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Experimental Thermal Analysis Of Eco-Friendly, Sustainable And Biodegradable New Mud/Clay Based Cooling Pad For Evaporative Coolers

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This paper presents an experimental thermal study on the performance of a new mud/clay-based evaporative cooling pad. A clay/mud balls-based evaporative cooling pad joins a plurality of clay/mud balls of appropriate diameter and is converted into layers made by arranging the plurality of garlands in an inline or staggered arrangement. The cross-section area 0.310 × 0.310 m^2, water temperature 35°C, air inlet temperature 42°C, thickness 38 mm, air velocity 4.3 to 7.3 m/s and water-flow-rate 0.237 kg/s are studied. The investigations are carried out in a suitably fabricated test rig. The performance parameters for evaluating the usefulness of cooling media as a cooling material are temperature drop and humidifying efficiency. The present paper investigated the mud/clay-based cooling pad performance for a wide range of air velocities. The results show that the humidifying efficiency of the new mud/clay ball-based pad highest obtained value is 86%. This new pad highest temperature drops are 17°C. The invention is envisaged in a setup where people from middle/lower income groups residing in arid /semiarid climates/regions use evaporative/desert coolers to beat the extreme heat of dry summers. In furtherance, environment- and energy-conscious people also use this evaporative cooling technology offered by desert coolers. This pad system consists of mitti balls with increased humidifying efficiency capable of providing a better cooling effect.

Keywords- Arid climate, temperature drop, inlet temperature, air velocity, humidifying efficiency.

1. Introduction

Cooling by evaporation is a supremely capable and inexpensive method. Direct evaporative cooling (DEC) applies to AC systems like air coolers [1]. However, building power bills have turned out to be too expensive. Thus far, the commercially leading cold structures, i.e., vapor-compression systems, are intensively power-consuming. Besides, these arrangements are accountable for leaving go of definite substances obsessed with their surroundings, which source global warming and ozone-layer depletion. It is an asset that brings up the energy essential for AC. accounts for just about 50% of structures overall energy feeding, and buildings energy used nearly 40% of the universal energy loads with the about carbon footprint [2].The electricity consumption in the construction industry signifies 32% of the universally utilized, as directed through the IEA [3]. Chasing the power utilized of a cooler in a small office complex has shown substantial energy reserves and upgraded thermal comfort associated with conventional air-conditioning arrangements [4]. It has numerous eco-friendly assistances, which contain the decline of CO_2 and chlorofluorocarbon (CFC)- hydro chlorofluorocarbon (HCFC) emanations [5]. Evaporative cooling is greatly a smaller amount of energy concentrated as compared to conventional cooling by way of energy reserves of up to 90% [6]. The evaporative cooling technology is an adequate and environmentally conscious substitute for current MVC arrangements in cooling applications [7]. It practices the vaporization of water, and the energy consumption is deficient [8]. Consequently, evaporator cooling has been a matter of significant investigation interest. Evaporative coolers are well-suited for hot and humid climates. Cooling through evaporation is used in temperate areas like southern Australia and the United States [9] and in hot and arid areas like the Mid-East and Northern areas of America. Evaporative cooling has turned into part of human life needs, even though it's applicable in temperate environments, such as the United Kingdom, Denmark, and areas of Europe, and is correspondingly quickly developing [10]. In peak duration in summer, that time environment is so much hot. At that time evaporative cooling is also used in numerous towns in China, Kuwait, etc. [11].

Evaporative cooling technology is so much eco-friendly and efficient. The working principle is heat absorption by evaporation of water, just evaporating cooling. Many investigations were conducted by the Mathematical modeling and Experimental performance for numerous cooling pad systems. A heat and mass transfer-based system is presented by Heidarinejad et al. [12]. In Iran, prominent towns used cooling media only water. It utilizes much less power to provide a comfortable system. A simplified study for explaining the relationship between water and air in the DEC system is developed by Wu et al. [13].

The performance of cellulose as a cooling medium was evaluated and maximum cooling efficiency was achieved and presented by Kachhwaha et al. [14]. A mathematical simplified study for a cooling system by Fouda et al. [15]. A study in the case of air and water related to cooling systems was presented by Kovacevic et al. [16]. The designed metallic cooling pad increases the interaction between air and water. Direct-contact cross-flow heat exchangers can also be used in air-cooled condenser applications. The performance study of Corrugated-cellulose paper pads in a greenhouse for Shanghai City located in China is experimentally investigated by Xu et al. [17]. A mathematical and experimental study using cellulose as a cooling material was presented by Camargo et al. [18]. The maximum effective obtained at 90 mm thickness in the evaporative cooling system. A numerical study by using air velocity for calculating the pad effectiveness was presented by Kovacevic and Sourbron [19]. Heat transfer development by DEC system with diverging micro channels was developed by Sung et al.

[20]. In the two heat exchangers, there is no significant difference in terms of pressure drop at low heat fluxes earlier it reaches the fractional dry-out circumstance. The pressure ratio and inlet air temperature is important parameters in the analysis of the system. A theoretical Modelling and simulation of the wet porous medium was developed by Tang et al. [21]. Results are associated with investigational data and provide better support for the effectiveness of the system. Nasr et.al [22] presented Enhanced Evaporative Fluid Coolers with evaporative cooling as a working principle. Pressure drop plays a vital role in the design algorithm. The Thermodynamic analysis with inlet air cooling was presented by Shukla et al. [23]. A data logger arrangement installed for data measurement of power consumption in an evaporative cooling system was presented by Weerts [24]. A study on air-cooling systems with pressure drop as a dominance factor is developed by Kumar et al. [25]. Zube et al. [26] developed an experimental analysis study by taking air flow rate as an operating parameter and pressure and temperature as a performance parameter. A numerical-study of a porous evaporative air cooler was presented by Anisimov et al. [27]. The maximum efficiency of 83% of an evaporative cooler was achieved at 32°C as an inlet condition and system presented by Lee et al. [28].

Schmit et.al. [29] presented an optimization technique for high-intensity cooler design. The results show improvements over the empirical design. Shukla et al. [30] presented the effectiveness evaporative cooling system. The study shows better efficiency with an inlet evaporative cooling system. A heat transfer study using porous obstacles with a cooling system was presented by Kumar et al. [31]. Porous obstacles show better performance and are suitable for local cooling applications. Nasr. et.al. [32] presented an algorithm for air coolers. In air coolers, total cost decision surface area and power consumption are important parameters.

Literature describes the different cooling pad materials like honeycomb, wood wool, khus, coconut, jute, Eucalyptus, Banana, Polyvinyl Chloride (PVC), etc. These pads were tested by various researchers in different regions/climates by experiment. The performance parameters include specific humidity, temperature drop, pressure drop, power consumption, humidifying efficiency, etc. flow rate of water, velocity of air, inlet air temperature, and thickness of pads are the parameters on which performance was calculated.

Nomenclature

T_{id} dry bulb temperature at inlet , °C

T_{od} dry bulb temperature at outlet , °C

T_{iw} wet bulb temperature at inlet, °C

V_{air} air velocity, m/s

$\dot{m}_w$ mass flow rate of water, kg/s

t_w temperature of water, °C

Greek symbols

δ thickness of cooling pad material, mm

ΔT temperature difference, °C

η_{hum} humidifying efficiency, %

Subscripts

a	air
in	inlet
out	outlet
w	water
wb	wet-bulb

Abbreviations

DEC	direct evaporative cooling
EC	evaporative cooling
AC	air conditioning
DEC	direct evaporative cooling
CFC	chlorofluorocarbon
HCFC	hydro chloro fluoro carbon
HVAC	heating ventilation and air conditioning
PUF	polyurethane foam
RTD	resistance temperature detector
PVC	polyvinyl chloride
MVC	mechanical vapor compression
IEA	international energy agency
UN	united nation

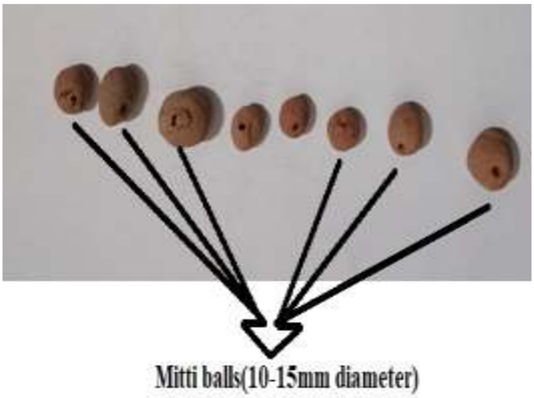
Usually, people use honeycomb, wood wool, khus, and coconut pad. Mitti ball-based pads are made by Mitti, which can be locally available, sustainable, biodegradable, easy to manufacture, and cost-effective. This work is in sync with UN Sustainable goals [33], like optimum energy usage for comfort conditioning for the well-being of incompetents and making society and cities of the said areas. It also covers the education and health domain.

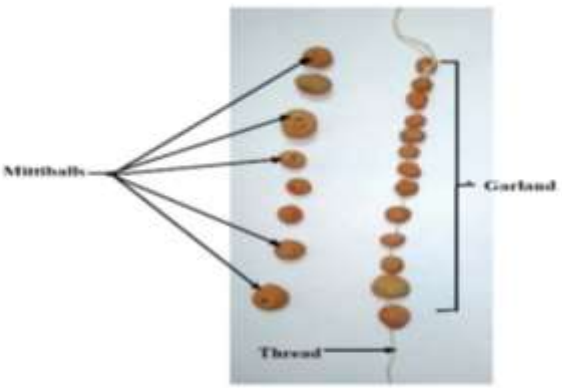
The usage of clay/mud as a pad material in the EC system in dry conditions has not been found yet. Mitti ball-based cooling pad systems for evaporative coolers provide cooling at a low cost. In this research, we are not doing heat and mass transfer modeling. In this paper, the thermal performance of the new Mitti-ball-based pad is experimentally investigated. The effects of "operating conditions" and geometric parameters on the arrangement of performance parameters (temperature drop and humidifying efficiency) are investigated. This experimental setup has been done and explained in this work.

2. Pad material and Experimental Methodology

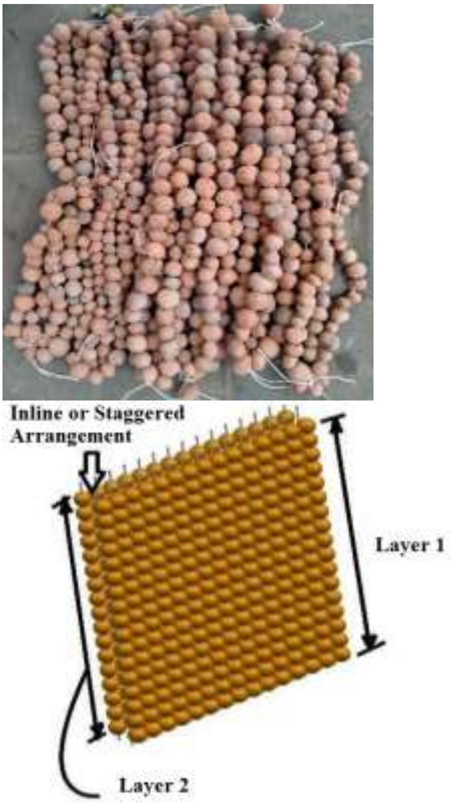
2.1 Evaporative cooling pad material

A mitt-ball-based pad is prepared with mitti (locally available) as a material. Balls are designed manually. The ball's diameter varies from 10-15 mm, and a hole at the center of the ball so that it can be easily arranged during netting. These clay balls are garlanded using string/thread. These garlands are arranged in layers and layers are arranged one after the other. Mud/clay ball-based arrangements are shown in Fig. 1. As per the requirements, pad thickness can be varied by increasing the layers of garlands.





1(a) 1(b)



1(c) 1(d)

Fig.1. New mud/clay based evaporative cooling pad system: 1(a) Mud/clay balls 10-15mm diameter, 1(b) Ball converted into Garland by using thread, 1(c) Balls arrangement in a Garlands form, 1(d). Layers of garlands arranged in an Inline or Staggered position.

Layers made out of balls netted/shaped in garland can be arranged in a curtain form whether in an inline/staggered arrangement. Balls are placed in the form of garlands by using thread as per the desired size. As per the requirement, pad thickness can be varied.

2.2 Experiment arrangement

An experimental arrangement was generated and erected to examine/investigate the "thermal-hydraulic" performance of a new mitt-ball-based pad. The test runs were performed over various operating conditions. Different cooling pads were tested under a steady-state conditions. The arrangement has a rectangular cross-section duct whose width is 340 mm, height is 330 mm, and duct length is 1m. The main components test rig are the air- fan, electric-motor, water- arrangement, and pad fixture arrangement. For measuring air temperatures (RTDs PT-100) was used. The duct walls are 0.8 mm in "galvanized iron sheet" thickness. The walls of the duct are 25 mm thick Polyurethane Foam (PUF) as thermal insulation to diminish the system's heat losses and ensure that the test rig is airtight (no leakage) and heat balanced in each section properly.Fig.2. Shows the complete picture of the experimental test rig/arrangement.

Fig.2: Complete diagram of the experimental arrangement.

The experimental setup consisted of an air and water loop arrangement. The environmental air is circulated by an air fan, having specifications of 1/10 HP and 220 V. The electronic speed controller is used for controlling the fan speed. The polarity of the motor has been changed to ensure the feasibility of the motor-fan assembly in the system by changing the polarity of the input voltage/supply terminals, and its field of direction and armature current has been changed to keep the same speed [34].The incoming air temperature and water used for dropping over pads are measured using a Resistance temperature detector (PT-100, range: 0 to 100 °C, 3-wires) platinum material. Air from the fan is made to pass through the duct and the cooling pad section. Thus incoming fresh air is humidified and cooled. The water pump has capacity 860 L/hr in a water loop arrangement. Water pumps over the cooling pad section from the water tank. The tank for water storage is made by a galvanized iron sheet of 0.8mm width with geometry for tank 305 ×152×152 mm.

The water distribution system is manufactured from galvanized sheet steel 1.0 mm thick with 8 holes with gaps of 35 mm and an entire length of 330 mm. The air-cooled and humidified by the cross-flow arrangement of water flowing down over the cooling pad section. On upstream and downstream hygrothermometer used in the test rig system for ambient condition measurement.

For measuring the temperature (Calibrated, 3-wires, PT-100) temperature RTD sensor (model: SDI-9608) is used. The velocity of air is measured by Anemometers (AM-4201).

2.3 Experimental Procedure and Measurements

The tests were conducted 74^{th}kM stone Faridabad Haryana India 121004) in the summer (June-July 2021, from 9:00 AM- 6:00 PM). The performance of the new mitti-ball based cooling pad over operating conditions were performed experimentally (Studied parameters: V_{air}= 4.3 to 7.3 ms^{-1},t_{db}=42°C, $\dot{m}_w$=0.237 kgs^{-1} , t_w =35°C and δ=38 mm) . The thickness of pad is considered to be 38 mm. Variations of air rate at various operating parameters were studied, i.e., temperature drop and humidifying efficiency of cooling pad. First, turn on the fan, and then the water circulating pump starts and carefully fix temperature sensors at the specific location on both sides of the cooling pad. Data were recorded at steady-state conditions; the system took 20 to 30 minutes to achieve steady-state conditions. Readings were taken at numerous air flow values. Dry and wet-bulb temperatures were recorded at the "inlet and outlet" positions by Resistance temperature detector sensors and the air flow rate by Anemometer was recorded.

2.4 Performance analysis of evaporative cooling pad

Duct walls were thermally insulated by polyurethane foam so that the test rig (model) becomes airtight (assuming no leakage) and has proper heat balance in each section: heat ingression or rejection of other means is considered to be neglected. The humidifying efficiency of the cooling pads for the evaporative cooler can be calculated by equation (1) [35]:

$$\eta = \frac{T_{id} - T_{od}}{T_{id} - T_{sat}} \qquad (1)$$

Where T_{id} and T_{od} are the dry and bulb temperatures at the inlet and outlet

T_{sat} = Saturation temperature.

3. Result and discussion

The results show that the new mud/clay-based cooling pad performance (based operating-conditions) is tested. Air-temperature drop should be maximized for effective cooling.

The air temperature drop for the evaporative cooler's specific size/capacity are influenced by the air-flow rate as an operating condition; these parameters, as mentioned in the literature [36], [37], [38], [39], [40], [41]. [42] and [43]. In this work, an extensive parametric-study of the new mud/clay-based evaporative cooling pads is accompanied by numerous ranges of conditions. The evaporative cooling pad performance was analyzed by air temperature-drop and humidifying efficiency. The consequences of the functioning environments and the "system-parameters" on each performance parameter have been investigated.

3.1 Air temperature drop and humidifying efficiency

Fig.3 represents the consequence of air velocity on the temperature drop of air (ΔT) and humidifying efficiency (η_{hum}).

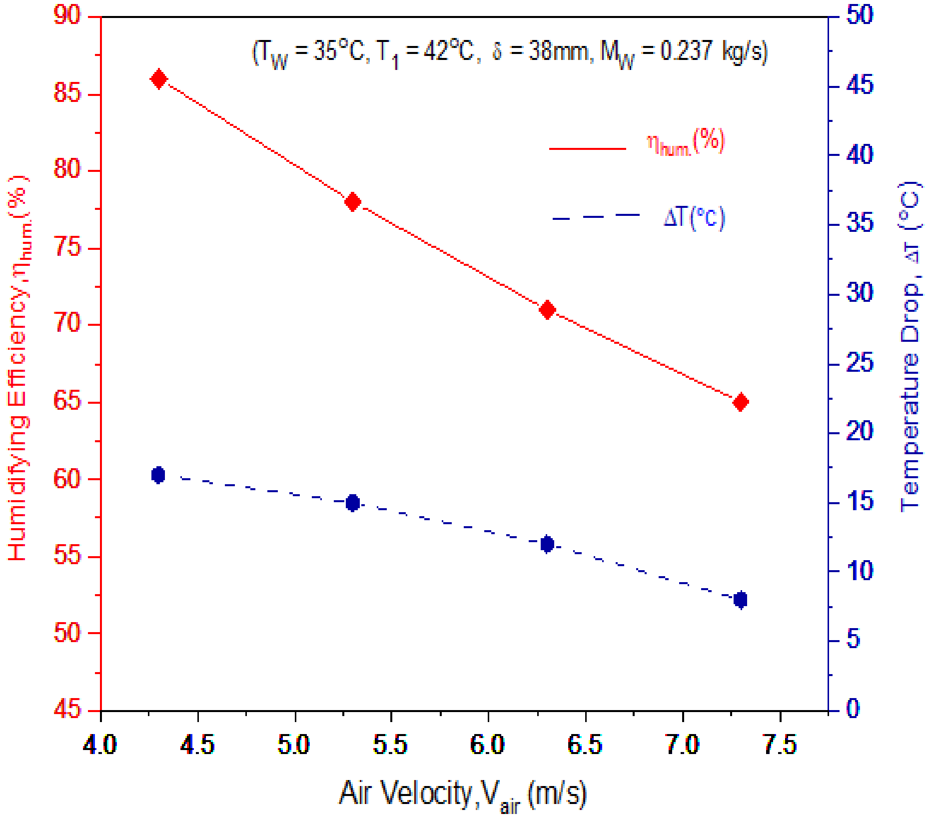


Fig.3. Consequence of velocity of air around the mud/clay-based cooling pad on temperature-drop of air and humidifying efficiency.

Fig. 3. Illustrates the decrease in the temperature of air causes an increase in saturation efficiency. As a result/outcome of the decreasing "air temperature" and decreasing air velocity, the humidifying efficiency increases. When air velocity increases, the amount of time that air particles spend in contact with the wetted pad decreases. This lowers the rate at which water evaporation occurs, which in turn lowers the air cooling potential. Because the "latent heat" needed for evaporation is drawn from the air, a significant rise in humidity is invariably followed by a substantial drop in air temperature.

The highest value obtained for ΔT and η_{hum} at 4.3 m/s velocity of air is 17°C and 86%, respectively. This was the trend in [40, 41, 44, 45] and [46], our experimental results reflect the same trend.

3.2 Assessment of the projected mud/clay cooling pad with others applied (as per literature).

As per the statistics achieved from the literature for various evaporative materials for cooling pad In comparison to other types of cooling pads, the pad tested in this work achieves the utmost drop in temperature of air (ΔT=17 °C) as indicated in Table 2 at pad humidifying efficiency (η = 0.86).

Furthermore, compared to the other types investigated in the literature [37, 41] and [44], the studied pad (mud/clay based cooling pad) maximum humidifying efficiency is much higher. Whereas, it has closer performance with honeycomb pad and Cellulose (bee-hive) in the literature [34] and [42].
Mitti ball-based pad are made out of mud/clay, which can be locally available, sustainable, biodegradable, easy to manufacture, and cost-effective (0.63 $/m^2.). The manufacturing process is straight forward to make a mitti ball-based pad compared to others. Manufacturing a Mitti-ball-based cooling pad is just like a Laghu Udyog. Therefore, the current pad (mud/clay ball based) is more applicable and reliable, it reveals the utmost temperature drop and humidifying efficiency.

4. Conclusion

Under a 4.3 to 7.3 m/s range of air velocity (as an operating conditions), the new mitt-ball-based cooling pad thermal performance is investigated experimentally. Temperature drop and humidifying efficiency are indicators of performance.
The present cooling pad detailed the study conclusion as follows.

- The enhancement in humidifying efficiency as air velocity decreases. The utmost humidifying efficiency (η =86%) is attained at v_{air} =4.3 m/s, δ=38 mm, $\dot{m}_w$=0.237 kg/s, T_1=42 °C and T_w=35 °C.
- The utmost drop in temperature (ΔT =17 °C) is attained at v_{air} =4.3 m/s, δ=38 mm, $\dot{m}_w$=0.237 kg/s, T_1=42 °C and T_w=35 °C.

Based on their easy availability, lower costs, performance, sustainability, and manufacturing, the new Mitti-ball-based cooling pad is the best. The Potential for sustainable growth in residential and commercial evaporative cooling systems may be expanded by using these pad materials as wetted medium. Evaporative coolers would be more energy-efficient if these materials were used in buildings to preserve energy.

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Appendix

By calculating the standard error of the mean (SE) using equation (A.1), the uncertainty was determined.

$$SE = \frac{SD}{\sqrt{n}} \tag{A.1}$$

Where n is the number of measurements and SD is the standard deviation.
For the analysis in case of uncertainty and 95% confidence level- 1.96 X SE in use.
Using the Taylor [47] method, the uncertainty was determinedTable A.1 illustrates the calculated parameters' uncertainty.

Table A.1 Calculated parameters with Uncertainty values

S.No.	Parameter	Calculated	Uncertainty (%)
1	Outlet WBT (°C)	Calculated	±2.16
2	Outlet DBT (°C)	Calculated	±2.5
3	Temperature Drop (°C)	Calculated	±2.17
4	Humidifying efficiency (%)	Calculated	±1.98

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