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Effects of Oil Layer Plastering on the Performance of Local Earthen Cistern

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Abstract

Water scarcity in Enugu State has been the greatest socio economic problem in the rural communities of the state. The people therefore, resort to many ways of harvesting and storing rainwater such as plastering walls of the Earthen Cistern with palm oil. The aim of this study is to investigate the effects of using palm oil as a cistern plastering material. It gives a comprehensive description of rainwater harvesting cisterns for rural water supply in some selected communities in the state such as Enugu-Ezike. This study tries to identify the various types of rainwater harvesting cisterns, their plastering materials with a great emphasis on palm oil as a cistern plastering material. The effects of palm oil as a cistern plastering material are well emphasized in this research. This work presents seven cisterns with different palm oil layers in them. The source of water to these cisterns was by pouring equal volume of water into the cisterns. The first cistern C_0 was not plastered with oil and it was used as control. The second cistern C_1 was plastered with only one oil layer on its wall. The third cistern C_2, fourth cistern C_3, fifth cistern C_4, sixth cistern C_5 and seventh cistern C_6 were plastered with two, three, four, five and six oil layers respectively on their walls. A layer of oil plaster consumed 1litre of oil. At C_4, the rate of water depletion reduced and at C_5 and C_6, the rate of water depletion became very negligible as compared to that of C_4. Therefore, the fifth cistern C_4 with four oil layers gave the best results.

Keywords: Oil layer plastering, Local earthen cistern, cistern plastering material, Rainwater harvesting, Rainwater storage

1. INTRODUCTION

Water is irreplaceable and indispensable natural resources for the survival and well being of human kind. It is essential for production of food and energy that contributes to the economic improvement and industrial advancement of any society. Safe and reliable supply of water is therefore essential for individual welfare and for community development. In most of the rural areas, the major source of water supply is through rainfall (rainwater harvesting). Therefore, rainwater harvesting is the means of collecting, conveying and storing rainwater for later use from relatively clean surfaces such as a roof, land surface/landscape or rock catchment. During rainfall, rainwater is collected on the roof/land surface and transported with gutters to a storage reservoir/cistern, where it provides water at the point of consumption or can be used for recharging a well or the aquifer [10]. Rainwater harvesting can serve as an additional and/or a supplementary water sources when they become scarce or are of low quality like brackish groundwater or polluted surface water in the rainy season. Therefore, rainwater is used to augment other sources of rural water supply. It also provides a good alternative and replacement in times of drought or when the water table drops and wells go dry ([6]; [4]). The technology is flexible and adaptable to a very wide variety of conditions. It is used in the richest and the poorest societies, as well as in the wettest and the driest regions on our planet [3].

Rainwater infiltration is another aspect of rainwater harvesting playing an important role in storm-water management and in the replenishment of the groundwater levels ([7]; [8]; [11]). Rainwater harvesting system consists of three basic elements; A collection area, conveyance system and storage facilities. The collection area in most cases is the roof of a house or a well cleaned and maintained land surface/catchment. The effective collection area or the size of the collection area and the material used for the construction of the cistern influence the efficiency of collection and the water quality. A conveyance system usually consists of gutters (cleared pathway) or pipes that deliver rainwater falling on the collection area to the cisterns. The storage facilities include the storage tanks or cisterns, where the water is ultimately stored for later use.

Rainwater harvesting has been practiced for over 4,000 years throughout the world, traditionally in arid and semi-arid areas, and has provided drinking water, domestic water and water for livestock and small scale irrigation. Today, rainwater harvesting has gained much significance as a modern, water-saving and simple technology. However, rainwater quality may be affected by air pollution, animal or bird droppings, insects, dirt and organic matter. Therefore regular maintenance (cleaning, repairs, etc.) as well as a treatment before water consumption (e.g. filtration or/and disinfection) are very important.

Cistern is a waterproof receptacle for holding liquids, usually water. Cisterns or rainwater harvesting systems are used to capture runoff, primarily from roof tops or land surfaces. Sometimes runoff from pavement is also temporarily held in cisterns. Cisterns are distinguished from wells by their waterproof linings. A cistern stores runoff and ranges in size from $0.19m^3$ (commonly referred to as rain barrels) to hundreds of cubic metres. The capacity of the modern cisterns ranges from a few litres to thousands of cubic metres, effectively forming covered reservoirs. Cisterns are typically found in areas where a potable water source is not available in the community, the area yields low well water capacity, or the groundwater quality is poor. Cisterns can also be used to store water in order: to supplement a low yielding private water well, as an emergency water supply and for seasonal/occasional use.

Cisterns can be employed above or below the ground, the type that is employed above the ground is cheaper to purchase and it is easy to install. Cisterns are constructed with reinforced concrete, fiberglass, polyethylene, concrete and steel, brisk, blocks, lime plaster, clay tiles or earth materials. The use of polyethylene (PE) plastic and fiberglass is increasing as these materials are waterproof and do not rust. Size, shape and cost of cistern typically influence material selection. Early domestic and agricultural cistern use waterproof lime plaster cisterns. Cisterns are essential elements of emerging water management techniques in dry-land farming communities [9].During the early days, the water stored in the cisterns is used for many purposes including cooking, irrigation, and washing. But the present day cisterns are often only used for irrigation due to concerns over water quality. Cisterns today can also be outfitted with filters or other water purification methods when the water is intended for consumption. It is not uncommon for cisterns to be open in some manner in order to catch rain or to include more elaborate rainwater harvesting systems. It is recommended in these cases to have a system that does not leave the water open to algae or to mosquitoes, which are attracted to the water and then potentially carry disease to nearby humans. Cisterns are classified based on their construction materials or plastering materials. The types of cisterns include; concrete plate cistern, wire mesh concrete cistern, brick cistern, reinforced concrete cistern and lime cistern.

Cistern Plastering Material (Plaster) also known as stucco or render is a building material used for coating walls and ceilings. It is manufactured as a dry powder and is mixed with water to form a paste when used. The reaction with water liberates heat through crystallization and the hydrated plaster then hardens. Plaster can be relatively easily worked with metal tools or even sand paper. These characteristics make plaster suitable for a finishing, rather than a load-bearing material. Stucco is another term, often used for plaster that is worked in some way to produce relief decoration, rather than flat surfaces, and also for formulations designed for exterior use, which normally requires a protective coating of paint that is regularly maintained. The term plaster can refer to gypsum plaster (also known as plaster of Paris), lime plaster, heat resistant plaster or cement plaster [2].

2. METHODOLOGY

2.1 Materials Used

Materials used for the work include; hoe, hand digger, measuring tape, calibrated dipstick/ruler, palm oil and water.

2.2 Methods

2.2.1 Description of the Cistern

The total numbers of cisterns used in the study were seven cisterns. The cisterns are circular in shape and they all have equal dimensions [equal diameters (300mm) and depth (450mm)]. The cisterns were labeled or denoted as C_0, C_1, C_2, C_3, C_4, C_5 and C_6 and they were all arranged with their respective catchment areas as shown in fig. 8 below. The first cistern C0 was constructed without any oil plastering/rubbing on its wall (control). The second cistern C_1 was constructed with only one oil layer plastering/rubbing on its wall. The third cistern C_2, fourth cistern C_3, fifth cistern C_4, sixth cistern C_5 and seventh cistern C_6 were constructed with two, three, four, five and six oil layer plastering/rubbing respectively on their walls as shown in figure 3.3 below. One oil layer was rubbed at an interval of 30 minutes before rubbing the next layer. A layer of oil consumed 1litre of oil. The seven cisterns were constructed on clayey soils due its high water retention ability. Equal volume of water was poured into the cisterns at the same time. The cisterns were filled with water to the height of 0.4m (400mm). The height of the water in one cistern was equal to the height of the water in the other cisterns. After pouring the water into the cisterns, the rate of water depletion was monitored in each of the cistern from 1 to 6hours, and thereafter, the cisterns were refilled with water to the height of 0.4m (400mm) and the rate of water depletion was monitored for five days.

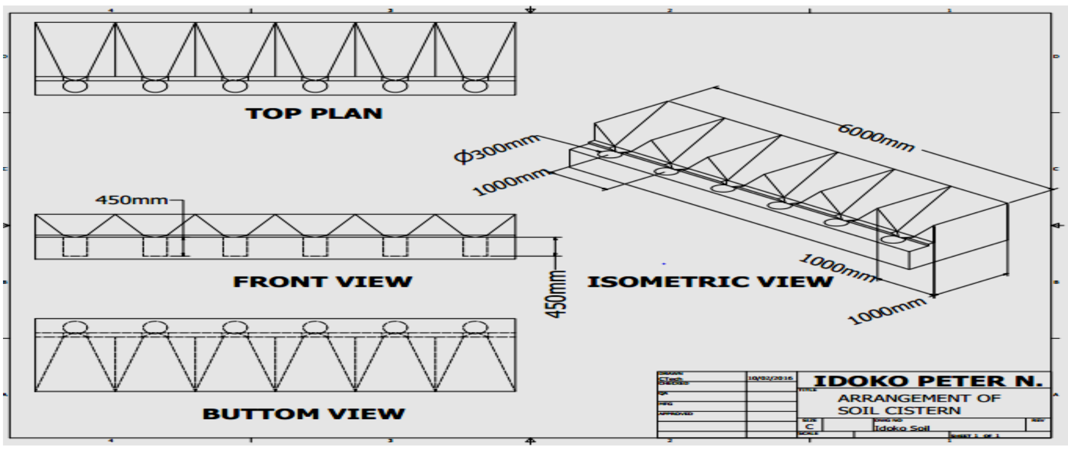

Fig. 2.1: The 2-D Arrangement of the Cisterns

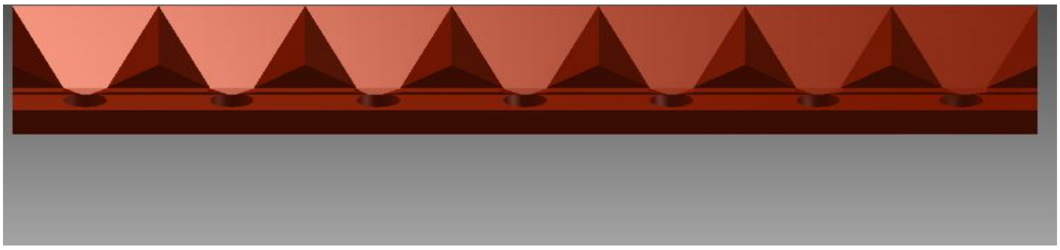

Fig. 2.2: The 3-D Arrangement of the Cisterns

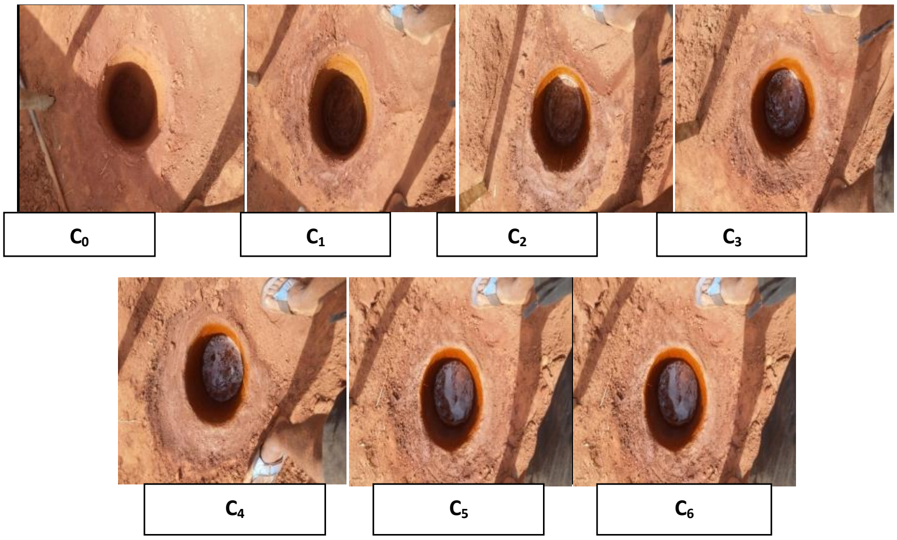

Fig. 2.3: Diagrams of the Cisterns after Construction and Plastering

2.2.2 Design Consideration

The design of the cisterns was based on following considerations;

1. All the six cisterns were constructed on clay soil because clay soil helps to retain water in the cistern for a longer time than any other types of soil due its high water retention ability.
2. Equal volume of water was poured in each of the cistern.
3. The cisterns have equal catchment area.

3.2.3 Design Factors that were considered

These refer to those factors that affect or influence the design of the cistern. These factors if not properly handled, can result to the failure of the cistern. It can also result to the inability of the cistern to serve its useful designed purpose. Modern cisterns have a range of capacity of a few litres to thousands of cubic metres, effectively forming covered reservoirs. A minimum storage capacity of 18.93m^3 is usually recommended for domestic cisterns [5]. This capacity should eliminate cases of buying or hauling water, which is a practice that is not only inconvenient but can become somewhat costly. Remember these words of wisdom when designing your cistern: "You pay for a large cistern once and a small one forever" which means that a large cistern is very expensive to construct, but after the initial construction, lesser amount of money may be paid on the cost of maintaining the cistern during the period of usage [5]. The vital point that will be considered in the design of a cistern is the capacity of the cistern and it can be determined through the following factors;

1. Number of persons in a family/community
2. Per capita water requirement
3. Average annual rainfall
4. Type and size of the catchment
5. Dry season demand versus supply approach

In practice the costs, resources and the construction methods tend to limit the cistern to smaller capacities than would otherwise be justified by roof areas or likely needs of consumers. For this reason elaborate calculations and design aimed at matching tank capacity to roof area is usually unnecessary. However a simplified calculation based on the following factors can give a rough idea of the potential for rainwater collection [5].

3.3 Design Procedures

Cistern design involves the following steps shown below;

1. Calculation of the Maximum Amount of Rainfall

Calculate the maximum amount of rainfall that can be harvested from the catchment area. Maximum amount of rainfall is calculated as the annual water harvesting potential as shown below;

AWHP = A x R x C ……………………….. (ii)

where; AWHP = Annual water harvesting potential (m^3 or L).

A =Catchment Area (m^2)

R = Average Annual Rainfall in the Area (mm)

C = Run-off Coefficient

2. Determination of the Cistern Storage Capacity

Determining the cistern capacity is based on the dry period, i.e., the period between the two consecutive rainy seasons. For example, the dry season in South Eastern Nigeria (Enugu State) starts from November to March which is five months or 181days.

3. Calculation of Drinking Water Requirement for the Family/Community for the Dry Season

The drinking water requirement for the family/community for the dry season

(L) = N x n x Rw ……………………….. (iii)

where; N = Number of days in the dry season

n= Number of persons in the community

Rw = Daily water requirement per person (L)

It is from the result of the drinking water requirement that the required capacity of the cistern is estimated. As a safety factor, the cistern should be built 20% larger than the drinking water requirement [1].

3.4 The Cisterns Design Parameters

The cisterns design parameters t are summarized as shown below;

Height of the cisterns, H = 450mm = 0.45m

Diameter of the cisterns, D = 300mm = 0.3m

Therefore, the volume of the Cistern $V = \frac{\pi D^2 H}{4}$

$$V = \frac{\pi X 0.3^2 X 0.45}{4}$$

$V = 0.0318\ m^3$

The required height of water to be supplied to the cistern, H_w = 400mm = 0.4m

Therefore, required volume of water in the cistern,

$$V_w = \frac{\pi D^2 Hw}{4}$$

$$V_w = \frac{\pi X 0.3^2 X 0.4}{4}$$

$V_w = 0.0287\ m^3$

Also, the required volume of water in the cistern V_w, is equal to the volume of water in the cistern before depletion V_b,

Thus; $V_w = V_b = 0.0287\ m^{3.}$

3. RESULTS

3.1 Analysis of Result

The results of the work can be analyzed in the following ways;

3.1.1 The Rates of Water Depletion in the Cisterns

The rates at which the heights of water in the cisterns decreased were analyzed in the format as shown in tables below;

3.2: Graphical Analysis of the Results

The graphs of the heights of water (in meter) in the cisterns were plotted against time of water depletion (in hours and days). The slope or gradient of the curve obtained gives the rate of water depletion (in meter per hour or meter per day). The tables below were extracted from water depletion tables above;

Table 3.1: Hourly water Depletion in the Cisterns

Time (hr)	Heights of water in the cisterns (m)						
	C_0	C_1	C_2	C_3	C_4	C_5	C_6
1.00	0.1342	0.2013	0.2341	0.2617	0.3347	0.3351	0.3351
2.00	0.1119	0.1678	0.1953	0.2182	0.2792	0.2792	0.2793
3.00	0.0984	0.1431	0.1651	0.1754	0.2321	0.2323	0.2323
4.00	0.0805	0.1140	0.1306	0.1455	0.1982	0.1982	0.1982
5.00	0.0626	0.0849	0.0959	0.1131	0.1652	0.1653	0.1653
6.00	0.0436	0.0519	0.0626	0.0914	0.1462	0.1462	0.1462

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Table 3.2: Daily water Depletion in the Cisterns

Time (day)	Heights of water in the cisterns (m)						
	C_0	C_1	C_2	C_3	C_4	C_5	C_6
1.00	0.0000	0.0250	0.0760	0.1680	0.2290	0.2330	0.2330
2.00	0.0000	0.0140	0.0250	0.0740	0.1430	0.1430	0.1430
3.00	0.0000	0.0000	0.0120	0.0690	0.1280	0.1300	0.1300
4.00	0.0000	0.0000	0.0090	0.0640	0.1220	0.1220	0.1221
5.00	0.0000	0.0000	0.0010	0.0210	0.1000	0.1000	0.1000

The tables above are used in the graphical analysis as shown below;

3.2.1 Hourly Water Depletion in the Cisterns

The overall hourly water depletion can be plotted as shown below;

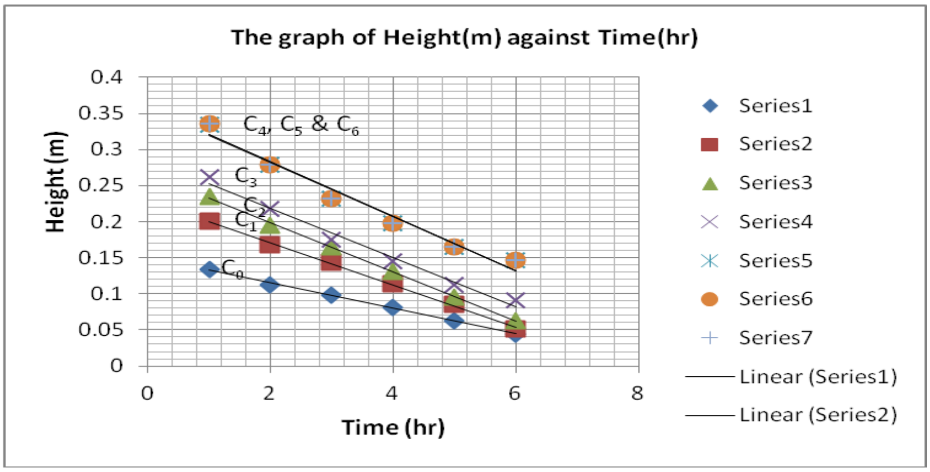

Fig. 3.1: The graphs of hourly water depletion Rate

3.2.2 Daily Water Depletion in the Cisterns

The overall daily water depletion can be plotted as shown below;

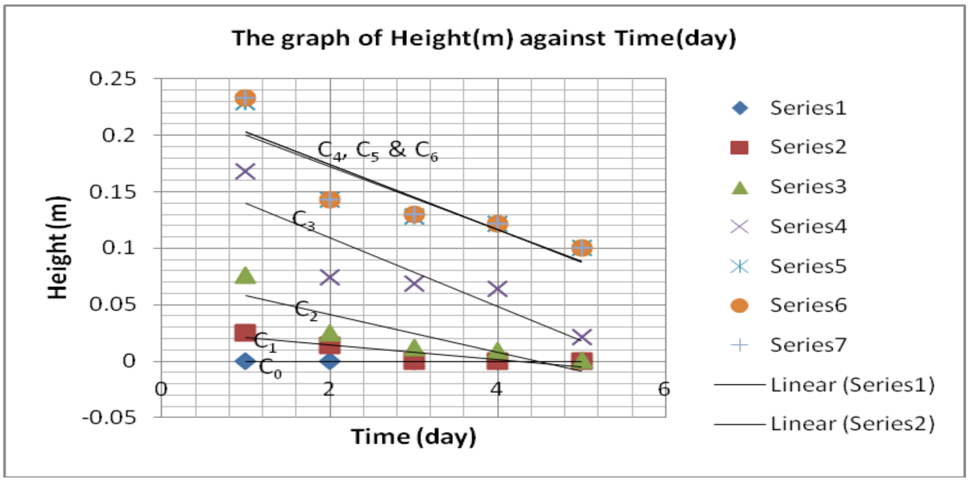

Fig. 3.2: The graphs of daily water depletion Rate

4. DISCUSSIONS

The result obtained showed that the rate of water depletion in the cistern was faster in the first cistern C_0 (control), followed by that of C_1, C_2 and C_3. At C_4, the rate of water depletion reduced. At C_5 and C_6, the rate of water depletion became very negligible as compared to that of C_4. Also the result of the graphical analysis showed that the gradients/slopes of the linear graphs obtained represent the rate of water depletion in the cisterns (in m/hr and in m/day). The table below presents the gradients/slopes of the linear graphs plotted for the seven cisterns;

Table 4.1: The table showing the gradients of the graphs above

Graphs of water depletion in the cisterns	Their gradients/slopes	
	(m/hr)	(m/day)
C_0	-0.017	-0.0
C_1	-0.029	-0.006
C_2	-0.034	-0.016
C_3	-0.034	-0.03
C_4	-0.037	-0.027
C_5	-0.037	-0.028
C_6	-0.037	-0.028

From the table above, the slope decreases from C_0 to C_6 indicating that the highest rate of depletion occurred in C_0 and the lowest depletion rate occurred from C_4 to C_6. The negative signs in the slopes of the graphs indicate that the heights of the water in the cisterns were decreasing with increase in time.

The R-square values for the graphs are analyzed using the table below;

Table 4.2: The table showing the R-square values of the graphs above

Graphs of water depletion in the cisterns	Their R-square values	
	(m/hr)	(m/day)
C_0	0.997	#N/A
C_1	0.998	0.792
C_2	0.999	0.765
C_3	0.999	0.794
C_4	0.973	0.786
C_5	0.972	0.782
C_6	0.972	0.782

The R-square values above shows the relationship between the heights of water in the cisterns and the time taken for the water to deplete or decrease. Also the equations of the graph are used for scientific, mathematical and future predictions and R-square also helps to give the relationship between the predicted value and the actual value. The result (table) above also shows that, as the R-square values approaches unity (1) or as the R-square values approximates to one (1), it indicates the accuracy and correctness of the graph and that of the work done. Thus, the R-square value for that of C_0 in meter per day does not hold (i.e cannot be determined) since the equation of the graph, y = 0.

5. CONCLUSION

In this study, the effects oil plastering on local earth cistern and the variability of storage losses in the local earth cistern were investigated. In this study, seven cisterns were constructed. The first cistern C_0 was not plastered with oil and it was used as control. The second cistern C_1 was plastered with only one oil layer on its wall. The third cistern C_2, fourth cistern C_3, fifth cistern C_4, sixth cistern C_5 and seventh cistern C_6 were plastered with two, three, four, five and six oil layer respectively on their walls. A layer of oil plaster consumed 1litre of oil. When the cisterns were filled with water of equal depth, the rate of water depletion was monitored in each of the cistern. The first cistern C_0 (control) gave a very poor result. The second cistern C_1, the third cistern C_2 and fourth cistern C_3 gave very less satisfactory results by retaining very little quantity of water in the cistern over a given time. The fifth cistern C_4, sixth cistern C_5 and seventh cistern C_6 gave much and almost equal satisfactory result by retaining much quantity of water in the cistern over a given time. Therefore, from the statistical (graphical) analysis and also from the result of this work, one can conclusively say that the fifth cistern C_4 with four oil layers is the optimal range of oil plastering practice which the local people should adopt since the cistern gives the optimum satisfactory result with a high water retention ability while conserving resources (i.e conserving further oil plastering up to five, six or seven layers).

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