THE HYBRID TOILET SYSTEM: GENERAL PRINCIPLES AND SYSTEM DESIGN DRIVERS

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Abstract

In October 1996, James Cook University, Townsville City Council, Port Moresby City Council, Sustainable Wastewater Technologies and Gough Plastics set out to produce a toilet system ideally suited to the environment of the Asia Pacific Region.

The toilet systems that were evaluated were those in use in many countries. The most common system found was variations of the septic tank system. The authors discussed at length the advantages and disadvantages of composting systems. The conclusion was there was currently no composting system available that was a viable long term alternative. The team then set about utilising the best of all the waste treatment technologies available, in both large and small scale capacities.

In simplistic terms, the Hybrid Toilet System (HTS) consists of a non-flushing drop toilet feeding directly into a septic tank filled with water, which then delivers, via displacement, clarified effluent to the secondary treatment unit. On completion of treatment the effluent is then dispersed to ground via a gravel bed. This paper outlines the processes and construction of the HTS.

1 Introduction

Through his work in Papua New Guinea and remote aboriginal communities in Australia, Dr Paul Turner of James Cook University came into contact with a very poor standard of sanitation. A great need for an appropriate treatment system was identified. Over a four-year period working with Mr Mark Langford of the Townsville City Council and Mr Andrew Gough of Gough Plastics, a process was developed to attack the problem of sanitation. The National Capital District Commission of Papua New Guinea financed prototype testing of the system for application in and around Port Moresby and so the Hybrid Toilet system came into being.

During the initial design concept stages we evaluated as many of the current systems as possible, looking at, not only Australian customs and habits, but also many other countries around the globe. The most common system of waste disposal we looked at was the septic tank system. While not ideal and not very successful in most cases, extremely resource wasteful and a high pollution generator it is the system most countries of the world are familiar with. Normally, there is to some extent some form of septic tank management infrastructure.

The team looked long and hard at composting type systems and went part way to designing a new compost system. They found, during their research that, when they looked at the ongoing personal involvement required by the user of the compost toilet, and giving consideration to the cultural taboo's surrounding waste contact in other countries as well as Australia, the conclusion reached was that they could not see them being a long term viable alternative. Similar to the standard septic tank, the composting systems studied were unable to accept any large amount of shock loading without severe overload occurring.

This paper outlines how the system work, which in simplistic terms, consists of a non-flushing drop toilet feeding directly into a septic tank filled with water, which then delivers, via displacement, clarified effluent to the secondary treatment unit. On completion of treatment the effluent is then dispersed to ground via a gravel bed.

2 Early Development of the Hybrid Toilet System In Australia

2.1 Methodology

Subsurface flow gravel bed systems are widely used in Europe and the United States of America (USA); these systems do suffer problems but represent the most cost efficient treatment of partly treated effluents. The goal of this project was to develop a system that required no mains power, and delivered high quality effluent with low *E.coli* levels. Plastic tanks were used to protect ground water.

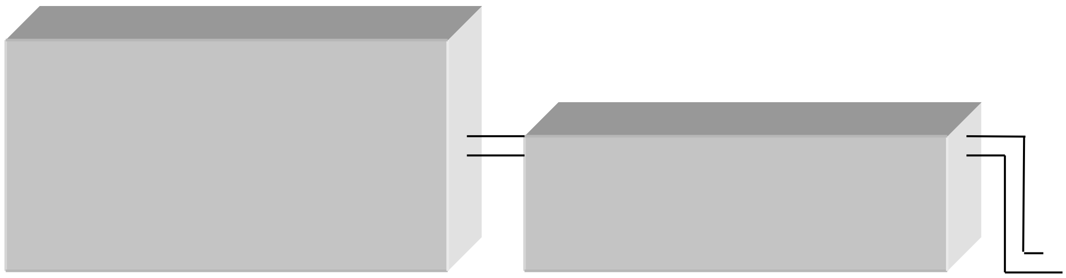
2.2 Research and Design

Working with the Department of Primary Industries (DPI), as one of the pilot studies for the development of wetland guidelines for Queensland, one of the authors, Mark Langford, was able to use the four-year studies research and literature as a basis for the secondary treatment unit design. Having constructed and managed the development of SF and SwF systems in the Townsville City Council pilot, this greatly assisted in the adaptation of the systems into the project.

A particular trial "Sewage treatment using Aquatic Plants and Artificial Wetlands" (Roser & Associates 1987) showed that a gravel bed control performed well with no plants present. This system showed the greatest potential for development. Faecal coliform removal was one of the main concerns in dealing with remote communities that use ground water as drinking water. This system looked promising in this regard.

The design of the prototype consisted of a primary tank volume of 770 L and a secondary tank volume of 670 L, filled with gravel, with an operating volume of 260 L. Gravel used was 10-15mm diameter, flow length was 3.5 m, and depth was 400 mm. The tanks were off-the-shelf polyethylene tanks provided by Gough Plastics as illustrated in Fig.1.

Figure 1 The Hybrid Toilet System Prototype



Primary Tank = 770 L Secondary Tank = 670 L

2.3 E.P Loading and Testing of Prototype

The system was designed for 10 person [adult] loading, each depositing 200 g of faecal waste and 1 litre of urine per day. This waste consisted of 2 kg of raw primary sludge and not 10 L but 20 L of effluent to mimic a high sludge level in the primary tank at full load. Effluent dosed was of a quality of 30 biological oxygen demand (BOD_5), 30 total suspended solids (TSS) and *E.coli* of 400,000 colonies/per 100 mL representing a higher loading than urine would represent.

Each day 2 kg of sludge and 20 L of effluent was dosed at one time, on the weekends the unit would be dosed with a pump and timer system, pumping raw sewerage to the unit with a loading of 300 mg/L BOD_5 and 250mg/L TSS shock loading the unit. Effluent detention in the primary tank was 35 days, before flowing to the secondary tank, for a further 11.8 days of treatment The gravel bed design was a conventional one, two baffles were used to cut down on short circuiting and a small solar powered fan assisted air flow across the gravel bed.

3 Test Results after Three Month Trial

The primary tank was seeded with 40 L of digester sludge on 31st January 1997 when dosing started; the system was left to dispel plant effluent from the secondary tank before testing was commenced. It can be seen that there was a slow decrease in quality over time, testing on the 26th March 1997 was ten days after a malfunction of a timer controlling a dosing pump. Instead of 20 L of raw sewage being dosed per day, approx. 60-80 L was dosed per day for three days. This represented three times the volume. The effluent results were still good, but there was a ten fold increase in *E.coli* levels due to hydraulic overload [80 L = 80 person use].

Raw sewage was used as a loading factor as it represented a highly soluble waste that would travel faster through the system and impact on the effluent quality. Using primary sludge in this situation it would settle quickly and lack the soluble waste required to shock the treatment system. Pit toilets and flushing septic systems have effluent levels of as high as 300 mg/L BOD and *E.coli* of 600,000 – 800,000 colonies/100mL. As seen in Table 2, the prototype effluent is of better quality and has less impact on ground water than a standard septic system.

The effluent from the unit was observed to have a bio-film carry-over that may represent the BOD loading. On further investigation, a pond area just inside the secondary tank outlet was found which grew a scum that discharged as effluent passed through it. It was agreed to install a small pea gravel bed of 4 to 5 mm dia. at the outlet. This modification proved successful and was included in the final system.

The results gave an indication that the system had good potential and was worth redesigning. The points to be improved are listed below.

PRIMARY TANK

1. Extend sludge and effluent detention
2. Redesign tank outlet pipe to minimise carry over [solids]
3. Design nestable tank for transport [Gough Plastics]

SECONDARY TANK

1. Improve flow system to completely stop any short-circuiting
2. Effluent to flow though aerobic and anaerobic zones
3. Vertical, horizontal and rotational flow design
4. Nitrification and denitrification and maybe P removal
5. Detention time increase to reduce *E.coli* levels
6. Increase evaporation out of the unit
7. Design nestable tank for transport [Gough Plastics]

As a result of the trials the various changes were made to the system and its operation

4 Modifications to Original System

4.1 Primary Tank Design Changes

The primary tank volume was increased to 900 L, which gave an effluent detention of 45 to 75 days at full sludge level, 10 days longer than previous trial. This extended volume gave approximately a three to five-year period before a sludge pump out is required. A sludge gauge, as shown in Fig. 2 was designed to accurately show the level of sludge in the primary tank.

The outlet dropper in the primary tank, shown in Fig. 3, is designed with a vertical face intake bend. Solids can rise and fall without entering the outlet, so stopping solids carry-over and reducing loading on the secondary system.

Figure 2 "Sludge Gauge"

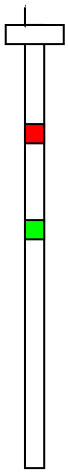
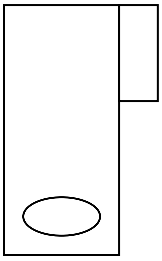


Figure 3 "The outlet dropper"



Side view

Plan view

4.2 Secondary Tank System

The flow path was dramatically redesigned to combat short-circuiting and to control effluent entering and leaving treatment zones. This was seen as a major break through in the system. The effluent flows down a 100 mm pipe to the bottom of the first gravel column 380 mm in dia. and 950 mm in depth. Effluent then flows upward through the column to the top and crosses into second 500 mm dia. column of gravel. Effluent then travels down to the bottom into the final gravel column on the opposite side of the outlet, then travels 950 mm upwards and around to the outlet. The path of the effluent is shown in Fig. 4. From this flow path, the effluent is subjected to anaerobic and aerobic treatment zones creating nitrification and some denitrification. Oxygen is supplied to the gravel surface by natural and assisted ventilation by means of a solar powered fan. This air movement also increases the evaporation rates from the system by up to 50% and greater depending on climate. The pipework layout also vents odours from the drop toilet. Detention times were increased to 25 days with a standard loading of 12 L per day and greater dependent on evaporation. The tank volume is 600 L, which when filled with gravel has a volume of 300 L.

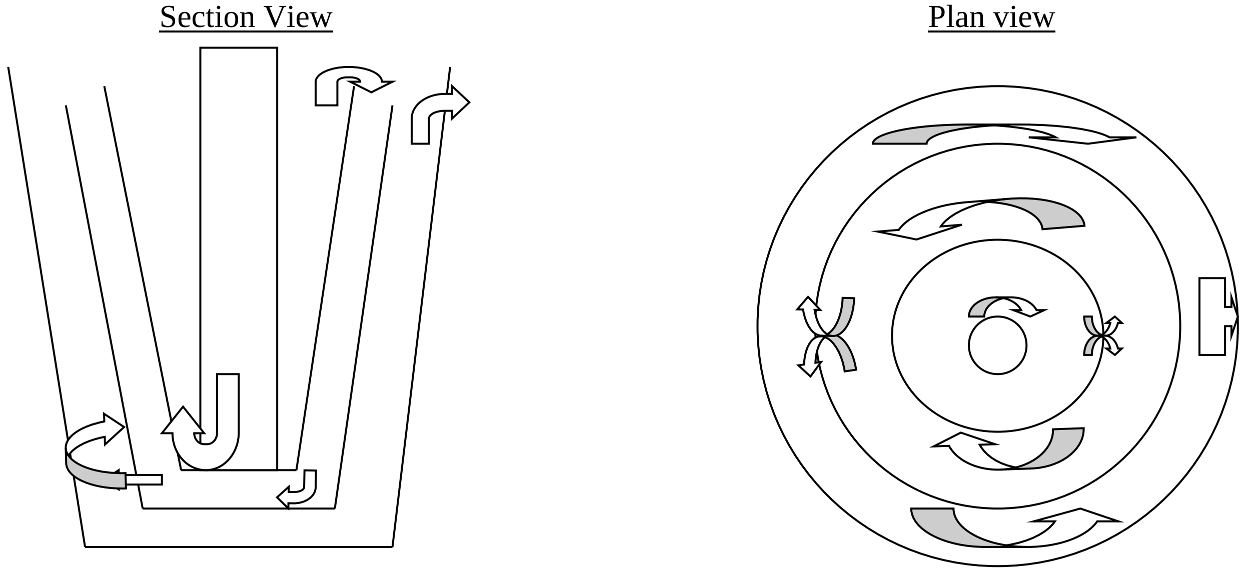
4.3 Pathogens

The holding time in the system was increased to encompass the life period of most pathogens, and decrease water born disease by using the Hybrid as a sanitation barrier in remote communities.

4.4 Hybrid Gravel Bed Loading

As the gravel bed system is unique in its design, only standard subsurface flow wetland guidelines and loadings can be applied to this system in regards to clogging as by Crites, Nolte & Associates 1992. The gravel bed has a surface area of 0.6 m^2 and a depth of 950 mm. Normally SF wetlands are around 500 mm in depth and are plug flow systems.

Figure 4 Secondary treatment zone flowpath



5 The Results

5.1 Primary Tank Effluent

Using the results obtained from the prototype above, loading rates can be applied to the hybrid gravel bed. The aim was to investigate any short-term risk of clogging in the gravel bed. The recommendations to prevent clogging require a maximum of 200 g m^{-2} BOD_5 and 80 g m^{-2} TSS.

Table 1. Hybrid Loading Rates

Volume	12 L			
BOD_5	216 mg L^{-1}			
SS	186 mg L^{-1}			
			Anti-clogging maximums	
BOD_5 Loading	4.32 g m^{-2}		BOD5 Loading	200 g m^{-2}
TSS Loading	3.72 g m^{-2}		TSS Loading	80 g m^{-2}

As seen above, the BOD loading is well under anti-clogging levels. There appears no risk of clogging and an extended life is expected with such low loadings on the system. Algae and root clogging have no influence, as the gravel bed is totally enclosed in a tank.

Table 2 Hybrid Effluent Results {Rock & Gravel test unit}

Date	BOD5	NFR	E.coli/100 ml
18.06.97	1	15	2
1.07.97	22	17	120
16.07.97	24	5	55

Dosing started 12th May 1997, and to ensure treated effluent used to fill the secondary unit was dispelled, a period of 36 days elapsed. The first test results on the 18th June 1997 indicate the last of the effluent used to fill the unit. After this point true effluent results can be seen in Table 2. The Hybrid unit was fully loaded at 10 EP through out the testing. The Prototype was shock loaded with a lower effluent detention period and a conventional gravel bed. As the Hybrid unit has a greater effluent detention period with a totally redesigned gravel bed system, it was able to take overload periods and buffer the load through its extended treatment process of 75 to 100 days of effluent contact in the unit.

The Townsville City Council, James Cook University, National Capital District Commission of Port Moresby, Mark Langford and Gough Plastics class the Hybrid unit as an ongoing project. The process has been patented with respect to its application in the water and wastewater industry here in Australia and overseas.

5.2 Final Results

The end result of our research was a waste treatment system with the following design requirements:

1. The method of waste removal had to be able to be easily performed without personal contact by either the waste removal contractors, where available, or by the user, in remote areas.
2. The frequency of waste removal had to be measured in years, approx 5 - 7.
2. There had to be a simple reliable method of measuring the sludge volume in the unit, which would indicate both the volume required for removal and the date of removal.
4. The unit would require no flushing water.
5. The systems has to be loosely based around the known technology of the septic tank and the potential existing infrastructure
6. The inherent ability to accept infrequent but potentially severe overload situations.
7. The ability to fit into a structured data based controlled waste removal control program, which could be overseen by the relevant local authorities and or operated by the authority.
8. Design a system that was as low profile as possible.
9. The entire treatment process had to be completed within the system and be totally isolated from high water tables and high rainfall and on discharge, have the absolute minimum impact on the surrounding environment.
10. The system had to be cost effective, be easily transported, assembled, and have an exceptionally long product life.

From the results, the authors believe they have managed to achieve all of the above and far more.

6 Monitoring

As part of the package that is offered with this system, a monitoring program is also available. Monitoring includes the installation of counters on the doors, and monitoring the level of sludge build-up in the primary tank using a sludge gauge. These data are recorded on a spreadsheet every month and a pump-out time can be predicted in advance, and this also highlights any necessity to install additional units.

7 Size and Costs

The technology has now been utilised into a number of different sized systems. Currently they are 6, 10, 25, 50, 100 & 150 EP units. The authors have always considered the HTS suitable for large scale application and the following table outlines the relevant costs.

<u>Price Per Person Per Day (over 5 years) for 10,000 people.</u>

A Population of 10,000 people would require 66 x 150 EP HTS
This cost would be $1.2 million total
To achieve a Per person per day, you divide $1.2m by 10 000 people
= $ 129.27 divide this by {(365 days x 5 years) = 1,825 days}
= $0.070 per person per day over 5 yrs

8 Conclusion

For many years people have searched for a solution to fill the void between sewage treatment plants and pit toilets. The authors believe the Hybrid Toilet system offers this on-site solution. The HTS can be left unattended for extended periods of time, cope with greater than 100% overloads, handle floodwater intrusion, effectively captures parasites forming a faecal-oral disease barrier, and requires minimal maintenance.

As a testimony to the design outcomes of the unit, Hybrid Toilet Systems are now installed and operating in two of the worlds finest National Park Islands; Hinchinbrook and Fraser.

Continued research and development is currently working on greywater treatment, an on-site wastewater stream not processed by the HTS. Together with plans for the world's first Rotationally moulded mains pressure Solar Water Heater, it is hoped that by combining these three products together, the results will deliver extremely good effluent quality from a single unit that treats both blackwater and greywater.

From this research and development, today's HTS evolved. The company that owns the worldwide patent rights is called Pacific Waste Technologies, made up of Gough Plastics, James Cook University, Sustainable Wastewater Technologies, Townsville City Council and the National Capital District Commission of Port Moresby.

9 References

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