Review Study for Performance Analysis of an Evaporative (Pot in Pot) Cooling System

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Abstract. Evaporative cooling has been utilized rigorously at places of less electricity access having hotter ambient (comparatively more temperature & less relative humidity). Current research study presents review of the previous research studies conducted all around the world. This paper presents various aspects related to pot-in-pot refrigeration and space heating systems. Aspects include performance, utility, setup arrangements, places of application, economy & materials to be used. Review of the available researches shows that pot-in-pot systems, on an average lower the temperature between 8-18°C, increase the relative humidity between 40-60%, Such systems are more useful and efficient at places nearer to equator where there is comparatively hotter ambient with less humidity. Review also reveals that this system is economical and cheaper than other refrigeration & space cooling techniques.

1. Introduction

Hunger is one of the major global problems and nearly 82.8 crore people across the globe remain hungry every day. Out of these 34.5 crore people are confronting acute insecurity of food (as per 2019). Approximately crore people panning 45 different nations are teetering because of dearth. People from dry corridor of central America, Sahel, Southern Sudan, central African countries, Yemen and Afghanistan are facing starvation problem because of climate shocks & conflicts 36.]. Nearly 33% of the food produced across the world gets wasted because of different reasons which start from spoilage at an early stage to customer's wastage. If half of this wastage is recovered, whole world can be fed very easily.

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Generally, in developed countries loss of food mainly occurs at the level of consumer because of mishandling of food whereas in the countries which are still in developing stage, post-harvesting losses are the main source of food loss & it accounts for nearly 40% of the food loss occurring mainly due to improper storage of the food. Most of the places in Western Africa doesn't have any access to the electricity. In such places refrigeration facility cannot be availed and hence these places are prone to health problems originating from soilage of food. To overcome this problem in areas where there is no access to electricity, evaporative cooling is proving to be the game changer technology for food preservation. In order to overcome this issue, evaporative cooling method is employed because in this method water absorbs the heat and evaporates. This heat absorption lowers the temperature of the dry air due to evaporation of water. This process cools the air consuming lesser amount of energy.

Evaporative coolers (aka swamp cooler, evaporative air conditioner, desert cooler, swamp box, wet air cooler etc.) cools the air by evaporating the water and differs from other such methods. For example, Zeer-pot is one such system employed to keep the vegetables and fruits fresh for a longer period of time. This method has been used in Africa & middle east for several centuries now where comparatively larger temperature is accounted for. Food placed inside the pot can be cooled using this method. This type of pot is constructed with clay pots having different sizes. Smaller size pot is setup inside the larger pot and gap between these two pots is filled with numerous materials having certain desirable properties (Fig 1).

Figure 1. Common arrangement of a Zeer pot

Water evaporation extracts heat from inside of the pot to outside and to the air which is similar to the cooling of humans by sweating. Materials placed between two pots act as insulators. Efficiency of the evaporation can be increased in a dry environment with light breeze.

A zeer pot (Pot-in-pot refrigerator) can be fabricated easily and it is a cheaper way to store food. Larger pot must be large enough to place the inner pot inside it and some space left for filling with some specific materials like wet sand. Now the in between space of both the pots is filled with water until the point of saturation. At last, top portion of pot gets covered by insulating material or any wet cloth. Water seeps through the walls of clay pot and gets evaporated in the atmosphere. This way the desired cooling is achieved.

1.1. Methods of Evaporative Cooling

1.1.1 Direct cooling system (DCS)

When water humidifies and evaporates simultaneously, the process is called DEC (Direct Evaporative Cooling). Its efficiency increases at higher temperatures. This method is basically used for space cooling & is based upon air moving past a moist material. Resultant cool air is moved to the places of requirement. Indirect cooling methods employ heat exchangers wherein cool air is used to cool down the dry air.

1.1.2 Indirect evaporative cooling system

Heat exchangers are employed in this system to cool the primary air without moisture being added. In this arrangement hot air is made to pass through tubes (outside of the tubes remains wetted). Another stream of air flows over the tubes and gets cooled. Moisture is not added in this process and hence this air can be used in some specific applications.

2. Theoretical Research Review

It has already been established that pot-in-pot refrigeration or zeer pot refrigeration systems (practical application of evaporative cooling) are applicable at the places where electricity access is still not reached & the places of large temperatures. Several researchers have studied about this concept over the years maximum portion of African continent is suitable for the execution of this concept.

The different types of evaporative cooler designs have been proposed from time to time which include: charcoal & static cooling chambers, pot-in-pot & cabinet. Gap between the pots is generally filled by sand, jute or damp cloth. Water remains connected to the top of the cooler hence the chamber remains cool (Isaac F. Odesola et al., 2009). This cooler performs

in such a way that storage temperature is lowered and hence it can be used for preserving the food for short term (M. C. Ndukwu et al., 2014).

Evaporative cooling methods have proven to be an environment friendly and cheaper to preserve medicines and food. Refrigeration by evaporative cooling has proved to be a successful alternative in providing inexpensive and environment friendly way to preserve food and medicines. This concept has remained in existence for long ago but its extensive use has only surged lately (Prabodh Sai Dutt R et al., 2015).

Table 1. Some recent methods of pot-in-pot Refrigeration

Ref.	Type of design	Materials to be filled	Evaporative Cooling	Liquid Used	Practical Application
24	Cabinet, charcoal and static cooling chambers, pot-in-pot	Jute, Damp Cloth, or Sand	Direct	Water	preservation of vegetables
19	Pot-in-pot (Inner pot of Iron)	Sand	Indirect	Water	preservation of fresh agricultural produce
10	ground-coupled heat exchanger having earthen tube, charcoal and static cooling chambers, cabinet,	Not Mentioned	Direct	Water	Fruits and vegetable preservation, space cooling
5	Pot-in-pot	sand	direct	water	Horticultural produce

2.1. Empirical Research Review

Various researchers have empirically analysed evaporative cooling technique over the years through several means. Most of these have been mass & heat transfer analysis of the setup using ambient conditions like temperature, relative humidity etc.

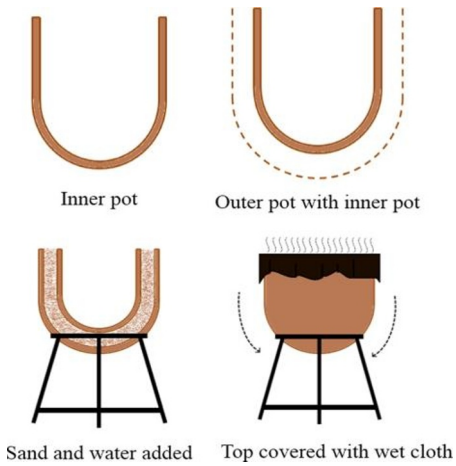


Figure 2. Schematic illustration for building a pot-in-pot system 27

Pandey, R. et al. (2016) conducted mass & heat transfer analysis in pot-in-pot system to analyse the performance. Performance has been studied as per relative humidity, ambient temperature, pot radius, pot height, hydraulic conductivity, total load due to heat, radiation heat transfer & thermal conductivity. According to the study, pot radius, pot height, radiation heat transfer & total heat load play important role in performance of the system. Maximum efficiency of 73.44% for the system is achieved at RH of 40% & temperature of 50°C. Temperature difference of 20°C is achieved at this condition.

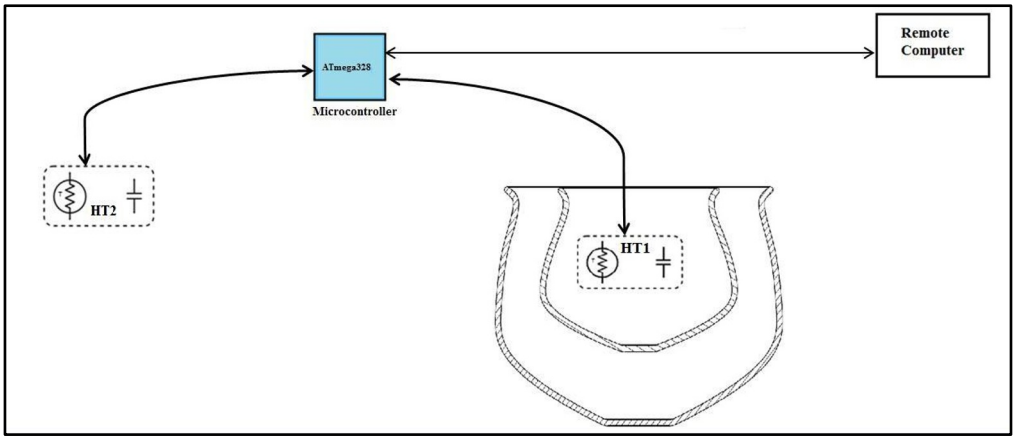


Figure 3. Experimental Arrangement 8

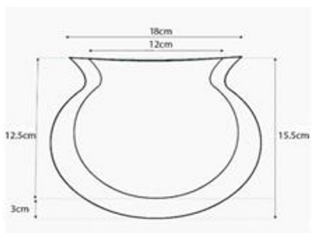
Chemin, Arsène et al. (2018) investigated experimentally the impact of wind on rate of evaporation for a pot-in-pot system. investigated the influence of the main physical parameters in model pot-in-pot coolers. Impact of different fluid properties like latent heat, specific heat & thermal conductivity is studied for three different fluids (ether, water & ethanol).

Kanchit Rongchai et al. (2017) constructed a mathematical mass & heat transfer model of an evaporative cooler. The model had two concentric pots. Heat mass transfer was evaluated using ambient temperature and humidity. Different materials for the pots were used having numerous dimensions for the experiment. This model has been simulated for ambient conditions northeast Thailand at relative humidity of 40% and 30°C temperature at a load of 1 kW. Food can be used to kept at 8°C lower than the ambient temperature at above conditions.

Table 2. Cooling Efficiency achieved at different Temperature and RH

Reference	Input Conditions		Cooling Efficiency Achieved	Temperature Difference Achieved
	Temperature	RH		
27	50°C	40%	73.44%	20°C
27	30°C	80%	14.79%	0.5°C
15	30°C	40%	Not Mentioned	8°C
15	35°C	30%	Not Mentioned	13°C
11	27-33°C	65-85%	58-69%	2-3°C
22	32-40°C	40%	20-92%	8-11°C
33	27.3 ± 1.5C	78.2 ± 7.1%	63%	3°C
4	20.4°C	59.42%	Not Mentioned	2°C
18	25°C	Not Mentioned	Not Mentioned	4°C
16	31.8°C	53%	Not Mentioned	0.3°C

Gunadasa HLCK et al. (2017) studied about pot-in-pot system using waste materials originating from plants as an absorbent instead of sand & its impact on cooling efficiency. Four different absorbents were employed in this study- crushed corn husk, saw dust, coir dust & sand. Cooling efficiency for these materials was 22.9%, 60.8%, 58.6% & 69% respectively. Results reveal that coir dust and saw dust can also be employed in this application in place of sand.



(a) (b) (c) (d)

Figure 4. Water saturated Zeer pots filled with (a) sand, (b) coir dust, (c) saw dust and (d) crushed corn husk together with corn hair 11

This system of Pot-in-pot can be modelled in modelling softwares like SolidWorks adding fins to increase the ratio of surface area and volume which can increase the cooling efficiency & performance of the system (Aniket Jadhav et al., 2018). Kiranprasad Tiwari et al. (2017) conducted a parametric analysis on performance of pot-in-pot system. Wind velocity & cooling area have been taken as the process parameters in order to study their impact on cooling efficiency of the pot-in-pot refrigeration system. Study results reveal that by

incrementing the radius of outer pot from 0.25 m to 0.45 m approximately doubles the cooling effect.

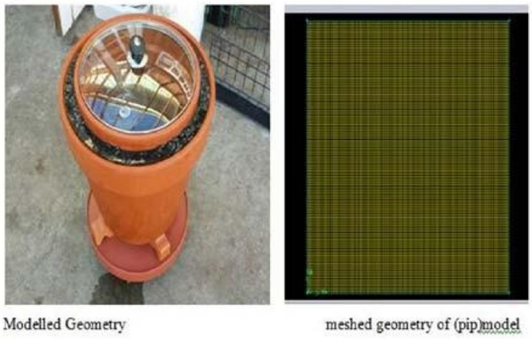


Figure 5. Actual and modelled geometry 34

Figure 6. Setup used by Suleiman A. Yahaya et al. 32

Uttam Sharma (2021) studied about direct evaporative cooling. The model developed is a highly efficient, theoretically. The design of the product is unique and the cost of manufacturing of the product is also very less because of the use of mud pots. The efficiency achieved with the use of two evaporative media pads and the surface evaporation phenomenon is more than 80% when 50 cfm, 4-inch fan is used and the efficiency keeps on increasing with increase in the speed of the air striking the pads and water surface. The product if developed on a large scale can create job opportunities for rural regions where mud pot craft is highly practiced. The major benefit of such a design is that the aerosol formation is eliminated which is very much observed in common desert coolers.

Vijesh V Joshi et al. (2018) studied about water temperature measurements in clay pots for various conditions. For the purpose four different pots with different painting (variable evaporation) have been studied. Pot having fully painted walls represents highest temperature among all the pots. Pot having unpainted walls reveals minimum temperature among all the pots. Remaining pots were painted half of the walls (in one pot upper half was pained and in other lower half was painted) & they showed nearly equal temperatures of water. Researchers concluded that painting upper half of the pot can result in equal cooling effect with 73% lesser water loss.

Some of the other researches are being presented here for reference-

Table 3. Empirical review for Pot-in-pot Systems

Ref.	Input Parameters	Filler Materials Used	Output parameters	Type of Analysis	Remarks
34	set-up height (0, 0.5 & 1 m)	Clay	Performance	CFD	8% increment in cooling effect with height increment from 0 to 1 m
22	Ambient Temperature, Relative Humidity	Locally materials which were available & clay	cooling capacity, evaporative effectiveness & temperature drop	Experimental	Temp. drop of 8°C, RH increment of 40-92%, Cooling efficiency of 20-92%, Better effectiveness during day time, tomato preservation for 19 days
29	device size, wind speed, and vegetable mass	Clay, available dishes	refrigeration efficiency	Experimental	More water consumption in bigger devices & favourable effect on efficiency at high speed of wind.
1	RH & ambient temperatures	Clay	performance of refrigerator	Experimental	Not Mentioned
30	RH & ambient temperatures	Saw dust, sand & charcoal	performance of the refrigerator	Experimental	Cooling efficiency of 75%, 66% & 58% for charcoal, sand & saw dust
2	ambient temperatures and relative humidity	sand, charcoal, gunny-cloth	Cooling Efficiency	Experimental	Not Mentioned
33	ambient temperatures and relative humidity	Water, Soil, wet soil	performance of the refrigerator	Experimental	Clay pot reduces the temperature of inside of the inner pot
4	ambient temperatures and relative humidity	Sand	performance of the refrigerator	Experimental	inside storage temperature up to 18°C, inside storage relative humidity for pot in pot was 67.31%
18	Humidity, Wind Speed	Sand, water	performance of the refrigerator	Experimental	higher wind velocity increases the evaporation rate
26	ambient temperatures and relative humidity	river-bed sand, Water, Polythene	performance of the refrigerator	Experimental	Not Mentioned
9	ambient temperatures and relative humidity	Sand, water	performance of the refrigerator, Weight loss, Shelf life	Experimental	temperature reduction of 2°C -16°C and increase in relative humidity of 24%-42.59%

O.S. Olaoye et al. (2020) studied about pot-in-pot systems & their performance. Different types of absorbent materials were used to predict the performance like saw dust, charcoal, jute with sand, coconut fibre jute & sand. Process parameters included in the current research are temperature of inside and ambient, RH & velocity of wind. Results for highest efficiency & lowest temperatures achieved are recorded for all the absorbents. Coconut fibre shows minimum temperature reduction. Sand reveals maximum efficiency of the process.

Table 4. Vegetable Shelf-Life 24.

Produce	Shelf-life produce without theZeer	Shelf-life of produce using Zeer
Tomatoes	2 days	20 days
Guavas Rocket	2 days	20 days
Okra	1 day	5 days
Carrots	4days	17 days
	4days	20 days

Harish. H. G et al. (2014) conducted an experimental analysis for a pot-in-pot for different process parameters like variable height of water inside the inner pot, water level in between space of both the pots & forced & free convection. Researchers concluded that height level is proportional to water height inside the inner pot, temperature in between space of both the pots is inversely proportional to water level of that space. Lowest temperatures were achieved for free convection.

Olaifa O. Peter et al. (2018) reviewed the available literature in the field of pot-in-pot refrigeration systems. They concluded that different types of absorbents like sand, jute charcoal etc. have been used over the years & all of these have provided good results. Sand represents maximum efficiency of the process.

3. Materials used for the System

Two kinds of materials are being used in Evaporative cooling (pot-in-pot) systems. First kind of materials are used for preparation of pots & second kind of materials to be used in these systems are the ones filled in the open space between the two pots. For preparing pots, clay is generally used because of its porous nature. This porous nature causes the water droplets to move inside the pores to the outer surface of the pots. Because of higher temperature of atmosphere, kinetic energy increases and these droplets vaporize and take the energy from the water kept inside the pot. In between space of inner & outer pots is normally filled with wet sand although some other materials like Polythene, Clay, charcoal, sawdust, gunny-cloth & wet soil have also been used. These materials provide the insulting effect so that the material kept inside the inner pot remains cooler than the atmosphere & at the same time

water filled in the space between both the pots keeps extracting the heat from the inside portion.

4. Conclusion

Comprehensive literature review of the Pot-in-pot systems is carried out in current research study. Primary aim of using these systems is to preserve food for some time. In some cases, these systems have also been used for space cooling. Different important points for concluding the research are presented here for reference-

4.1. Different type of Arrangements

Several researches have shown two different arrangements for evaporative cooling systems. One kind of system is pot-in-pot systems which employ two concentric pots made up of different materials with smaller pot placed inside the larger pot & different kind of filler materials being filled in the desired place. Second kind of arrangements is of earthen Pots which are placed indie the earth surface. In some cases, fins have also been found to be used to increase the ratio of surface area & volume which increments the efficiency of cooling.

4.2. Performance of the Pot-in-pot refrigeration systems

Pot-in-pot systems are found to be quite efficient as far as their performance is concerned. Different setup under consideration were achieving a temperature loss of 8-18°C. Various concerned refrigeration systems were also able to increase the relative humidity of 40-60%.

4.3. Economy

Pot-in-pot systems are found to be economically cheaper as these don't require any mechanical component required for the VCRS, VARS and other industrial refrigeration systems.

4.4. Utility

Pot-in-pot refrigeration systems have been used and employed by several researchers but the use of such evaporative cooling systems is limited to be used for food preservation & space cooling in some cases. Several researches have shown that this kind of refrigeration & space cooling system is most efficient at hotter places with lower relative humidity. Hence the places nearer to equator are more suitable for such kind of systems.

4.5. Materials of pots

In most of the cases wet sand has been used as the filler material but some studies have shown several other materials too like charcoal and sawdust, gunny-cloth, Soil, Polythene etc. As far as pot developing materials are concerned, mostly clay pots have been utilized by the

researchers. In some cases, metallic inner pots have also been observed to be employed for the process.

5. Future Scope

Although a lot has been said and done in the concerned field of evaporative cooling over the years across the world but yet much is still left to be studied so that the results may be generalized. Some of the areas for future research are pointed out for reference-

- Measurable solution for a given evaporative cooling setup has not been seen in the reviewed literature. Hence several parametric studies need to be performed so that measurable results are obtained for a given evaporative cooling problem.
- Software simulation of such problems has also not been observed in the researched literature hence it would be beneficial for the future researchers to go for software simulation of such kind of problems.

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