A REVIEW ON EVAPORATIVE COOLING

Prof. Santosh G. Dabade 1, Ms. Pinky Kumari 2, Mr.Nikhil K.Dable2, Yash S. Dhanawade 2, Akshay D. Bauskar2
1: Assistant Professor Sinhgad Institute of Technology Lonavala
2: UG students Sinhgad Institute of Technology Lonavala

Abstract—India is a tropical country which experiences a very high temperature during summer and becomes highly uncomfortable for the people. For cooling purpose people use refrigerator and air coolers which generates a high electricity bill, which leads to the investigation of water cum air cooler using the principal of evaporative cooling and thermosyphon, using solar energy as the source of power. This paper shows the research work in Evaporative cooling using clay materials and thus helps us in learning and understanding the cooling system more efficiently. This paper combines the different research work on evaporative cooling.

Index Terms—Analysis of evaporation, Additives for improving evaporation, Clay pot cooler, Direct and indirect evaporative cooling, Evaporative cooler, Natural cooler, Water cum air cooler.

◆

1 INTRODUCTION

Refrigeration is defined as the process of removing heat from a body or enclosed space so that its temperature is first lowered and then maintained at a level below the temperature of surroundings. In such a case, the body or enclosed space is said to be refrigerated system.

Refrigeration in its natural from dates to medieval times when food preservation was achieved by storing it in cave which were colder than the prevalent atmosphere outside. Also, cooling of products for preservation was achieved by immensingthem either in a steam of cold water or in cold shallow well. These methods could produce the temperature upto 10 to 15 degree Celsius. Cooling of water in earthen porous pots is well known to mankind.

It is general knowledge that from ancient practice, moulded clay materials keep the contents cold. This research work sought to identify to what extent it does this under specified conditions and the scientific proof to that effect. The work went further to do an in-depth analysis of evaporative cooling on sintered clay sample materials and the information obtained by experiment was used to model an evaporative cooling pad

2EVAPORATIVE COOLING

Evaporative cooling process remains one of the least expensive techniques, environmentally clean, fresh supply air and natural fragrance of air, to bring dry bulb temperature to a more comfortable range, during hot season since ancient times. It is based on the thermodynamic process of evaporating water to the surrounding air, which involves exchange sensible heat and latent heat between air and exposed water surface at constant enthalpy.Evaporative cooling is deemed to be an appropriate alternative cooling mechanism for the cooling of engineering systems in operation due to its simplicity, power saving characteristics as well as its attendant success as a cooling mechanism in other relevant applications. In principle there are two types of evaporative air cooling systems

- Direct Evaporative Cooling (DEC)
- Indirect Evaporative Cooling (IEC)

2.1DirectEvaporative cooling

In a Direct Evaporative Air Cooling (DEC) system, air is taken in through porous wetted media or through a spray of water. In the process sensible heat of air evaporates some water. The heat and mass transferred between the air and water lowers the dry-bulb temperature of air and increases the humidity at a constant wet-bulb temperature. The dry-bulb temperature of the nearly saturated air approaches the ambient air wet-bulb temperature. The process is an adiabatic saturation one. The wet bulb temperature of the entering airstream limits direct evaporative cooling. This is so because the Dry Bulb Temperature (DBT) of the outgoing airstream can at most be brought to the Wet Bulb Temperature (WBT) of the incoming airstream.

2.1 Indirect Evaporative cooling

In Indirect Evaporative Air Cooling (IEC) heat transfer between primary and secondary airstreams takes place. The air supplied from outside air to the conditioned space is termed as primary air. The primary air is cooled by secondary air with the help of heat transfer. Secondary air evaporates some of the water which reduces the temperature of secondary air and water. Theoretically temperature of secondary air and water can be reduced to the secondary air wet bulb temperature. Heat transfer takes place from the primary air to the secondary air through the wall of the heat exchanger. While constant wet bulb temperature cooling takes place in the path of secondary air and sensible cooling takes place in the path of primary air.

3. CERAMIC/CLAY POTS

Ceramic in an inorganic, non-metallic solid prepared by the action of heat and subsequent cooling. They withstand chemical **erosion** that occurs in other materials subjected to acidic or caustic environment. Ceramic pots are made of normal mud used for making water pots which is present in abundant, cheaply available everywhere and easy to process. It is heated at 70 degree Celsius for five hours. A material's strength is dependent on its microstructure. The engineering process to which a material is subjected can alter this microstructure. Theoretically, a material could be made infinitely strong if its grain is made infinitely small.

3.1 proprties of clay/ceramic material

Clay pipe is made of chemically combined silica, alumina and water.In its natural state, it is rarely pure and usually contains impurities such as sand, limestone, pebbles, iron oxide and traces of other elements it has accumulated over the long period of time it has taken to become clay. These impurities in any combination provide the clay with a unique set of properties that make different types of clay useful for different purposes. Pure clay with little or no impurities lacks some of the properties that a potter need.

1) Shrinkage --- The reduction of the clay mass that occurs when water in the clay evaporates during drying and firing.
2) Plasticity --- The property of the clay that allows it to change shape without tearing or breaking.
3) Moisture --- All clay has moisture, as the moisture evaporates the clay gets harder to shape.

4 RESEARCH WORK

4.1 Analysis of water in ceramics

Due to the ability of clay vessels to store and retain water below ambient temperature, it has become a basic commodity for water storage among the rural dwellers. It therefore, becomes necessary to study and determine how effective and efficient porous clay pot serves as evaporating coolers. The effectiveness of the clay pots depends upon the shape of pots used, ambient air conditions, water holding capacity and also the composition of clay material. Experimental analysis of clay pots with different shapes are carried out previously. It was observed that the mass loss of the water by evaporation was significantly affected by the surface area of the pots and the microstructure (closeness of the pores in the structure).

The pot with the widest surface area results into most effective cooling and heat transfer of the water in pot by evaporation.

Enthalpy is the amount of internal energy within the system. Enthalpy is a function of temperature rise a positive enthalpy values indicate an endothermic reaction which results in marginal cooling of water in pots. There exist a relationship between temperature, enthalpy and evaporative cooling rate. Higher the temperature higher will be the enthalpy and evaporativecooling rate. At initial stages the temperature of the water is high which will result into high enthalpy and high evaporative cooling rate but with time the temperature of water will be lowered down consequently lowering down the enthalpy and evaporativeCooling rate [1]

Relative humidity is also an important parameter in evaporative cooling because it affects critically the evaporation. Experimental studies have been carried out on effect of relative humidity (RH) on evaporation. In a small porous clay vessel if the surrounding relativehumidity is 60% the depression of water is found 4.7 degree Celsius, decreasing the relative humidity to 15% water temperature depression was 8.7 degree Celsius. Hence it is observed that the cooling effect enhances in a drier environment. [2]

Nowadays a new method of pot in pot vessels are used as evaporative coolers to store vegetables or fruits. It is a method with zero energy consumption and hence a very economical one. But between two pots instead of directly adding the water a mixture of sand and water is used because of the additional value of sand to be used as an insulator. [3]

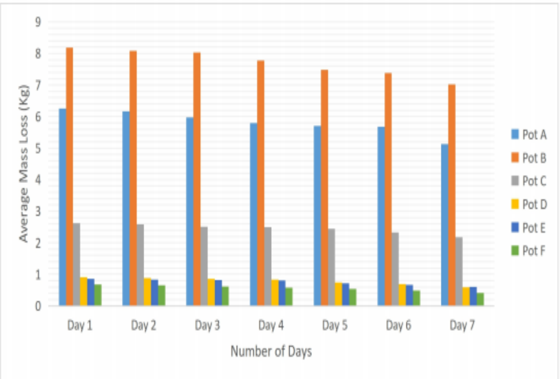

Fig 1 Average Mass Loss with Number of Days [1]
The average mass loss readings were taken bihourly for 8 hours daily for seven days for various pots shape.

4.2 Analysis of effect of evaporation on ambient air

Evaporative cooling is primarily cooling from the evaporation of water. Evaporation of water results in significant increase in humidity. Analysis of effect of evaporation on ambient air are carried out with variations. Pots with different arrangement and orientations are studied to find out the effectiveness in cooling. Single, Double, three pot arrangement with aligned and staggered positions are analyzed. Staggered alignment with three pots gives the most effective cooling at lower air velocity. At 1 m/s air velocity 47% and 57% cooling effectiveness by evaporation was found out for aligned and staggered positions respectively. Increase in Relative humidity for staggered and aligned positions were 9% & 7% respectively. Hence the staggered configuration allows greater flow of air mass over the pots turning out to be the most efficient one. [4]

Cooling of air by evaporation is endothermic ability of air which is driven by temperature difference. With increase in relative humidity there is a loss of endothermic ability. [5]

4.3 Additives to improve evaporation

Practically, evaporative coolers do not reach their theoretical minimum temperature which is the wet bulb temperature. Therefore, the role of any additive would be to push it towards the WBT. This can only happen if the additive can increase the rate of evaporation of water. However, adding additives just to push the temperature to its WBT may not make it worthwhile for commercialization, considering the additional cost and system complexities that might be incurred due to such additives.Evaporative cooling depends on the evaporation of water into the air stream only. There is no need for any additive to improve this. Some problems exists, like impurity of water. If water is hard or muddy pricipitation of these impurities occur frequently and may clog wetted pads rendering low evaporation rates of water into the air and putting some pressure on the fan. So clean pure water is an advantage. Research was done [6] by adding a polymer which will show the effects, and the reduction was found by adding drag reducing polymer solutions having concentrations of 20 and 50 PPMW. The percentage decrease in the evaporation loss becomes less effective with increasing CMC-7H concentrating higher than 50 PPMW.

4.4 Optimization of microchannel spacing

The evaporative cooling process can be optimized to **provide the maximum phase-space density with a specified number of atoms remaining.** We show that this global optimization is approximately achieved by locally optimizing the cooling efficiency at each instant. The inter space plays a vital role in the cooling process and hence the micro channel spacing is very important factor while designing a cooling system.An experimental investigation of porous ceramic evaporators for building cooling has been carried out by [7] and it was found that the high porosity ceramic evaporator consistently performed best, while increased water supply head also improved performance. Dry bulb temperature drops of 6–8 K have been achieved parallel with a 30% rise in relative humidity. Maximum cooling of 224 W/m2 has been measured during test of the high porosity ceramic evaporator placed in a single row stack with water supplied at 1.0 m head. Empirical formulae relating mean cooling performance to [es − e], the ambient to saturated vapour pressure difference have been derived. The direct evaporation of water into supply air using porous ceramic surfaces has demonstrated significant potential for building cooling.

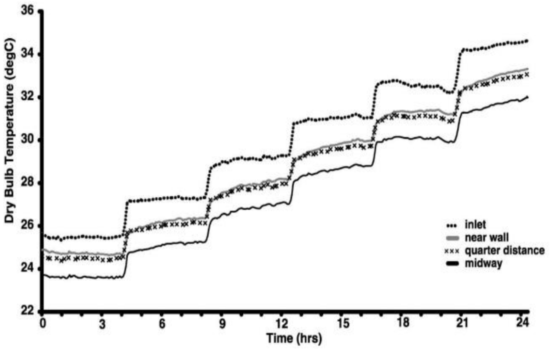

Fig 2 Graph of typical duct air dry bulb temperature trends during a test. A drop in temperature occurs as it passes over the ceramic surfaces.The greatest drop is in center of the duct

4.5 Effect of climatic condition on evaporative cooling

Direct **Evaporative Cooling** When water evaporates in the indoor air, the temperature drops but the humidity goes up. In hot and dry **climates**, the increase in humidity actually improves comfort. However, direct **evaporative cooling** is not appropriate in humid **climates** because the **cooling effect** is low and the humidity is already too high. Ancient architecture has used various passive techniques to restrict the flow of heat to and from a building. But recently the emphasis on these passive cooling techniques has been neglected due to the availability of electrical supply to run the cooling systems [8].The study was aimed at providing lower temperatures for the efficient performance of machineries and human comfort as well as lower temperature and higher relative humidity necessary for overcoming the above adverse condition. The performance of the cooler was evaluated in terms of temperature drop, cooler capacity, saturation efficiency and feasibility index. Co-efficient of performance of refrigeration systemmainly depends on temperature difference between the condenser and that medium where heat is to be rejected.More temperature difference, more heat rejection so more cooling on account of same work to refrigerationsystem. But if the temperature difference is less, less heat rejection will be there so less cooling by giving sameamount of work which decreases the Co-efficient of performance of the system [9]

5 CONCLUSION

After investigating about evaporative cooling, the following key conclusionshave been derived:

1) The shape, size and composition of the ceramic matters a lot. The whole cooling effect can be changed with concentration to the shape, size and composition. Pots having widest surface area gives the most cooling effect whereas pots with the least surface area gives the least

cooling effet as it will take the maximum time because of the larger size and water inside it will get maximum time to cool down.

2) Evaporative cooling is a physical process, meaning that the relative humidity does affect the effectivity with which an evaporative cooling system cools. The more humid a climate is, the harder it is for an evaporative cooling system to cool effectively.
3) Evaporative cooling depends on the evaporation of water into the air stream only. There is no need for any additive to improve this. Some problems exists, like impurity of water but the additives like polymer helps in to improve evaporation.
4) Interspacing is a matter o great concern in evaporative cooling and while doing the investigation it was found that the arrangement in parallel gives better cooling effect.
5) Environmental and climatic change effects a lot in evaporative cooling. We get maximum cooling effect in hot sunny days when the temperature is very high.

REFERENCES

1. Experimental Analysis of evaporative cooling water in porous clay vessels under varyig Ambient Conditions S.O Oyedepoetal 2021 IOP Conf. Ser.: Mater. Sci. Eng. 1107 012103
2. Evaporative cooling of water in a small vessel under varying ambient humidity. Ashutosh Mittal, T Kataria, GK Das, SG Chatterjee – International journal of green energy. Dec(2006)
3. An experimental study on an evaporative cooler for hot rural areas. K Gustafsson , H Simson -2016
4. Experimental Investigation of Indirect Evaporative cooler using clay pipe (R. Ramkumar* A. Ragupathy).
5. A New Approach to Analysis and Optimization of Evaporative cooling system (Qun Chen a,b,*, Kangding Yang a , Moran Wang c , Ning Pan b , Zeng-Yuan Guo a)
6. Effect of polymer additives on the evaporation rate of water droplets.(M. F. Khalil, S. Z. Kassab, A. A. Elmiligui, F. A. Naoum)
7. Performance of porous ceramic evaporators for building cooling application. Energy and Buildings 35: 941–949. Johnson, D.W., Yavuzturk, C., Pruis, J. (2003).
8. The effect of evaporative cooling in tropical climate.(RobertPoku, Tokoni W. Oyinki and Ezenwa A. Ogbonnaya.)American Journal of Mechanical Engineering 2017
9. A Review on comparison of computational fluid Dynamics analysis of natural fluid and Nanofluid in Helical coil heat exchanger.(Mohit Yadav & Yogesh Tembhurne)
10. Aimiuwu, V.O. (1992). Evaporative cooling of water in hot arid regions.Energy Conversion and Management 33(1): 69–74. Aimiuwu, V.O. (1993).
11. Ceramic storage system based on evaporative cooling.Energy Conversion and Management 34(8): 707–710. Anyanwu, E.E. (2004).
12. Design and measured performance of a porous evaporative cooler for preservation of fruits and vegetables.Energy Conversion and Management 45: 2187–2195. Armbruster, R., Mitrovic, J. (1998).
13. Evaporative cooling of a falling water film on horizontal tubes. Experimental Thermal and Fluid Science 18: 183–194. Bergero, S., Chiari, A. (2001).
14. Experimental and theoretical analysis of air humidification/dehumidification processes using hydrophobic capillary contactors.Applied Thermal Engineering 21: 1119–1135. Chatterjee, S.G., Ramarao, B.V., Tien, C. (1997).
15. Water-vapour sorption equilibria of a bleached-kraft paperboard – a study of the hysteresis region. Journal of Pulp and Paper Science 23(8): 366–373. Downloaded by [Tufts University] at 11:33 09 October 2014
16. EVAPORATIVE COOLING OF WATER IN A SMALL VESSEL 367 Cheikh, H.B., Bouchair, A. (2004).
17. Passive cooling by evapo-reflective roof for hot dry climates. Renewable Energy 29: 1877–1886.
18. Chuntranuluck, S., Wells, C.M., Cleland, A.C. (1998a). Prediction of chilling times of foods in situations where evaporative cooling is significant − Part 1. Method Development. Journal of Food Engineering 37: 111–125. Chuntranuluck, S., Wells, C.M., Cleland, A.C. (1998b).
19. Prediction of chilling times of foods in situations where evaporative cooling is significant − Part 2. Experimental Testing. Journal of Food Engineering 37: 127–141. Chuntranuluck, S., Wells, C.M., Cleland, A.C. (1998c).
20. Prediction of chilling times of foods in situations where evaporative cooling is significant − Part 3. Applications. Journal of Food Engineering 37: 143–157. Dai, Y.J., Sumathy, K. (2002).
21. Theoretical study on a cross-flow direct evaporative cooler using honeycomb paper as packing material. Applied Thermal Engineering 22: 1417–1430. Dash, S.K., Chandra, P. (2001).
22. Effects of different structural and operational parameters on the thermal environment of an evaporatively cooled storage structure. International Agricultural Engineering Journal 10(3–4): 231–253. Dhemre, J.K. Waskar, D.P. (2003).
23. Effect of post-harvest treatments on shelf-life and quality of mango in evaporative cool chamber and ambient conditions. Journal of Food Science and Technology 40(3): 316–318. Dzivama, A.U., Aboaba, F.O., Bindir, U.B. (1999).
24. Evaluation of pad materials in construction of active evaporative cooler for storage of fruits and vegetables in arid environments. Agricultural Mechanization in Asia, Africa and Latin America 30(3): 51–55. Fu, W-S., Lin, J-D., Tu, K-C., Tseng, C-C. (1990).
25. Numerical study of a structure protected by water film from an incident heat flux. International Communications in Heat and Mass Transfer 17(3): 331–342. Ghiabaklou, Z. (2003).
26. Thermal comfort prediction for a new passive cooling system. Building and Environment 38: 883–891. Giabaklou, Z., Ballinger, J. A. (1996).
27. A passive evaporative cooling system by natural ventilation. Building and Environment 31(6): 503–507. Ibrahim, E., Shao, L., Riffat, S.B. (2003).
28. Analysis of heat and mass transfer phenomena in hollow fiber membranes used for evaporative cooling. Journal of Membrane Science 227: 159–171. Kassem, A-W.S. (1994)
29. . Energy and water management in evaporative cooling systems in Saudi Arabia. Resources, Conservation and Recycling 12: 135–146. Kumar, A., Ghuman, B.S., Gupta, A.K. (1999).
30. Non-refrigerated storage of tomatoes – effect of HDPE film wrapping. Journal of Food Science and Technology 36(5): 438–440. Liu, W., Peng, S.W., Mizukami, K. (1997).

31. Moisture evaporation and migration in thin porous packed bed influenced by ambient and operating conditions. International Journal of Energy Research 21: 41–53. Mordi, J.I., Olorunda, A.O. (2003).
32. Effect of evaporative cooler environment on the visual qualities and storage life of fresh tomatoes. Journal of Food Science and Technology 40(6): 587–591. Nahar, N.M., Sharma, P., Purohit, M.M. (1999).
33. Studies on solar passive cooling techniques for arid areas. Energy Conversion & Management 40: 89–95. Perry, R.H., Green, D.W., Maloney, J.O., Eds. (1984). Perry's Chemical Engineers' Handbook. Sixth edition. New York: McGraw-Hill. Prange, H.D. (1996).
34. Evaporative cooling in insects. J. Insect Physiol. 42(5): 493–499. Song, C.H., Lee, D-Y., Ro, S.T. (2003).
35. Cooling enhancement in an air-cooled finned heat exchanger by thin water film evaporation. International Journal of Heat and Mass Transfer 46: 1241–1249. Taha, A.Z., Rahim, A.A.A., Eltom, O.M.M. (1994).
36. Evaporative cooler using a porous material to be used for preservation of food. Renewable Energy 5(1): 474–476. Downloaded by [Tufts University] at 11:33 09 October 2014 368 A. MITTAL ET AL. Tang, R., Etzion, Y. (2004).
37. On thermal performance of an improved roof pond for cooling buildings. Building and Environment 39: 201–209. Thakur, K.S., Lal Kaushal, B.B., Sharma, R.M. (2002).
38. Effect of different post-harvest treatments and storage conditions on the fruit quality of kinnow. Journal of Food Science and Technology 39(6): 609–618. Tien, C. (1994).
39. Adsorption Calculations and Modeling. Boston: Butterworth-Heinemann. Treybal, R.E. (1980).
40. Mass-Transfer Operations. New York: McGraw-Hill. Upchurch, D.R., Mahan, J.R. (1988).
41. Maintenance of constant leaf temperature by plants – II. Experimental observations in cotton. Environmental and Experimental Botany 28(4): 359–366. Uppal, D.S. (1999).
42. Effect of storage environments on chip colour and sugar levels in tubers of potato cultivars. Journal of Food Science and Technology 36(6): 545–547. van der Sman, R.G.M. (2003).
43. Simple model for estimating heat and mass transfer in regular-shaped foods. Journal of Food Engineering 60: 383–390. Waskar, D.P., Khedkar, R.M., Garande, V.K. (1999).
44. Effect of post-harvest treatments on shelf life and quality of pomegranate in evaporative cool chamber and ambient conditions. Journal of Food Science and Technology 36(2): 114–117. Zalewski, W., Gryglaszewski, P.A. (1997).
45. Mathematical model of heat and mass transfer processes in evaporative fluid coolers WojciechZalewskia Piotr AntoniGryglaszewskibjuly (1997).