy efficient, it is necessary to develop effective methods for cooling, and one such method is evaporation of water.

Evaporation of water by the use of heat energy present in atmosphere is an environment friendly technology for air conditioning. Evaporative cooling systems consume about one fourth of electric energy compared to conventional air conditioning systems [4]. Additionally, these systems also contribute in reducing fossil fuels consumption and greenhouse gases. Two major types of evaporative cooling systems are direct and indirect evaporative cooling systems. In hot and arid climatic conditions the use of Direct Evaporative Cooling (DEC) is much successful. However, the capacity of such a system is limited by the amount of vapor the cooling stream can hold. On the other hand, Indirect Evaporative Cooling (IEC) offers an advantage by lowering the temperature to wet bulb temperature without increasing the humidity. Not only has it overcome the potential health hazard of contaminated water droplets (as in DEC) also it requires much less electric power compared to vapor compression cycles.

The effectiveness due to temperature depression of direct evaporative cooling systems is found to be 75–95% [5]. In contrast to direct evaporative systems, indirect evaporative systems have low cooling effectiveness ranging from 40 to 60% [6]. It shows that in hot climate when ambient air dry bulb temperature is 34 °C and corresponding wet bulb temperature is greater than 27 °C, the temperature of supply air will theoretically decrease and approach toward its wet bulb temperature i.e. 27 °C [7].

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A number of evaporative cooling variants have been tried to improve the efficiency of the systems. For instance, Ray suggested a technique by coalescence of direct and indirect processes to reduce the temperature of surrounding air below its wet bulb temperature without the use of conventional mechanical refrigeration systems [8]. In another study, Maclaine-Cross and Banks examined the evaporative transfer of heat theoretically in a regenerative cooling process. Linear slope for saturation enthalpy–temperature relation of air was assumed and proposed a modified model that can prognosticate performance of cooler by analogy to heat exchangers of dry surface type. Their results suggest that regenerative evaporative cooling process has the capability to reduce below the wet bulb temperature [9]. Hsu et al. theoretically and experimentally studied three different types of indirect evaporative cooling systems with different configurations of air flow: cross-flow, regenerative and counter-flow arrangements [10].

Previous researches have indicated the usefulness of evaporative cooling systems to achieve the conditioned air temperature below wet bulb temperature of ambient air. Recently a new type of heat and mass exchanger (HMX) using Maisotsenko cycle has been introduced in IEC [4]. Maisotsenko cycle or M-Cycle uses the wet and dry sides of the plate just like IEC, but with a much different air circulation pattern. This allows the temperature of the product air to approach dew point. The wet bulb effectiveness of M-cycle system is reported 20% higher than the conventional IEC [11]. Therefore, the effectiveness of M-cycle evaporative cooling systems can be increased compared to conventional IDE systems [12]. In humid and hot climate this system can be coupled with dehumidifier unit such as desiccant system to control the humidity level of supply conditioned air. Few systems with varying configurations have been built using M-cycle to assist conventional refrigeration and air conditioning systems as well as standalone applications. However influence of important parameters such air flow patterns in HMX, geometrical configuration and constituents of HMX are yet to be analyzed in detail. Different HMX configurations have been tested, mainly experimentally, and comparison has been made with mathematical models also [13]. Recently, performance and optimization study of different M-cycle based heat exchangers have been carried out in different air-conditioning applications [14,15]. Apart from air-conditioning, M-cycle has also been used in other applications such as gas turbine power cycle [16].

In the current study, an experimental investigation of an evaporative cooling system based on cross flow configuration of M-cycle is presented. The main objective is to achieve high dew point effectiveness with an improved and low cost system design in terms of channel width to height ratio and efficient absorbing material. The evaporative system was installed at the Renewable Energy Resource Development Center (RERDC) of University of Engineering and Technology (UET), Taxila, Pakistan. Mostly commercial and research HMX designs involve high flow rates suitable for commercial and industrial applications. The focus of the research is design and development of cost effective small scale air conditioning unit. Experimental study targets low air flow rates and the results of the purposed design are shown along with other published studies for qualitative comparison only.

## 2. Psychometric comparison of direct, indirect, and dew point evaporative cooling

In direct evaporative cooling, a direct contact of air is made with water where the lowest temperature which can be possibly achieved theoretically is wet bulb temperature as described in psychometric path 1–2′ in Fig. 1a. Therefore, theoretically speaking wet bulb effectiveness up to 100% can be achieved; however in practice wet bulb effectiveness is significantly less than 100% as depicted by process 1–2 in Fig. 1a. Whereas, two separate channels for air flow

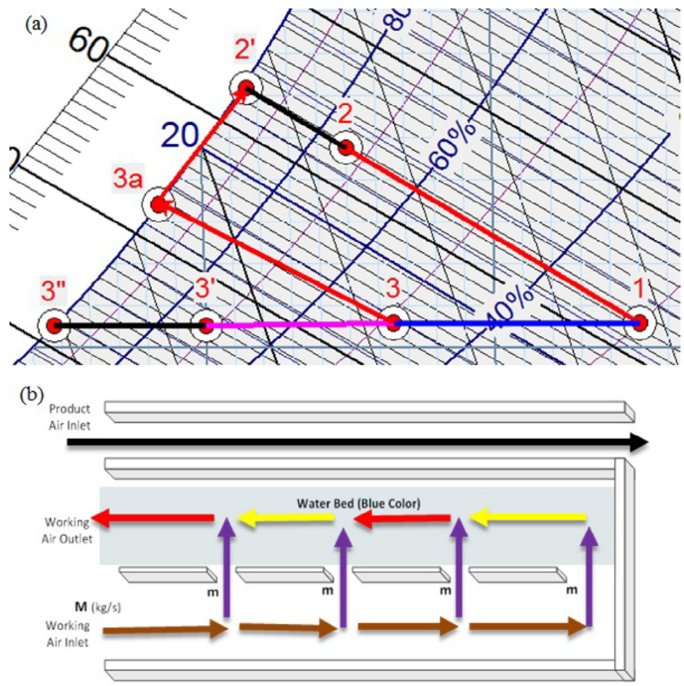


**Fig. 1.** (a) It is psychrometric analysis; not psychometric analysis of different evaporative cooling processes; (b) Schematic of M-cycle evaporative cooler.

are usually used in an indirect evaporative cooling system. One channel is kept wet while other remains dry. Air flowing through the wet channel causes evaporation due to which the temperature reduces toward wet bulb temperature as shown by path 1–2′. The adjacent side is dry therefore air entering through the dry channel loses its sensible heat to adjacent wet side and cools down following path 1–3′. The temperature drop at wet side can theoretically reaches wet bulb temperature of ambient air at the inlet as shown in Fig. 1. However, due to ineffectiveness and inefficiencies, the actual processes are limited to 1–2 (wet side) and 1–3 (dry side).

M-cycle works on a principle of indirect evaporative cooling albeit with a different flow pattern. As depicted in Fig. 1b, it uses two channels; product and wet channels. The distinctive part of M-cycle is the flow pattern in the wet channel. The key idea is to pre-cool the air entering in the wet channel, through the dry part of the wet channel. Moreover, some of the air from the dry part is passed on to wet side at intermediate stages as well, as shown in Fig. 1b. The process path is shown in Fig. 1a as 3–3a, the location of point 3a is somewhat arbitrary as it depends on geometric configurations and flow patterns. After mixing, the wet side air gets humidified through evaporation and extracts heat from the product/supply side. Eventually, this working air will discharge to atmosphere. Theoretically, temperature of supply air can reduce to sub-wet bulb temperatures and can reach the dew point temperature of incoming inlet air [17]. The relationship among the conditioned air temperature and factors like mass flow rate can be established by enthalpy balance of fluid entering and leaving the system.

The change in enthalpy in the dry side is due to sensible heat loss which depends on the working to intake air ratio (r). The temperature of supply air at outlet depends on the inlet/ambient air temperature, working to intake ratio of air and the enthalpy difference of working air at the wet side. Supply air temperature can be varied by changing the working-to-intake ratio of entering air. However, by increasing the working-to-intake ratio of air the outlet air flow rate to the conditioned space will be reduced with high