CLAY EVAPORATIVE COOLER PERFORMANCE RESEARCH

Introduction

Food preservation is an important issue in the harsh climate of North Darfur in Sudan. The heat and dust take their toll on precious crops. When you have a good harvest it is vital to keep produce in a market saleable condition. The clay refrigerator project was first initiated by Practical Action in 2001 following research conducted by Practical Action Country Director Mohammed Majzoub who had heard about the idea being promoted by a teacher named Mohammed Bah Abba in Nigeria. Following the successful experiments conducted by Practical Action and Al Fashir University to measure the clay refrigerators value in maintaining nutrients and extending the shelf life of vegetables, training was given to 21 ladies from the Al Fashir Association for Earthenware Manufacturing on how to make the cooler.

Since then Practical Action has continued to promote the idea within Sudan as well as abroad by producing literature on how the clay refrigerator works and is manufactured. This technology promotion is carried out as part of the Practical Answers project - a knowledge dissemination service for development practitioners and the rural poor. In conjunction with that project Practical Answers operates a technical enquiry service (TES) which has led to a number of enquiries about the refrigerator the most recent ones of which have led to this research and short report. The enquiries regarding this technology came from Qasid Safir, who having implemented a clay refrigerator pilot project in Zambia had some concerns and reservations. Below is an extract from an email he sent outlining these issues:

"During this visit I was very concerned that despite the excellent results it seemed to me that the Desert Fridge was not being correctly used.

I had noticed that some users were keeping it indoors or in enclosed spaces. I would imagine that due to the way it works by evaporation of the water it should be raised up and kept out in the open to ensure it receives as much fresh air as possible to maintain a higher water potential gradient from the moist sand to the air.

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In the case of the market sellers who were using it there was a very good reason for this. They did not have enough space around there market table to put the Desert Fridge out and were afraid if they were to put it on there table it could be knocked over. Therefore they kept it under there table (which is enclosed from 3 sides).

In the case of the farmers some would keep it under there veranda and others would keep it in there homes.

Therefore I would be most grateful if, drawing from your experience in Sudan, you could advice me as to the optimum positioning of the Desert Fridge bearing in mind the limitations mentioned above."

Following this enquiry research was conducted to determine how the performance of the refrigerator is affected when stored in different locations.

Methodology

The planned variables to be investigated were:

a) The difference in performance between a clay refrigerator confined from 3 sides and above with one completely unconfined
b) The difference in performance between a clay refrigerator kept in the shade and one in the sun
c) The difference in performance of a refrigerator raised up off the ground compared with one sat directly on the ground
d) The difference in performance of a refrigerator stored outside and one inside.

These tests were conducted originally using two refrigerators being tested comparatively at the same time. However one of these broke 11 days into the test when it was in the process of being moved. The test continued with one refrigerator after that date.

The test involved an outdoor temperature test next to the refrigerator with another one taken within 10 - 15 minutes (sometimes simultaneously) from within the inside of the refrigerator. The pots were watered twice a day with a total volume of water between 1.5 to 2.5 liters (3 liters for the very first watering). The humidity was taken after the tests using website data.

As well as temperature tests the refrigerators were tested with vegetables. This led to another issue of concern that was identified and subsequently addressed.

Results

The following table shows the different locations of the refrigerator under test with a colour code that hopes to identify the factor under test in the subsequent refrigerator performance table:

Refrigerator variables under test - Colour code chart

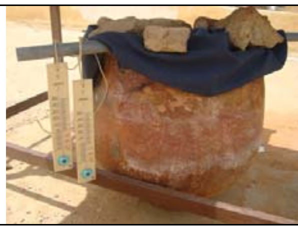
Colour Code	Description	Photo
	This is the control temperature for the experiments; the thermometer is outside the pot, on the roof in the shade, about 10cm from the ground	
Factor i	Unconfined refrigerator on the roof not in the shade	
Factor ii	Confined refrigerator on the roof; covered from 3 sides and above	
Factor iii	Unconfined refrigerator on the roof in the shade	
Factor iv	Refrigerator (on the roof) on a stand raised approx 30 cm from the ground (in the shade)	

Table 1. Clay refrigerator performance table

Note: Humidity readings were collected from: http://www.weatheronline.co.uk/weather/maps/city?LANG=en&CEL=C&SI=mph&MAPS=&CONT=afri&LAND=SU&REGION=0010&WMO=62721&UP=0&R=0&LEVEL=150&NOREGION=1

Date	Watering Time (1st) and No of liters (both CRs, l = liters)	Watering Time (2nd) and No of liters (both CRs, l = liters)	Time and Temp Outside in shade	Relatively Humidity	Time and Temp inside Refrigerator A	Time and Temp inside Refrigerator B
10/6/09	13:30 – 3 l		16:00 - 45.5°	31	16:20 - 39.5°	16:20 - 38.5°
11/6/09	9:30 – 1.5 l	19:00 – 1 l	12:15 - 45.5° 16:15 - 47°	13	12:00 - 38.5° 16:35 - 43°	12:00 - 33.5° 16:35 - 38°
12/6/09	10:30 – 1.5 l	17:00 – 1 l	12:15 - 45°	11	12:00 - 40.5°	12:00 - 35°
13/6/09	11:00 – 1.5l	18:00 – 1l	12:00 - 48.5°	12	12:15 - 41°	12:15 - 34°
14/6/09	9:30 - 1.5 l	17:00 - 1 l	12:15 - 42°	16	12:30 - 39°	12:30 - 34°
15/6/09	9:30 - 1.5 l	18:15 -1 l	15:05 - 48°	10	14:45 - 41°	14:45 - 35°
16/6/09	8.35 - 1.5 l	18:45 - 1 l	8:10 - 35° 8:50 -36.5° 12:15 - 45.5°	12	8:25 - 32° 9:05 - 33° 12:30 - 36°	8:25 - 32.5° 9:05 - 31.5° 12:30 - 35°
17/6/09	9:30 - 1.5 l	5:30 - 1 l	13:00 - 45.5°	11	13:15 - 36°	13:15 - 35°
18/6/09	9:15 - 1 l		9:30 - 33° 12:30 - 39°	27	9:45 - 30° 12:50 - 33 °	9:45 - 29.5° 12:45 - 32.5 °
19/6/09	12:30 - 1 l	4:05 - 1/2 l	12:10 - 39.5 °	27	12:25 - 36 °	12:25 - 34°
21/6/09	9:30 - 1 l	4:30 - 1/2 liter (1 pot only)	12:00 - 44 °	21	12:15 - 38 °	12:15 - 35°
22/6/09	10:00 - 1 l	6:45 - 1/2 l	15:00 - 52°	24		15:00 - 38°
23/6/09	9:30 - 1 l	5:45 - 1 l	13:30 - 50°	27		13:30 - 36°
24/6/09	10:20 - 1 l	5:30 - 1 l	13:05 - 46.5°	29		13:20 - 41°
25/6/09	9:15 - 1 l	18:00 - 1 l	13:00 - 42°	26		13:00 - 35°
28/6/09	9:00 - 1.5 l	18:25 - 1/2 l	13:15 - 44°	26		13:15 - 38.5°
29/6/09	9:35 - 1 l	17:10 - 1 l	12:45 - 38.5°	29		13:00 - 33.5°
30/6/09	9:30 - 1 l	18:15 - 1 l	13:00 - 39°	30		13:15 - 33.5°
1/7/09	9:15 - 1 l	17:15 - 1 l	13:45 - 43°	26		13:30 - 35.5°
2/7/09	9:30 - 1 l	17:00 - 1 l	POT NOT IN SHADE SO NO RESULTS TAKEN			
4/7/09	10:30 - 1.5 l		13:10 - 40°	34		13:10 - 35.5°
5/7/09	9:00 - 1.5 l	17:30 - 1 l	13:15 - 42°	44		13:40 - 36.5°
6/7/09	9:30 - 1 l	17:00 - 1 l	13:45 - 43°	31		13:45 - 36°
7/7/09	9:45 - 1 l		13:00 - 46°	32		13:15 - 39.5°

Analysis

a) The first factor to test was difference in performance between a clay refrigerator kept in a confined space (3 sides and above) with one that is unconfined although not exposed to the sun. This test was able to be done by comparing two pots at the same time therefore fixing the variables of temperature, humidity, time of watering and amount of water. The results can be seen in Table 2 below:

Table 2

Date	Watering Time (1st) and No of liters	Watering Time (2nd) and No of liters	Time and Temp Outside in shade	Relatively Humidity	Time and Temp inside Refrigerator A	Time and Temp inside Refrigerator B	Temp Difference (A from B)
16/6/09	8.35 - 1.5 l	18:45 - 1 l	12:15 - 45.5°	12	12:30 - 36°	12:30 - 35°	1
17/6/09	9:30 - 1.5 l	5:30 - 1 l	13:00 - 45.5°	11	13:15 - 36°	13:15 - 35°	1
18/6/09	9:15 - 1 l		12:30 - 39°	27	12:50 - 33 °	12:45 - 32.5 °	0.5
19/6/09	12:30 - 1 l	4:05 - 1/2 l	12:10 - 39.5°	27	12:25 - 36 °	12:25 - 34°	2
21/6/09	9:30 - 1 l		12:00 - 44 °	21	12:15 - 38 °	12:15 - 35°	3

Note: Where: [red] is factor iii, the refrigerator unconfined in the shade

[yellow] is factor ii, the refrigerator confined (in the shade)

Therefore, average temperature difference between factors i and iii is:

$$= \frac{\text{Total of Temp differences between factors ii and iii}}{\text{No of days testing}}$$

$$= \frac{1 + 1 + 0.5 + 2 + 3}{5}$$

$$= 1.5^{\circ}$$

This means that keeping the refrigerator in a confined space decreased the temperature inside the refrigerator by 1.5°

b) The second factor to test was the difference in performance of the clay refrigerator when exposed to direct sunlight for the whole day. This factor was not initially planned for testing but after the first testing that took place it was assumed that the pot performance was affected by exposure to the sun, which would be natural of course. However, it was uncertain to what degree it would effect the performance.

Unlike the first test this comparison was not conducted on the same day so we have had to be very careful when comparing results from different days. What I have tried to do is compare days where the outdoor temperatures are within 2.5° of each other and a difference in humidity of no more than 3%. The importance of humidity can be seen from looking at Table 1 which highlights that the big temperature differences usually occur on days with low levels of relative humidity.

From the data below we have two groups, in the first group there are 4 readings (or days) that fit this criteria and another group of only readings (or days) that fit this criteria. The difference between the two groups is the % of humidity. The first group of 4 has been cross checked against each other, 2 readings by 2 readings giving 4 comparative results. See Table 3 below:

Date	Watering Time (1st) and No of liters	Watering Time (2nd) and No of liters	Time and Temp Outside in shade	Relatively Humidity	Time and Temp inside Refrigerator	Temp Difference
Group 1 (2 readings x 2 readings)						
Cross reference 1						
11/6/09	9:30 – 1.5 l	19:00 – 1 l	12:15 - 45.5°	13	12:00 - 38.5°	7°
16/6/09	8:35 - 1.5 l	18:45 - 1 l	12:15 - 45.5	12	12:30 - 36°	9.5°
Cross reference 2						
12/6/09	10:30 – 1.5 l	17:00 – 1 l	12:15 - 45°	11	12:00 - 40.5°	4.5°
17/6/09	9:30 - 1.5 l	5:30 - 1 l	13:00 - 45.5°	11	13:15 - 36°	9.5°
Cross reference 3						
11/6/09	9:30 – 1.5 l	19:00 – 1 l	12:15 - 45.5°	13	12:00 - 38.5°	7°
17/6/09	9:30 - 1.5 l	5:30 - 1 l	13:00 - 45.5°	11	13:15 - 36°	9.5°
Cross reference 4						
12/6/09	10:30 – 1.5 l	17:00 – 1 l	12:15 - 45°	11	12:00 - 40.5°	4.5°
16/6/09	8:35 - 1.5 l	18:45 - 1 l	12:15 - 45.5	12	12:30 - 36°	9.5°
Group 2 (1 reading x 1 reading)						
Cross reference 1						
24/6/09	10:20 - 1 l	5:30 - 1 l	13:05 - 46.5°	29	13:20 - 41°	5.5°
28/6/09	9:00 - 1.5 l	18:25 - 1/2 l	13:15 - 44°	26	13:15 - 38.5°	5.5°

Table 3

Note: Where: [blue] is factor i, is the refrigerator unconfined in the sun

[red] is factor iii, the refrigerator unconfined in the shade

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Therefore, average temperature difference between factors i and iii is:

$$= \frac{\text{Total of Temp differences between factors i and iii}}{\text{No of cross reference checks}}$$

$$= \frac{2.5 + 5 + 2.5 + 5 + 0}{5}$$

$$= 3^{\circ}$$

This means that keeping the refrigerator in the shade decreases the temperature by an average of 3° inside the refrigerator.

c) The third factor that was tested was the difference in performance when the clay refrigerator is elevated. Like the test in b) above this comparison was not conducted on the same day so we have had to be very careful when comparing results from different days. What I have tried to do is compare days where the outdoor temperatures are within 2.5° of each other and a difference in humidity of no more than 3%.

From the data below we have two groups, in the first group there are 4 readings (or days) that fit this criteria and another group of only three readings (or days) that fit this criteria. The difference between the two groups is the temperature and also the humidity. The first group of 4 has been cross checked against each other, 2 readings by 2 readings giving 4 comparative results, and the second group has been cross checked, 2 readings by 1 reading producing two comparative tests. See Table 4 below:

Table 4

Date	Watering Time (1st) and No of liters	Watering Time (2nd) and No of liters	Time and Temp Outside in shade	Relatively Humidity	Time and Temp inside Refrigerator	Temp Difference
Group 1 (2 readings x 2 readings)						
Cross reference 1						
19/6/09	12:30 - 1 l	4:05 - 1/2 l	12:10 - 39.5 °	27	12:25 - 36 °	3.5
29/6/09	9:35 - 1 l	17:10 - 1 l	12:45 - 38.5°	29	13:00 - 33.5°	5
Cross reference 2						
18/6/09	9:15 - 1 l		12:30 - 39°	27	12:50 - 33 °	6
30/6/09	9:30 - 1 l	18:15 - 1 l	13:00 - 39°	30	13:15 - 33.5°	6.5
Cross reference 3						
19/6/09	12:30 - 1 l	4:05 - 1/2 l	12:10 - 39.5 °	27	12:25 - 36 °	3.5
30/6/09	9:30 - 1 l	18:15 - 1 l	13:00 - 39°	30	13:15 - 33.5°	6.5
Cross reference 4						
18/6/09	9:15 - 1 l		12:30 - 39°	27	12:50 - 33 °	6
29/6/09	9:35 - 1 l	17:10 - 1 l	12:45 - 38.5°	29	13:00 - 33.5°	5
Group 2 (2 readings x 1 reading)						
Cross reference 1						
28/6/09	9:00 - 1.5 l	18:25 - 1/2 l	13:15 - 44°	26	13:15 - 38.5°	5.5
1/7/09	9:15 - 1 l	17:15 - 1 l	13:45 - 43°	26	13:30 - 35.5°	7.5
Cross reference 2						
25/6/09	9:15 - 1 l	18:00 - 1 l	13:00 - 42°	26	13:00 - 35°	7
1/7/09	9:15 - 1 l	17:15 - 1 l	13:45 - 43°	26	13:30 - 35.5°	7.5

Note: Where: is factor iii, the refrigerator unconfined in the shade

is factor iv, the refrigerator unconfined and raised

Therefore, average temperature difference between factors iii and iv is:

$$= \frac{\text{Total of Temp differences between factors iii and iv}}{\text{No of cross reference checks}}$$

$$= \frac{1.5 + 0.5 + 3 - 1 + 2 + 0.5}{6}$$

$$= 1.1^{\circ}$$

This means that keeping the refrigerator in an elevated position decreases the temperature by an average of 1.1° inside the refrigerator

d) Due to time constraints the effect on performance of the refrigerator being located inside was not tested.

e) A further test that was taken alongside the temperature tests was the actual affect on vegetables that were put in the pot. From the beginning there were issues with the tomatoes getting infected after 2 - 3 days. After the first time the test was done again with new tomatoes that were washed extensively with clean hands, incase the source of bacteria was due to bad hygiene. However, the same thing happened after a couple of days which meant there was an alternative explanation.

Following the second time that it happened it was also obvious that it was not natural rotting that had taken place, but that the tomatoes had been inflicted with a fungus infection. On closer inspection of the tomatoes it could be seen that the skin had split where it was in contact with the inside of the clay pot. A possible cause was that due to the surface of the inner pot being moist it had softened the tomato skin until it broke and thus exposed it to bacteria.

To test this theory a third test was conducted with six tomatoes; where two were left open in the pot, two in a box and two in a bag. As can be seen from the diary (and photos in Annex A) the tomatoes in the box lasted 6 days longer than the ones left open and the ones in the plastic bag lasted 12 days longer than the ones that were left open.

Conclusions

The research produced some interesting findings although due to the reletively limited amount of data collected it should not be seen as conclusive. The difficulty with conducting this research is controlling the number of different factors involved in the evapourative cooling process. The timing of temperature readings, the time between water top ups and the amount of water used were controlled relatively well. The latter changed more than intended half way through the exercise, because water was accumulating in the inside of the pot so slightly less water was used; one liter instead of one and a half liters.

It is thought that these control factors do not change the performance as much as say the humidity or outdoor temperatures which are impossible to control in a not laboratory environment. That is why it was frustrating when the second pot broke meaning that direct comparisons had to be made on different days in order to get results, concerning the effect of the sun and elevation of the pot.

Ironically the result which in theory is the most concrete due to the variables being compared on the same day, is the one that that is most illogical, namely the effect on the performance of the refrigerator when stored in a confined space. It's hard to come up with an explanation for the refrigerator actually performing better when confined, by an average of 1.5°. It may be that the wind speed was low on those days, although the fact that the experiment was carried out on the roof of a three storey building would question this justification. Another theory would be that because it was open on the one side this facilitated the part of the cooling process caused by the air rushing past the outside of the refrigerator. Needless to say it would be interesting to test this factor again.

The other two variables tested are less concrete scientifically but produced results that are more comprehensible; the elevated refrigerator has more efficient cooling by an average of 1.1° and the effect of exposure to direct sunlight all day reduced the refrigerator performance by 3°. It should be noted that this is the sun in the Sudan in the summer and that it may have less impact on performance in countries with a cooler climate.

The use of a bag for the tomatoes was an interesting finding as this problem of infected tomatoes was also reported from Gambia.

Recommendations

This research highlights some of the difficulties in testing the refrigerator as well as a basic research plan that could be followed by others. Recommendations would be:

- Further testing of the variables tested in this research as well as the impact of using the refrigerator inside the home

- At this stage there is no need to be overly concerned about the refrigerator being stored in a confined space assuming one side is open, like it is being kept under a table.
- The results would suggest that the refrigerator should be elevated and kept out of the sun although the former at least is not critical
- Tomatoes should be kept in a bag. It is suggested that the bag has small holes to allow moisture to escape. This test should also be tested again but this time with a large bag full of tomatoes
- The refrigerator should not be moved when it is filled with sand. The one that broke was moved very slightly, which was enough to cause a crack around the whole circumference of the outer pot (see photo in Annex A below).

Annex A. Research Diary with Photos

Wednesday June 10th

Saturday June 13th

Notes: all tomatoes bar 1 infected in fridge outside and 1 carrot confined 11:00 am. Destroyed

Notes: all tomatoes infected in fridge outside unconfined 6:00 pm Destroyed

Carrots, tomatoes and peppers withered that were left outside

Sunday June 14th

Notes: Remaining tomato and another carrot in confined refrigerator infected 9:30 and Destroyed

Tuesday 16th

Notes: Fungus on the green peppers and cucumbers in the confined refrigerator
Shade cover was given to the unconfined pot at 9:20 and covered the top half of the refrigerator in shade. Water can be seen accumulating at the bottom of the confined refrigerator

Wednesday 17th

Fungus increased in confined refrigerator

Thursday 18th

All veg in confined pot infected except one pepper. All were removed and at 10:30 a tomato test started where 2 tomatoes in a bag, in a box and left free were left in the refrigerator.

Mangos start to rot

Saturday 20th

No watering

Sunday 21st

Unconfined Refrigerator broke - see photo

Monday 22nd

Tomatoes in test 2 that are not in a box or bag have fungus on them
Mangos rotten

Tuesday 23rd

Confined pot became unconfined at 1:30 after temp test

Wednesday 24th

Photos taken of rotten tomatoes

Thursday 25th

Photos taken of all tomatoes for comparison. The refrigerator was put in the shade at 9:00 am and a photo was taken.

Sunday 26th

Other tomato infected. 1.5 liters used as no water the previous two days

Monday 27th

Early signs of fungus in the box therefore removed as well as other rotten tomato. Refrigerator was raised at 9:30

Wednesday 27th

Photo of tomatoes in the bag

Saturday 4th July

It was very windy and would have been a good example of the difference made by elevating the pot. The result was also verified at 13:30 by swapping the thermometers.   40 degrees and 46 degrees. The tomatoes in the bag were infected to the extent that they were inedible.

This research and document were produced by Liam Morgan for Practical Action Sudan in 2009.

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