LIFE CYCLE ANALYSIS OF FERRO-CEMENT RAINWATER TANKS IN SRI LANKA: A COMPARISON WITH RCC AND HDPE TANKS

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ABSTRACT

Ferro-cement tanks are promoted in water stressed rural communities as a low cost alternative to other generic types of water tanks; reinforced cement concrete (RCC) and plastic-typically high density polyethylene (HDPE) to store harvested rainwater. It is argued that beside the high cost, the low accessibility to technical knowhow and shortage of skilled labour in construction of RCC tanks and the non availability of larger capacity HDPE tanks in remote areas make ferro-cement tanks a viable low cost option. However, given the durability differences, the concerns of environmental impact each type of tanks make, together with the inflow of knowledge, improved transportation and the commercial availability of low cost plastic tanks in a wide range of capacities in recent times, scientific assessment of the viability of ferro-cement tanks for storage of rainwater is important and timely. In this study, life cycle analysis techniques are used to assess the cost, embodied energy and the environmental impact of ferro-cement tanks compared with RCC and HDPE tanks under normalized conditions.

Key words: ferro-cement, rainwater, durability, life cycle, embodied energy, environmental impact.

INTRODUCTION

Life Cycle Analysis (LCA) quantifies the resource use over the useful life of a product. In this study LCA is carried out covering all stages; construction, transport, use and disposal, in the useful lives of ferro-cement, reinforced cement concrete (RCC) and high density polyethylene (HDPE) tanks used to store rainwater in domestic rain water harvesting (RWH) systems to determine the viable options in terms of cost, embodied energy and environmental impact. While the life cycle cost indicates the economic viability, the total embodied energy and CO_2 emissions are used to assess the environmental burden of each water tank.

Ferro-cement is a modified form of reinforced cement concrete- a composite construction material, in which the reinforcement is finely subdivided and dispersed in the matrix in order to achieve a closely spaced crack regime coupled with excellent corrosion resistance and high permeability to ingress of water [6]. It is well accepted as an efficient low cost construction material and in Sri

Lanka and elsewhere it is widely used in the construction of water retaining structures such as tanks for domestic rainwater harvesting systems, particularly for communities in remote areas. Ferro-cement water tanks are generally considered as cost effective and low in weight, and can be cast at site requiring no formwork and are easy to maintain.

In the study, ferro-cement tanks introduced by World Bank funded Community water Supply and Sanitation Project (CWSSP) under the Ministry of Housing, Construction and Public utilities is considered for the comparison. Tanks are of roughly spherical shape with an average diameter of 1700 mm. Construction of tanks is carried out using a skeleton mould, made out of shaped 25 mm ‘L’ iron, fixed around a circular foundation with 8 vertical and horizontal rings made of 6 mm mild steel bars every 100 mm vertically [7]. Two layers of 12 mm steel hexagonal woven mesh are used as reinforcement. Exterior walls are plastered first and the interior is plastered after removing the mould from inside for a total wall thickness of 40 mm. Mortar used is ordinary Portland cement mixed 1:3 with well graded medium silt free coarse sand. The base is of 1450 mm diameter of 1:2:4 concrete 100 mm thick with 20 mm thick 1:3 cement mortar plaster and the opening of the tank is covered with a 750 mm diameter 2 mm thick GI sheeting (Fig. 1). The durability of a well maintained ferro-cement tank can be taken as 25 years. Life cycle tree of ferro-cement tanks over its useful life is given in Fig. 1. Indicated within the dotted line boundary is the cement manufacturing process. The life cycle tree of RCC is identical to Fig. 1 with the term ferro-cement replaced with RCC.

The equivalent capacity (5 m^3) RCC tanks are taken as of basic dimensions 1.75 x 1.75 x 1.75 m, rectangular in shape, wall thickness of 100 mm with a 25 mm thick 1:3 cement mortar plaster interior lining. The reinforcement detail for the walls is 10 mm steel bar at 150 mm c/c and the base at 100 mm c/c for a thickness of 100 mm. A steel cover made of 2 mm thick GI sheeting is proposed for easy access to clean and maintain the tank. A structurally sound RCC water tank that will not leak constructed by providing the proper amount and distribution of reinforcement, the proper spacing and detailing of construction joints and the use of quality concrete can be taken as having a durability of 50 years.

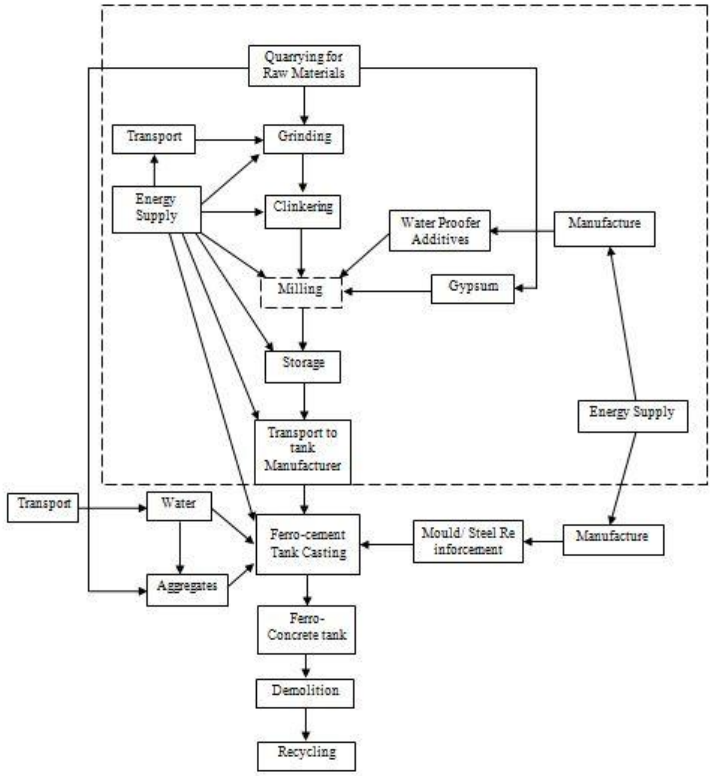

Figure 1: Life cycle tree of ferro-cement rainwater tank over its useful life

Plastic water tanks are generally of High Density Polyethylene (HDPE), made by rotational moulding and are commercially available in varying capacities. A 5 m^3 capacity cylindrical shaped tank is considered for the comparison with a diameter of 1200 mm, a height of 1500 mm and wall thickness of 15 mm. The interior surface of the tank is lined with food grade polymer and the total weight is 100 kg. According to warranty periods given by manufacturers the durability of HDPE tanks can be safely taken as 10 years. The lower life time compared to the reported 25 years elsewhere could be due to high UV contents to which tanks are exposed in tropical countries such as Sri Lanka, regardless of including UV stabilizers in manufacturing. HDPE tanks at the end of useful lifetime are generally not considered recyclable due to the UV degradation are therefore are burnt to recover energy. Life cycle tree of HDPE tanks over its useful life is given in Fig.2. Indicated within the dotted line boundary is the HDPE resin manufacturing process.

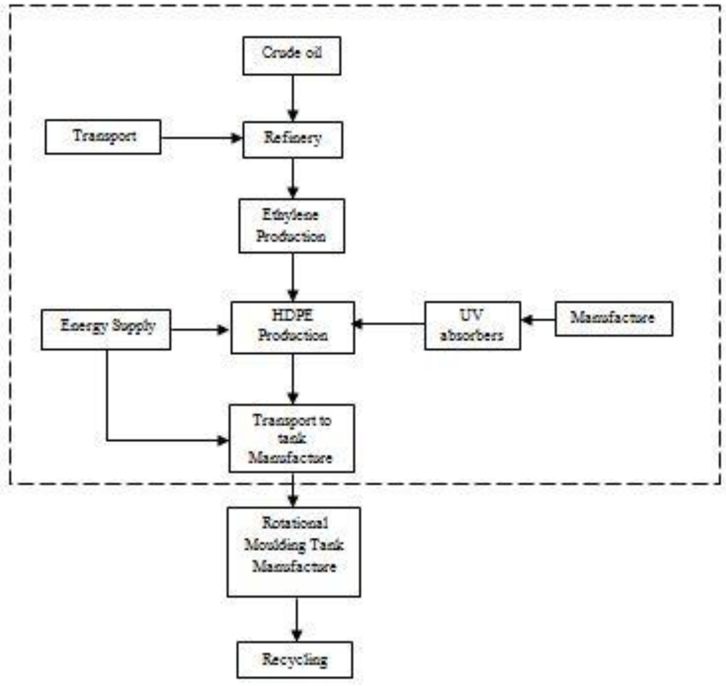

Figure 2: Life cycle tree of HDPE water tank over its useful life

The selection of tank capacities as 5 m^3 is appropriate since in many locations in the country it can be considered as the optimum tank size for the supply of adequate quantities of potable water in rainwater harvesting (RWH) systems. Using generalized curves for water saving efficiency (WSE) [4] validated for tropical countries [9], it is estimated that a 5 m^3 capacity rainwater tank can supply 150 liters of water, sufficient for daily potable demand of a household of diffuse setting with 4-5 occupants, given a catchment area of 100 m^2 of collection coefficient of 0.8 and an annual average rainfall depth of 2000 mm, experienced by Sri Lanka in a bimodal pattern spread through the year.

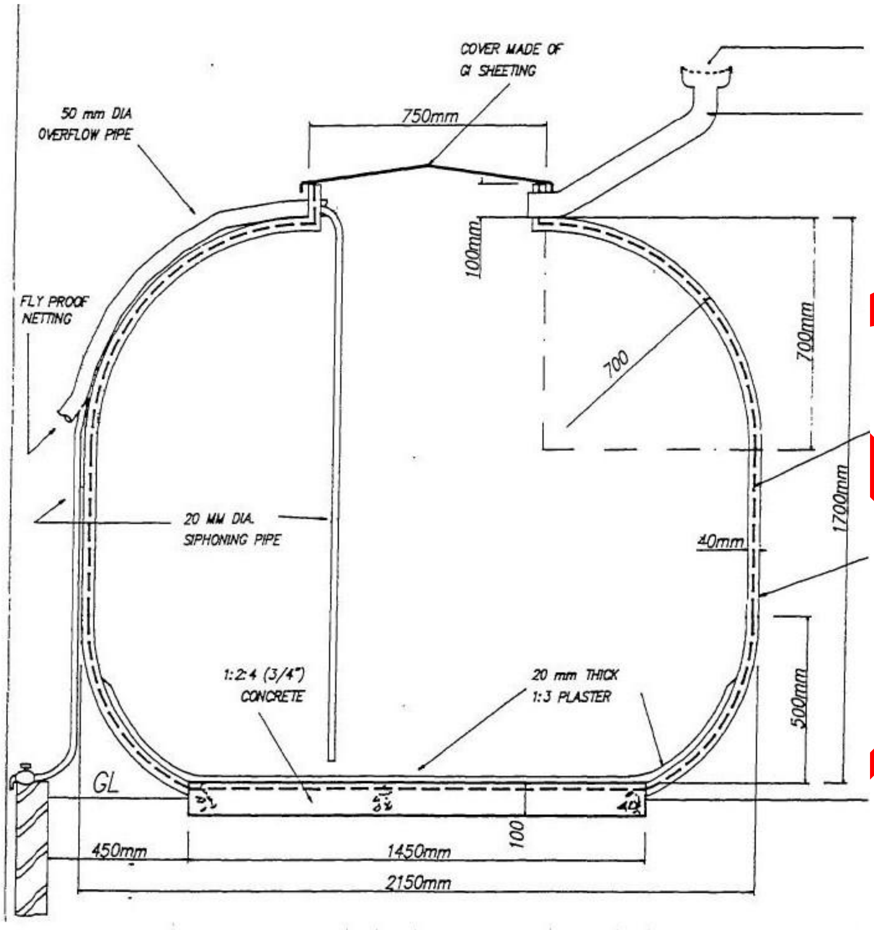

Figure 3: Detailed diagram of ferro-cement rainwater tank [7]

OBJECTIVE

The objective of the study is to assess the viability of using ferro-cement tanks as the storage option in domestic RWH systems compared to RCC and HDPE tanks. The study focuses on the cost, embodied energy and the impact on the environment by way of CO_2 emission contributions during the useful life of the 3 types of tanks.

METHODOLOGY

In the study, techniques of life cycle analysis (LCA) are used to estimate the cost, embodied energy and CO_2 emissions in the construction, use and disposal stages of each type of tank. Taking into consideration the differences in durability of the 3 generic types of tanks in focus, the calculated values are normalized using a functional unit (FU) for realistic comparisons. The FU is taken as 1 m^3 of collected rainwater used per capita per year.

In the LCA of tanks the system boundaries are taken as that covering construction, usage and disposal stages only. All pipes, accessories such as pumps are not considered in the analysis as they are external to the tank.

Data from the Inventory of Carbon and Energy (ICE) (University of Bath, UK), Alcorn [1] and the Centre for Building Performance Research, New Zealand [2] are used to identify the embodied energy and CO_2 emissions of materials in each tank while costs and quantities are gathered from local suppliers and contractors.

CALCULATIONS

For the calculation, the average daily demand of water for drinking, cooking and cooking related activities (potable water) in a typical household of 4-5 occupants in a diffuse setting is taken as 150 liters [10]. Therefore the per capita water use is calculated as 13.69 m^3 per year. Calculations are based on publicly available typical data. Although this is a simplified approach to the life cycle analysis procedure, the assumptions in the study are kept constant, enabling a comparative life cycle assessment of the 3 types of water tanks. In all 3 cases, the energy in manufacturing of tanks is not considered. It is reported that typically energy of manufacturing is less than 1% of the total embodied energy [3].

In the calculations the following assumptions are made;

- The steel frame mould used in the construction of ferro-cement tank is assumed to be fabricated elsewhere and transported to site.
- Concrete mixing is carried out manually, taking into account the volumes involved and the possible remoteness of the site from the nearest batching plant. However, the cost of concrete is calculated per m^3 adding the cost of cement, sand and aggregates together for simplicity. A cost is not allocated for water assuming ground or surface is used either from site or transported from elsewhere. It is assumed that vibrators are not used in the process.
- Tanks are assumed to be not painted and any attachments to the tank cover such as handles, supports etc are assumed to have no significant contributions to the calculation.
- The cost and energy for maintenance is negligible.
- It is assumed that plywood and lumber used in the formwork are not re-used. Any lumber used is not taken into calculation due to its relatively low quantities and cost.
- At the end of the useful lives, both ferro-cement and RCC tanks are assumed to be de-constructed and materials used for land filling at site. In the case of RCC tanks, recycling of materials from deconstruction is considered non-viable due to low volumes. Energy required for the deconstruction is considered minimum. HDPE tanks are assumed to be removed from site, but recycling is not anticipated due to lower quality of resulting recycled material. HDPE tanks can be burnt to recover a percentage of energy but the amount is not

taken into the calculation as it does not have an impact on the embodied energy of the tank over its useful life.

Cost analysis:

Costs of procurement, construction, usage and disposal are calculated at current prices in Sri Lankan Rupees (SLR, Conversion ratio; 1 US$ = 145 SLR). Cost calculations for ferro-cement, RCC and HDPE tanks of 5 m^3 capacities are given in Table 1. It also shows the normalized costs (cost per FU).

Transport cost is calculated based on charges per km and average distance to the supplier bases. Material transportation to site is taken as from an average distance of 50 km assuming the sites are remotely located.

Table 1: Cost analysis for Ferro cement, RCC and HDPE Tanks

Tank type (5m^3 capacity)	Quantities	Unit Cost (SLR)	Normalized Cost (SLR)
Ferro Cement			
Cement	400 kg	18	21.04
Aggregates 20mm			
Sand	0.175 m^3	2000	1.02
Steel 12 mm hexagonal woven mesh	1.5 m^3	5185	22.70
Labour			
Skilled	40 m^2	160	18.70
Unskilled			
Steel mould inclusive of labour	56Hr	225	36.82
GI cover 2 mm	112Hr	175	57.27
Transportation			
	1	15000	43.83
	1.5 m^2	3000	13.15
Total	100 km	60/km	17.53
			232
RCC (Cast-in-place) (1:2:4)			
Cement	500 kg	18	13.14
Sand	1 m^3	5180	7.56
Steel			
(10 mm bar)	275 m	75	30.11
12 mm thick			

Aggregates			
20 mm	1 m^3	2000	2.92
Plywood sheets	30 m^2	1080	47.30
Labour			
Skilled	48 Hrs	225	15.77
Unskilled	112Hrs	175	28.61
Tank Cover			
GI sheet	2.85 m^2	3,000	12.48
Transportation	200 km	60/km	17.52
Total			175.41
HDPE	1	65,000	474.80
Transport	50 km	60/km	21.90
Total			496.70

Embodied energy and CO_2 emissions

In the calculation, the embodied energy of the steel mould used in the construction of ferro-cement tanks is not taken as it is not considered as part of the final product.

Both ferro-cement and RCC tanks can be deconstructed and recycled. However, in this study, recycling is not anticipated as the volumes of material concerned are too low for transporting to a crushing plant. It is assumed that deconstruction to be carried out manually and materials disposed at site.

However, HDPE tanks are assumed to be transported out of site for recovery of energy by burning after their useful lifetime. For HDPE tanks, the largest embodied energy is associated with the production of HDPE, part of which is recovered by combustion at the end of its useful life, displacing an equivalent amount of fuel oil [8]. The amount of CO_2 emissions in the production of HDPE and in the disposal is not known.

Table 2: Embodied energy & CO_2 Emission Comparison of ferro-cement, RCC and HDPE tanks

Tank Type (5 m^3)	Qty. kg	Embodied Energy (MJ/kg)	Embodied Energy /FU	Carbon Kg CO_2 per kg	CO_2 emissions /FU
Ferro-cement					
Cement	400 kg	5.6	6.55	0.93	1.09
Sand	3000 kg	0.081	0.72	0.0048	0.04
Aggregates					
20 mm	275 kg	0.083	0.07	0.0048	0.00

Steel 12 mm hexagonal woven mesh	10	20.1	0.59	1.37	0.04
GI sheets (Cover)	10	20.1	0.59	1.37	0.04
Transportation (Diesel)	200 t.km	2.5	1.46	0.0687	0.10
Total			9.96		1.32
RCC					
Cast-in-place					
Cement	500 kg	5.6	4.09	0.93	0.68
Sand	1000 kg	0.081	0.12	0.0048	0.01
Aggregates 20 mm	1500 kg	0.083	0.28	0.0048	0.02
Steel 10 mm	155 kg	20.1	4.55	1.37	0.31
Plywood (Formwork)	160 kg	15	3.50	1.07	0.25
GI sheets	45 kg	20.1	2.64	1.37	0.18
Transportation	330 t.km	2.5 /t.km	1.20	0.0687	0.03
Total			17.41		1.55
HDPE					
Production of HDPE	100 kg		58.44	3.45	2.52
Tank mfg.	100 kg	32.4	2.37	-	
Transportation	50 km	2.5/t.km	0.91	0.0687	0.06
Disposal	100 kg	(9.13)		-	
Total			61.72		2.58

RESULTS AND DISCUSSION

When costs are normalized in order to account for the differences in durability, the cost per 1 m^3 of rainwater used per capita per year (FU) is the highest for the HDPE tank at SLR 496.70 while ferro-cement tanks costing SLR 232 with the mould used for one unit and SLR 192.45 when the same mould is used for 10 units, still 8.8% higher than same capacity RCC tanks in cost/FU.

Both ferro-cement and RCC tanks are cast-in-place highlighted by high labour content of 40.6% and 25.3% in the overall normalized cost (Fig. 4). However, taking into consideration that these tanks are constructed as community based projects, it is possible to consider unskilled labour as contribution from the potential user and hence free of cost. In such a scenario the cost of ferro-cement and RCC tanks drop as much as 41.7% and 16.3% to SLR 135.18 and 146.80 per FU respectively. Usually, plywood for formwork is used up to 4 times with a 10% loss at each time. If only 25% of the cost of plywood is taken, the total construction cost of RCC tanks would drop by a further 24.2% for a cost per FU of SLR 111.40 thus making the life cycle cost of RCC tanks the lowest while HDPE tanks with their low durability (taken as per manufacturer's warranty) stands the highest with SLR 496.70 per FU. It is noted that in the case of RCC tanks a further economic gain can be anticipated when approximately 155 kg of steel used for reinforcements is disposed as scrap iron at the end of the useful lifetime of the tank.

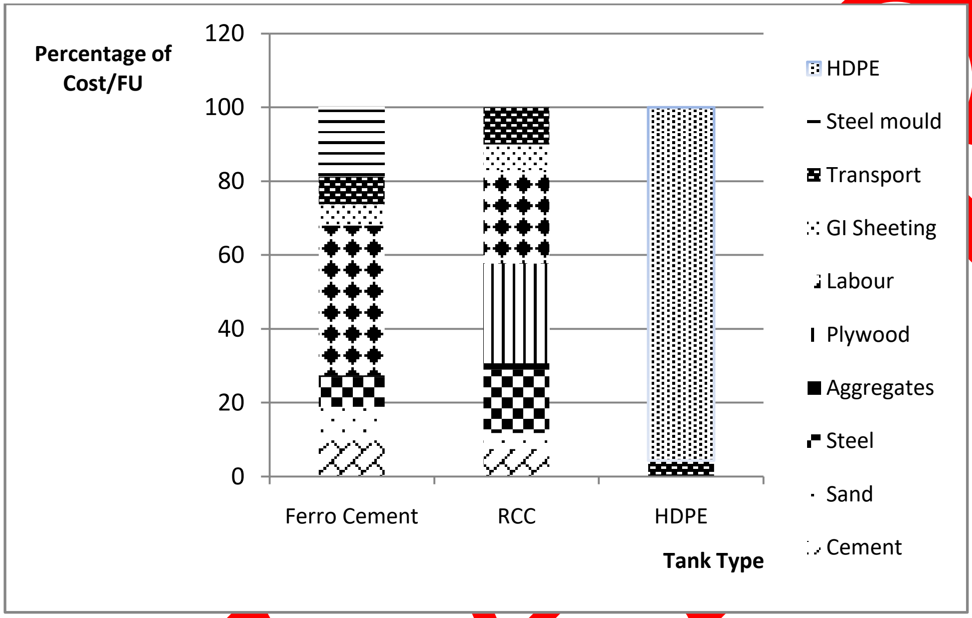

Figure (4): Contribution to normalized costs, of Ferro- Cement, RCC and HDPE Tanks.

Comparing the embodied energies of the three types of tanks, cement at 65.7% in ferro-cement tanks, reinforcement steel at 27% in RCC tanks and HDPE resin at 97.6% dominates. Since it is known that the embodied energy in the manufacturing process of HDPE tanks is typically less than 1% of the total, it is not taken into the calculation. From Table (3) it can be seen that the total normalized embodied energy in the 5 m^3 capacity ferro-cement tank is the lowest at 9.96 MJ compared to 17.41 MJ for RCC and 61.72 MJ for HDPE tanks. Ferro-cement tank therefore is almost 40% lower than RCC and 30% lower than HDPE tanks. However, if plywood used for RCC form work is taken as reused, embodied energy in ferro-cement tanks is only 25% lower than that of RCC and hence more sustainable than the same capacity HDPE tanks. It should be noted that the embodied energy of RCC tanks is calculated inclusive of the cover made of GI sheeting. If an alternative material such as wood is used, the normalized embodied energy would be lower, thus becoming more competitive with ferro-cement tanks (Fig. 5).

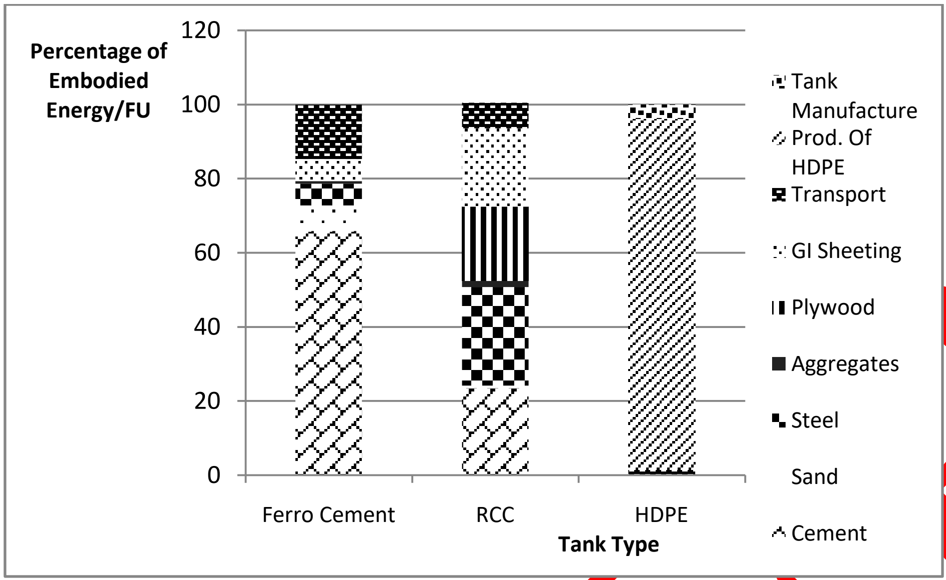

Figure (5): Contribution to normalized Embodied Energy, of Ferro- Cement, RCC and HDPE Tanks.

Comparing the normalized CO_2 emissions, ferro-cement tanks at 1.31 kg is the lowest and RCC tank would be at 1.34 kg if plywood is taken as reused. HDPE tanks on the other hand are having the highest embodied CO_2 at 2.5 kg, despite disregarding the emissions in the manufacturing process. Since CO_2 emissions in the disposal process of HDPE is not known and can be assumed to be negligible compared to production of HDPE resin, it is not included in the calculation.

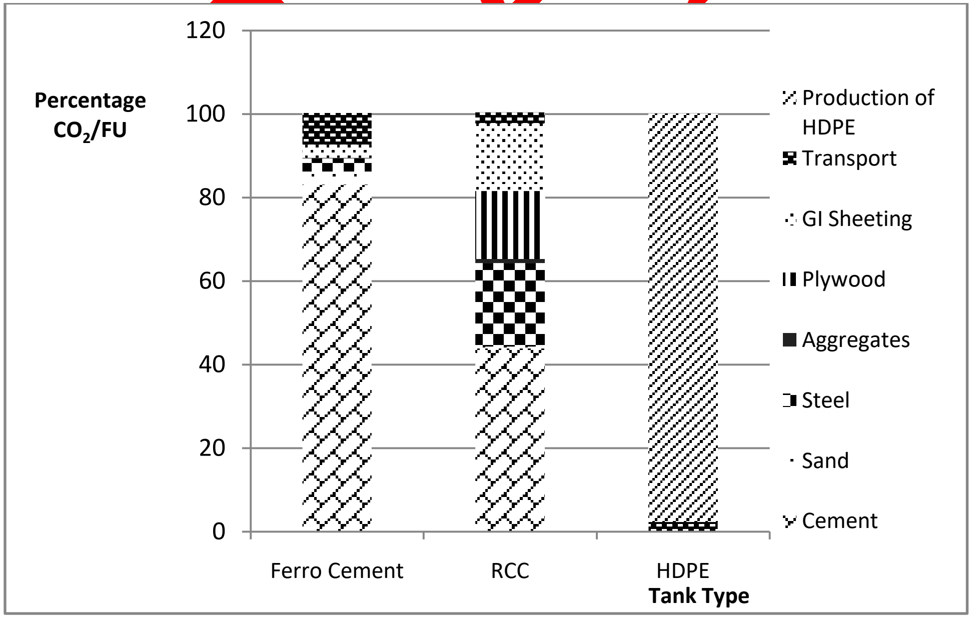

Figure (6): Contribution to normalized CO_2 Emissions, of Ferro- Cement, RCC and HDPE Tanks.

As the durability of each type of tank has a major bearing on the normalized cost, energy and emission figures, any possibility of change in durability is important. While well constructed RCC tanks are known to have a useful lifetime of 50 years, the lifetime of ferro-cement tanks depend heavily on the design, materials used and workmanship. Ferro-cement tanks with specially formulated admixtures containing bonding agents, plasticizer and pore sealants included in the mortar, a minimum mesh reinforcement of 0.3% by volume and 2 to 6 layers of hot dip annealed galvanized mesh reinforcement has been reported to be showing higher durability even beyond 50 years [Sharma]. Also important is maintaining a minimum cover of 5 mm to the outermost layer of wire mesh and good workmanship in compacting the mortar. However, as ferro-cement tanks considered in the study are constructed in community based projects with minimum cost as the main objective, a higher durability cannot be expected. Information gathered from users of these tanks confirms that the durability of 25 years taken for the study is justifiable.

In social acceptability however, pumpkin shaped ferro-cement tanks are not so popular due to low aesthetic appeal. HDPE tanks on the other hand are gaining popularity due to ease of procurement, maintenance and replacement. They also can be well sealed from insect vectors and other contaminants. However, with a higher thermal conductivity of 0.47 W/mK and thinner walls, collected rainwater stored in HDPE tanks gets warmer, particularly in tropical climates, allowing for possible bacterial growth compared to brick and ferro-cement tanks. It is also of interest to note that both ferro-cement and RCC tanks leaching Ca over time balancing the pH values of collected rainwater at locations where rainwater is known to display slight acidity.

It can be seen from Table 2 that the heaviest is the RCC tank at around 2600 kg inclusive of reinforcement steel and HDPE tank the lightest at 100 kg. However, at full capacity the total weights would be between approximately 5000-8000 kg and therefore, much of a change in supporting structure design cannot be anticipated. As such, the cost, embodied energy and CO_2 emission potential calculations for the supporting structures are not carried out in the comparison. However, it should be noted that an elevated supporting structure allowing the collected rainwater to flow into service points through gravity thus saving on pumping energy, is an important aspect in the social acceptability of RWH systems.

CONCLUSIONS

Comparing ferro-cement, RCC and HDPE tanks, RCC tanks prove to be the most economical with the lowest normalized life cycle cost at current prices, particularly when construction is carried out as community based projects. Under equal conditions, even though ferro-cement tanks are 17.6% higher in normalized cost compared to RCC tanks, they are 43% and 2.6% lower in embodied energy and embodied CO_2 in comparison to RCC tanks.

If however, the durability can be increased by possible improvements in materials, reinforcements and workmanship, ferro-cement tanks would be much superior in cost, embodied energy and CO_2 per functional unit. In the study, the use of energy and emission data from multiple sources is taken as not substantially affecting the estimated values. Assumptions and values used were kept constant enabling a comparative LCA of the three types of rainwater tanks.

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