# Feasibility of Novel Quadric (Egg-Shaped) Sludge Digesters within Wastewater Treatment Plants Hydraulic Infrastructure across the Caribbean.

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## Abstract

Wastewater infrastructure across the Caribbean has been actively advancing due to the need to manage water as a resource in a cost-effective manner. Most wastewater treatment facilities across small island developing states (SIDS) stop treatment after the primary stage. Individual Caribbean government's infrastructural ministries weighs the benefits of various wastewater treatment processes thus making decisions to allow for either disposal of sludge after the primary stage or to provide further treatment. The latter comes at a higher cost, both for initial construction and maintenance. One secondary treatment component that can be beneficial to the Caribbean region is the Quadric-shaped Sludge Digester (QSD). Also commonly known as the egg-shaped sludge digester, it has proven itself to be cost effective during the secondary treatment phase of wastewater sludge. The QSD's basic form can be described as a revolution of a parabola where the polar regions are either curved or conical. This provides a greater surface area to volume ratio, where the plan area of the sludge reactor is considerably small. Settled sludge can be removed easier thus reducing the power requirements needed when compared to conventional cylindrical tanks. This type of digester (egg-shaped) reduces maintenance costs as a result of the seamless circulation mixing patterns which eliminates girt build-up and the need to halt operations for cleaning and maintenance services. Previous research into the dynamic responses to seismic activity has already been conducted via numerical and scaled earthquake simulation laboratory models. Favourable seismic performance under earthquake simulation table testing has proven the use for these sludge reactors in seismic zones. Construction costs, usually, is the determining factor which dissuades clients from moving forward with the QSD. However, with new advances in materials, construction techniques, structural integrity, the cost and complexity of construction and maintenance can be significantly reduced, thus making it affordable both in terms of economics and construction logistics. This paper outlines ongoing research which illustrates the benefits QSD can be as novel hydraulic infrastructure within existing Caribbean wastewater treatment plants for islands and small economy territories.

*Keywords: quadric-surfaced, egg-shaped sludge digester, wastewater reactor, shell structures, hydraulic infrastructure*

## 1.0 Introduction

Water conservation is a crucial objective in water resource management across the globe. Climatic changes have redistributed rainfall intensities causing smaller islands to look closer at water quantities accounting. The reuse of wastewater has now become essential in areas where low potable water levels are existent. Traditionally, domestic wastewater across small island developing states (SIDS), have been treated via localised septic tanks. In many low income residential and rural communities, pit latrines are still being utilised. There is a degree difficulty for assessing proper functionality of these structures since little or no maintenance usually occurs during the life of these hydraulic structures. Hence groundwater contamination in the indigenous aquifers becomes a high possibility. Centralised wastewater treatment facilities can eliminate groundwater contamination hence not only ensuring the non-pollution of groundwater but also providing reuse of treated water for commercial activities. Some SIDS are heavily dependent on tourism and are reliant on using water for activities such as landscaping (Hutchinson, 2010). Wastewater reuse can be a supplemental alternative for water resources when compared to the reliability of rainwater harvesting. The secondary treatment phase offers removal of bacteria and sludge from the effluent, preparing it for the final or tertiary stage of disinfection.

Within the secondary treatment stage, anaerobic digestion of the sludge usually takes place in a sludge digester. These tanks are typically cylindrical in shape. The problem with this shape is that due to improper mixing, dead zones *(see Figure 1)*develop, leaving a build-up of scum and grit on the tank walls(Zingoni, Stresses and deformations in egg-shaped sludge digesteors: Membrane effects, 2001). This inefficiency causes the plant operations to be temporarily halted to facilitate cleaning of the digesters. Recommencing operation of the tanks usually requires time and energy for the bacteria to develop which results in further delays. With the advent of the quadric surfaced sludge digester, the efficiency of mixing is increased, thus eliminating the scum build-up, hence reducing the overall costs associated with operation and maintenance.

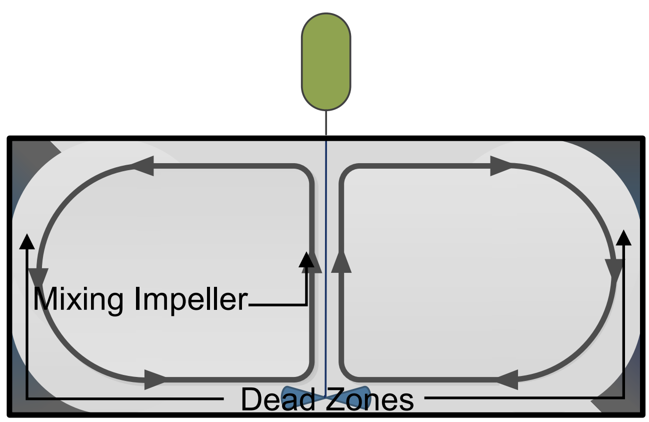



*Figure 1 – Mixing pattern in a typical cylindrical digester showing dead zones*

**2.0 SecondaryTreatment**

The QSD replaces the typical cylindrical sludge digester within the secondary stage of the treatment process *(see Figure 2)*. During the primary treatment stage, undissolved

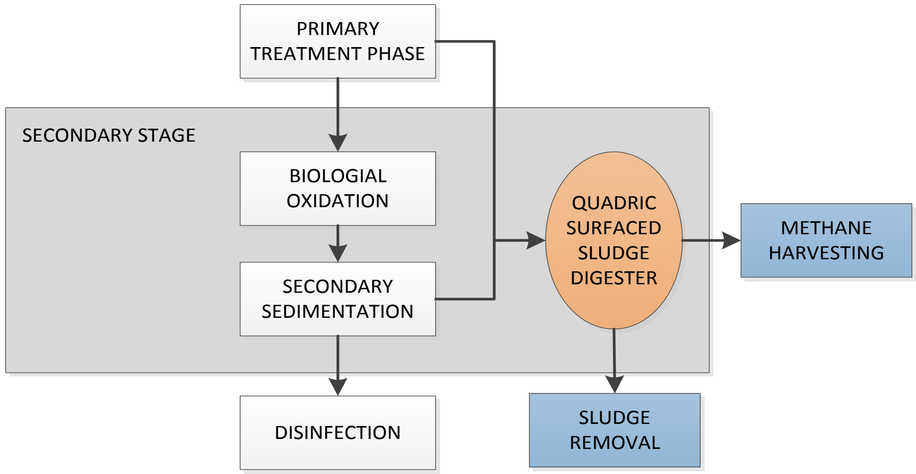



*Figure 2 – Schematic of secondary treatment process.*

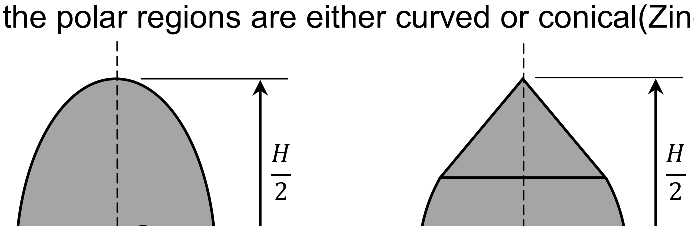
solids removal which are settled in primary sedimentation tanks. These are removed and sent for treatment in the secondary stage. Similarly, the undissolved coagulated solids that settle during the secondary sedimentation, in the secondary treatment stage, is also removed and sent for further treatment. Both are placed in a sludge digester where anaerobic digestion stabilizes the sludge. This digestion process utilises various anaerobic bacteria that produces biogas (Priadi, Wulandari, Rahmatika, & Moersidik, 2013) including methane which can be harvested and used as an alternative source of energy for various plant activities thus reducing the power consumption. The digestion process also degrades harmful bacteria by depriving them of oxygen since the most present gas is methane. Hence the methane sterilizes the digested sludge which makes it safe for use as fertilizers post treatment.

### 3.0 The Quadric Shaped Sludge Digester

### 3.1 Form

The quadric surfaced digester's basic form can be described as a revolution of a parabola where the polar regions are either curved or conical(Zingoni, Parametric stress





distribution in shell-of-revolution sludge digesters of parabolic ogival form, 2002) *(see figure 3).*

*Figure 3 – (a) Spherical ogival shell with spherical closures, (b) Parabolic ogival shell*

In particular this research focuses on the parabolic-ogival (PO)form because of is low discontinuity effects of meridional membrane stresses. The PO shell is formed by a revolution of a parabola along the y-axis. This hemisphere is this mirrored along the x x-z plane. ξis a dimensionless parameter that denotes the ratio of height to diameter for the digester. Figure 3 shows a quarter profile of the PO QSD for various values of ξ. The coordinates for each trace on the chart were computed using:

$$x = \left(\frac{D}{2}\right) - \left[\frac{(2\times D)}{H^3}\right] y^2 \qquad \text{(eqn 1)}$$

*where: D = the diameter of the tank*

*H = the height of the tank*

*x = the x-coordinate of the profile*

*y = the y-coordinate of theprofile*

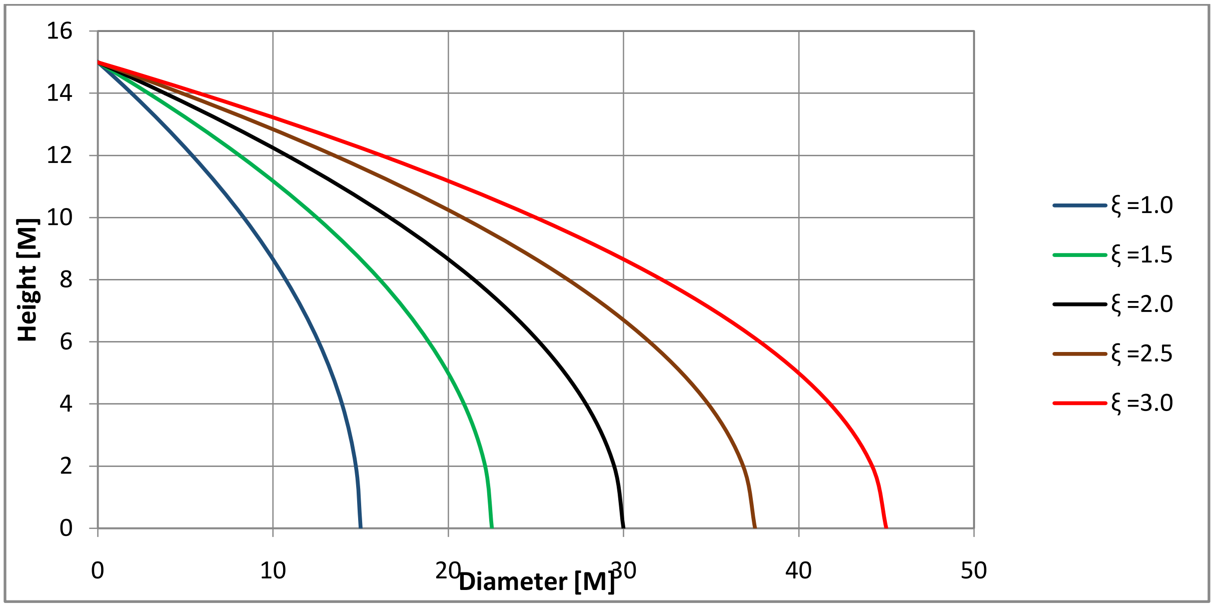



*Figure 4 – Parabolic ogival shell quarter profiles with varying values of ξ.*

### 3.2 Structural Efficiency

As outlined earlier, the operational cost benefits outweigh that of traditional cylindrical digesters. However, for the QSD to be compatible with conditions in the Caribbean, a look at the structural efficiency need to be considered. Zingoni (2001) examined the internal stresses of the shell. Different values of ξ were compared in a parametric study and the meridional stresses were computed using:

$$\frac{N_\phi}{\gamma H^2} = \frac{\xi}{16}\left(\frac{\sin\phi}{4\sin^2\phi - \xi^2\cos^2\phi}\right)\Bigg[-\left(\frac{4+\xi^2}{\sin^2\phi}\right) + \left(\frac{\xi^2}{2\sin^4\phi}\right) - \xi(4 + \xi^2)\left(\frac{\cos\phi}{\sin\phi}\right) + \frac{\xi}{3}(4+2\xi^2)\left(\frac{\cos\phi}{\sin^3\phi}\right)(1+2\sin^2\phi) - \frac{\xi^3}{15}\left(\frac{\cos\phi}{\sin^5\phi}\right)(3 + 4\sin^2\phi + 8\sin^4\phi) + \frac{1}{30\xi^2}(112 + 120\xi^2 + 15\xi^4)\Bigg] \quad \text{(eqn 2)}$$

and,

$$\frac{N_\theta}{\gamma H^2} = \frac{1}{32\xi^2}(4\sin^2\phi - \xi^2\cos^2\phi)\left[\left(\frac{2\xi\sin\phi - \xi^2\cos\phi}{\sin^4\phi}\right)\right.$$
$$-\left(\frac{\xi\sin\phi}{4\sin^2\phi - \xi^2\cos^2\phi}\right)\times\left[-\left(\frac{4+\xi^2}{\sin^2\phi}\right)+\left(\frac{\xi^2}{2\sin^4\phi}\right)-\xi(4+\xi^2)\left(\frac{\cos\phi}{\sin\phi}\right)\right.$$
$$+\frac{\xi}{3}(4+2\xi^2)\left(\frac{\cos\phi}{\sin^3\phi}\right)(1+2\sin^2\phi)-\frac{\xi^3}{15}\left(\frac{\cos\phi}{\sin^5\phi}\right)(3+4\sin^2\phi+8\sin^4\phi)$$
$$\left.\left.+\frac{1}{30\xi^2}(112+120\xi^2+15\xi^4)\right]\right] \qquad \text{(eqn 3)}$$

*where $N_\varphi$ = the meridional stress within the shell*
*$N_\Theta$ = the hoop stress within the shell*
*$\xi$ = H/D (height to diameter ratio)*
*$\gamma$ = density of the shell*

The results showed that stress resultants in the shell are directly proportional to $H^2$ for tanks of the same shape. It was found that for values of $1.5 \leq \xi \leq 2.0$ *(see figure 5)*, the stresses were in an optimum range and a recommendation was made that these proportions fall in the practical range for QSDs.

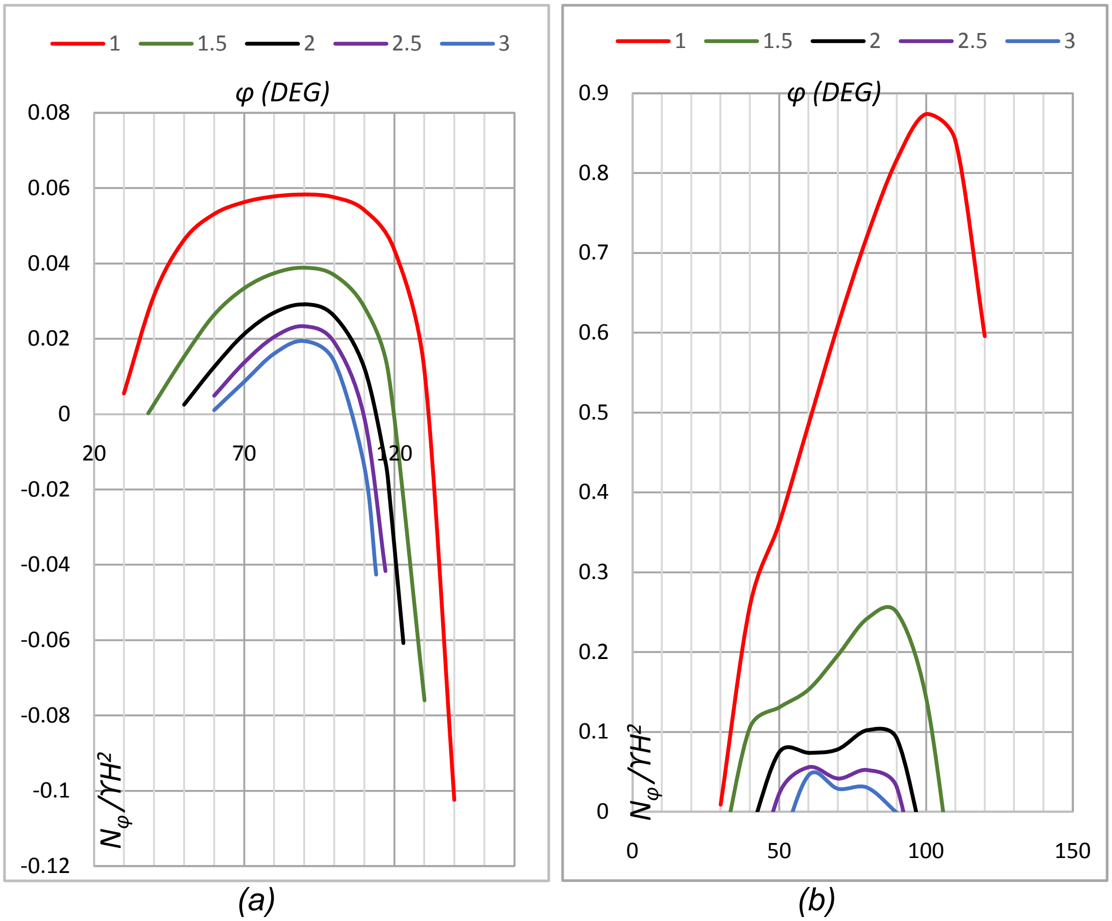



*Figure 5 – Non-dimensional stress variations- (a )Meridional (b)Hoop*

### 3.3 CaribbeanSeismic Applicability

Acceptable criteria for using the QSD in the Caribbean would be a cost efficient seismic design. The digester should be able to withstand seismic activity that would include both lateral and vertical ground motions which are noted typical responses for Caribbean tectonics. Shell structures usually are excellent at resisting lateral forces, however in the case of the QSD, an additional component, the filled liquid, intensifies the complexity of the behaviour under earthquake forces. Li et al. conducted seismic analyses, both finite element and seismic simulation labortory tests to determine the applicability of the structure for use in seismic zones. A scaled model *(see figure 6)* was build and tested using time-history data of the Guangzhou, China Earthquake*(see figure 7).*

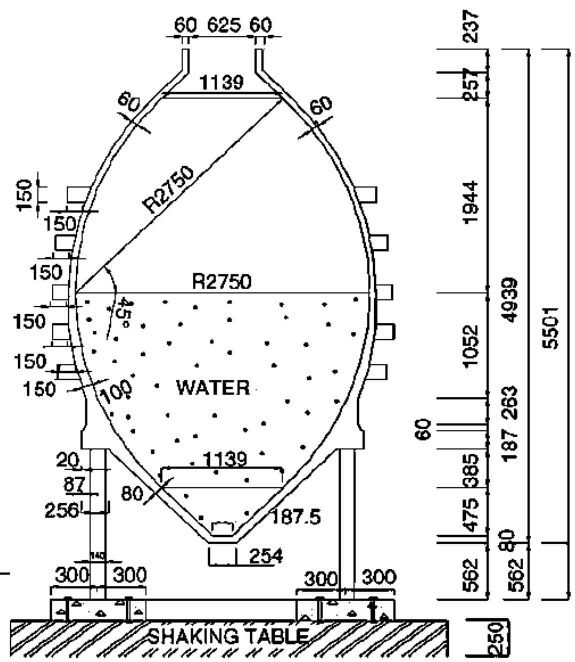



*Figure 6 –* … *ESD model under*

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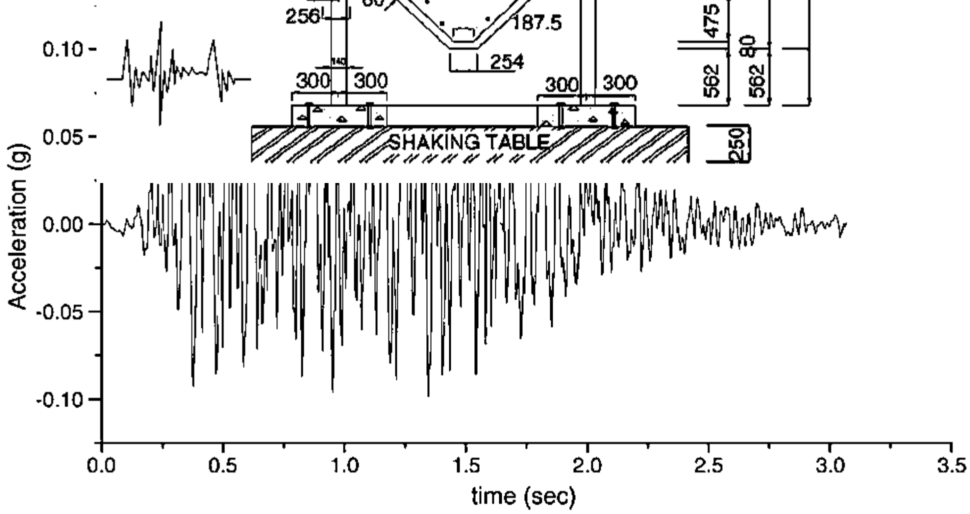


*Figure 7 – Time history data of acceleration in Guangzhou* (Li, Chen, & Chen, 2007)

This test is applicable to the Caribbean region since both tectonic fault lines are subductive in nature hence producing similar horizontal and vertical accelerative effects. The analyses concluded that non-linear effects were amplified in localized regions along the shell. Even though this is expected, the design engineer should take note to include this non-linearity in the structural design. It was also found that the sloshing within the QSD increased the dynamic responses below the midriff and alternately reduced the responses above the midriff. The circulation of the liquid that causes this particular response is given due to the shape of the digester. This can be beneficial since flexure and the associated bending stress is reduced towards the top of the structure thus allowing the shell cross-section to taper upwards.

## 4.0 Conclusionand Outlook

The quadric surfaced sludge digester has been used satisfactorily in the secondary treatment of wastewater sludge.  Despite having higher construction costs, the benefits due to its shape translates to an overall cost reduction during operation and maintenance. Further research is currently being conducted in developing the structural form such that the initial construction cost can be further reduced, hence making the QSD readily available and practical for small island developing states (SIDS) across the Caribbean region.

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