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MAXIMIZING THE BENEFITS FROM WATER AND ENVIRONMENTAL SANITATION

Proposals for a rapidly deployable emergency sanitation treatment system

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This paper discusses a novel concept design for a sanitation treatment system, based on membrane bioreactor (MBR) technology, to be used as a rapidly deployable unit in emergency situations such as a refugee camp. This study carried out on behalf of Oxfam GB, firstly, took a look at the types of emergency scenarios a MBR system may become applicable for such as site situations that preclude the use of traditional sanitary solutions like pit latrines. Secondly the study then assessed the feasibility of using a MBR to treat the wastewater generated from such a refugee camp environment. Three different concept designs were successfully developed to meet the sanitary needs of the emergency situation and some recommendations were made for testing these designs in the field. This study concluded that the use of a MBR in these difficult circumstances could prove appropriate on technical and operational grounds if not purely financial ones.

Introduction

The purpose of this study is to confirm the feasibility, both technically and financially, of using a MBR to treat the wastewater generated from a refugee camp environment. In particular for situations and site conditions that highlight inherent technical constraints of the more traditional sanitary solutions such as pit latrines (Paul 2003). The writer feels that in the majority of situations on-site sanitation would be the obvious and most appropriate method of excreta disposal, whether by using pit latrines, septic tanks, defecation fields, etc (Davis & Lambert 1995). In terms of off-site systems, then depending on land availability and soil conditions, a low maintenance waste stabilisation pond system may prove appropriate for most other instances. However, in certain extreme limiting situations a portable off-site system may be applicable. Such situations include:

1. Rapid, complex (and urbanised) emergency situations causing a large build up of refugee numbers where a pit latrine construction programme will take too long to implement and defecation ditches are not practicable due to severe land limitations or underlying-soil/groundwater conditions (or the possible long-term environmental pollution affects associated with these solutions).
2. In emergency situations where scarce water resources mean expensive water trucking/bowsering is required, and hence greywater recycling would prove advantageous.
3. For military expeditionary forces to use in their camps in order to reduce environmental pollution of surrounding areas and the reliance on existing, usually inadequate, treatment facilities.

At first glance it may appear an odd suggestion in using an energy-intensive packaged, portable sewage treatment works in a refugee camp context or similar setting to treat wastewater, where the camp itself is meant to be a transitory set up for a period of anything from 3 months to 2 years or more and where financing for such a system is limited. More especially the suggestion would seem even more unreasonable if it was advocated that a membrane bioreactor (MBR) system be the main form of wastewater treatment, which so far have been only used in heavily industrialized countries for treating of strong industrial wastewaters or for meeting stringent discharge standards for sensitive waters receiving treated municipal effluent.

The main reason prohibiting the use of an off-site sanitation system such as a packaged plant in a refugee context would be cited as the extremely high initial capital costs and the daily operation and maintenance costs including availability and cost of highly trained technical personnel. In contrast most traditional on-site systems such as pit latrines have very low capital costs and zero electro-mechanical energy requirements when compared to most other types of off-site treatment and/or storage systems.

Oxfam criteria for a rapidly deployable portable wastewater treatment system

Oxfam GB has specified the following criteria for a rapidly deployable system that will meet their needs out in the field (Walton-Knight 2002):

1. Ideally it should be pre-packaged into a kit form that can be rapidly and easily assembled on site, and should be capable of handling excreta produced by a camp population of 5,000.
2. Assembly should be possible by untrained personnel under Oxfam technical supervision.
3. It should meet Oxfam's volume, height and weight re-

strictions of being able to be transported on a 6 m length 4 tonne flat bed truck.

4. The capital and operating costs of the system should meet Oxfam's criteria of US$25,000 overall and US$5,000 per month respectively, i.e. US$5-00 and US$1-00 per head of camp population respectively.

The writer has added the following additional criteria to make a more comprehensive and flexible design (Paul 2003):

5. The design should be simple (i.e. a single flow train with no recirculation), easy to operate by unskilled (but trained) labour, robust with little chance of breakdown, reliable in effluent quality produced, and very quick to start up.
6. The system should be capable of producing effluent of sufficient quality so that greywater recycling is possible to alleviate possible camp water shortages.
7. The sewerage delivery system (if used) and the communal toilet trays/pans with toilet float system should also come as a matching quick assembly kit.
8. To increase flexibility on very flat or congested sites where a sewer system is impractical, then a matching latrine vault and vacuum truck/cart system should also be offered.

Site conditions and land considerations – why is a system of this type required?

The principle areas in which pit latrines can prove ineffective are as follows (Cairncross & Feachem 1983):

- *Rocky ground* - Latrine construction in solid rock areas can become both difficult and expensive since large mechanical diggers and/or jackhammers are needed.
- *Sand* - Building latrine pits in loose, sandy, unconsolidated soils can be hazardous as they are prone to collapse. The lining must also control the seepage rate of faecal liquors into surrounding soil that has a very high porosity and permeability.
- *High water table* - Digging pits in high water table areas is difficult as they will soon fill with water and are prone to collapse in the wet season.
- *Water contamination* - Surface and ground water sources can become polluted by nearby latrines leaking effluent.
- *Land constriction and congested camps* - Often refugee camps are constructed around an existing permanent settlement so that the refugees can understandably access nearby services and facilities. This usually means that the land area is already congested in these usually illegal squatter camps with more refugees arriving daily. Consequently existing communal latrines can begin to fill up at a much faster rate than safely designed for and this leads to an almost constant latrine construction programme in an already congested site.

Methodology

The design flow and load for the system are critical factors since they determine the size of the aeration basin and the number of membrane units required, both of which are important factors in determining the overall system's capital and operating costs. When sizing the treatment plant the loading rate of BOD (biochemical oxygen demand) produced per person per day is needed together with the amount of water put down the pit per person per day. The design engineer can design the facilities so that only urine, faeces and flush/cleansing water are put into the system thus reducing plant size by omitting other "unnecessary" and uncertain flows and loads from the system.

Accurate treatment plant sizing using a Monte Carlo simulation for a range of flow and load conditions

Since no data is available for a system of this type, a simple Monte Carlo procedure was developed to more accurately estimate the design volume of the aeration basin and the MBR membrane area required for a wide range of influent conditions. Under this procedure the flow and load parameters were not entered as single integer values but as a range of possible values (see Table 1). Thus the Monte Carlo simulation generated up to 10,000 randomly calculated volume and area values within the parameter ranges specified, and the 95th percentile optimal value for volume and area was determined as 88 m^3. This means that the designer can say with a strong degree of confidence that a standard Oxfam T95 tank of volume 95 m^3 should be able to cope as an aeration basin for a refugee population of 5,000 (see Fig. 1).

A universal discharge standard for effluent

As there is no existing universal sewage discharge standard for either normal or emergency situations, Walton-Knight (2002)

Table 1. MBR Design using 10,000 Monte Carlo Simulations for Various Parameter Ranges

Variable	Units	Range
Per Capita BOD per day	g BOD/p/d	3 - 9
Per Capita flow per day	l/p/d	5 - 15
Camp population	persons	2,500 - 7,500
Food / Microrganism ratio	1/d	0.05 - 0.10
Mixed liquor suspended solids ratio	mg/l	8,000 - 18,000
Membrane flux rate	$l/m^2/h$	15 - 30
Influent concentration from septic tank	mg BOD/l/d	600 - 600
Daily flow rate out of tank	m^3/d	12.5 - 112.5

carried out a comprehensive review of existing world-wide standards and produced the following universal one: absolute limits of 20 mg/l BOD, 40 mg/l TSS, 15mg/l ammoniacal-nitrogen and a maximum of 5,000 faecal coliforms per 100 ml. It is important to note that it costs 5 times more in energy usage terms to remove the last 20% of BOD then the first 80% (Horan 2003). So for a system of the type described here, a more realistic consent of 50 mg/l is advocated that would mean real cost savings in aeration tank volumes and even more significantly in aeration rates and thus the power rating of aeration equipment employed.

Design of the sewerage network/vault emptying system

Two types of delivery system can be employed to match up with the prefabricated toilet kits and the kit for the deployable MBR system:

- *A set of small bore* simplified sewer pipes with quick-fit joints for rapid assembly to be laid at very shallow falls requiring the minimum of excavation.
- *A desludging system* employing hand-pumps, vacuum trucks or vacuum carts to regularly desludge the holding vaults coming from the toilet blocks. The desludgers would empty their contents directly into the head of the treatment works (see Fig. 2).

Other design considerations

The inclusion of a septic tank at the head of the works means a 70% reduction in incoming BOD levels for design

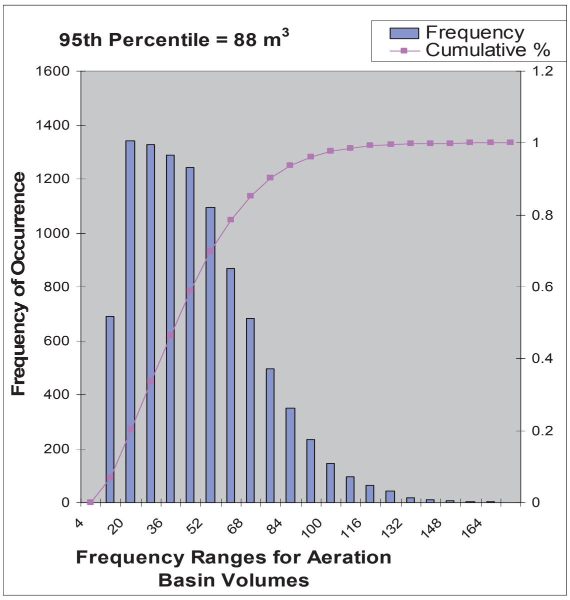

Figure 1. Outcome of 10,000 Monte Carlo simulations for a submerged MBR system connected to a septic tank

Source: Paul, 2003

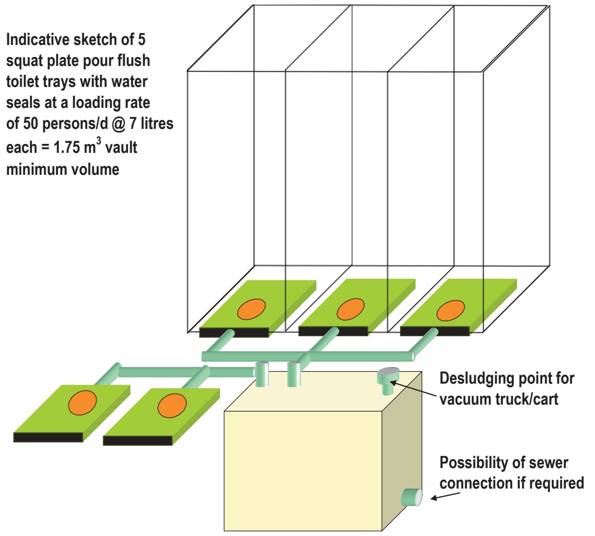

Figure 2. Proposed pre-fabricated toilet trays, vault and connector pipes

Source: Paul, 2003

temperatures above 25°C (Mara & Mills 1994). This means significant reductions in aeration rates and costs. With a six day retention time, it would also preclude the need for coarse screening and grit removal. The only pretreatment suggested after the septic tanks is by using 3mm disposable sack screens which affix to a nose box holder (IWEM 1992). Out of the various submerged membrane systems currently available (see Photo.1) it is recommended that the Kubota system is selected because it has the lowest energy requirements in terms of hydraulic pressure and simplest

Photograph 1. Typical submerged membrane module

and lightest cleaning regime (Churchouse 1997, Judd 2002). The overall hydraulic head requirements of the whole train should be no more than about 2 metres altogether, so in very flat areas this can be still supplied by raising up some of the tanks accordingly. The advantage of the Kubota system is that it is operated under gravity so no energy is required for pumping. The membrane modules themselves consist of either 100, 150 or 200 flat panel plate and frame membranes sandwiched together, and theoretically only require a 2 hour caustic chemical clean every 6 months.

Aeration system and other supporting mechanical equipment

The only energy requirement for this concept design is that of aeration. A slightly higher effluent quality requirements of 50mg/l will give a substantial reduction in the aeration rate needed and hence the energy cost in fuel usage terms. There are a multitude of aeration systems available on the market that would all need to be looked at closely to see which performed the best for this situation.

Recommendations

Three different concept designs were developed for Oxfam under this study to suit slightly different field conditions and population requirements (Paul 2003). Only Option C is described in further detail in this paper as it is thought to be the most flexible and economical solution. The idea behind Option C is the use of existing pre-packaged Oxfam water tank kit combined with an aerated lagoon design. A mechanical aerator located on a floating platform is used in the design to aerate the lagoon. The lagoon outfall discharges into the membrane module (see Fig. 3). This design can be used for very large camps with fluctuating populations and is flexible in that various lagoon sizes can be specified. Table 2 summarises the calculations carried out for this system with basic costs attached to give an indication of whether Oxfam's financial constraints for a system of this type can be met.

As noted this design should be used for very large populations located in an urbanised context and only uses a mini-aerated lagoon about the size of a swimming pool (see Box

Table 2. Summary of Entire Calculations for Design Option C that uses Aerated Lagoon as Aeration Basin

a) BOD Concentration Out & Area and Volume of Aerated Lagoon	
Soluble BOD_5 in effluent in mg/l = 24.24 Assume depth of lagoon, D = 3 m Then mid-depth area, A in m^2 is 66.67 And lagoon volume, V in m^3 = 200 ∴ choose 1 square lagoon 9m x 9m = 81 m^2	
b) Aerator Sizing	
Aeration Power, P in kW = 1.38 Power for complete mixing in kW, P_M = 1.00 ∴ choose 1 central 1.5 kW aerator for lagoon	
c) Total Capital Cost Calculation for System (includes equipment needed for 6 months operation) - 2003 values	
3 x T95 Oxfam Tanks (with full accessories) 1 x Butyl Rubber Liner (12m x 8m) 1 x Set of pipes, valves, etc 1 x 100 Panel Kubota Unit (in 4m^3 plastic tank) 1 x 1.5 kW Submersible Aerator 1 x 1-2.5 kW Diesel Genset 1 x Sack screen housing 10 x 50 packets of 3mm Sack Screens 1 x Spare parts, filters, etc for aerator and Genset 5% for contingencies	\$ 12,704 \$ 547 \$ 2,000 \$ 8,330 \$ 3,870 \$ 3,909 \$ 1,000 \$ 1,000 \$ 3,000 \$ 1,818
TOTAL Estimated Capital Cost in US dollars	\$38,177
d) Estimation of Monthly Fuel Usage Costs for the System - 2003 values	
Using the formula given in the US EPA's Wastewater Technology Fact Sheet for Aerated Partial Mix Lagoons Sept 2002, where electrical energy in kWhr/yr, $E = 6598(HP)^{1.026}$ where HP is the aerator horsepower, hp. To convert kW to hp, use 1 hp = 0.7457. Therefore aerator power in hp = 1.85 and Energy Usage in kWh/month = 1,100 Assuming continuous operation, and using a fuel usage rate of 0.3 litres/kWh taken from Davis & Lambert (1995), then for a 30 day operation: Amount of diesel fuel needed for a month = 330 Assuming a diesel cost per litre of US\$ 1.50 in-country , then month fuel bill in US\$ will be = 495	
Diesel Fuel Desludge costs Labour 5% for contingencies	\$495 \$1,000 \$1,000 \$125
TOTAL Estimated Operating Cost in US dollars	\$2,620

Box 1. Design Option C - Pre-fabricated Kit Version using Oxfam Storage Tanks & Aerated Lagoon

Advantages	*Disadvantages*
- Can deal with populations greater than 10,000 - Comes as kit so easily transported - For larger populations simply add more tanks in series & increase lagoon size - Only sac screening required - Simple aeration system to install & operate - Probably will meet Oxfam's capital cost requirements	- Mechanical aerator not efficient but cheap - Will need to desludge septic tank every 6 mths - Will need to double tank & lagoon lining as safeguard against puncture, & seepage - Will need to take rainwater in account when designing lagoon - Major excavation work needed for lagoon - Footprint much larger than other design options

1). The lagoon would be lined with butyl rubber to prevent groundwater seepage and hence will need substantial excavation works. However any excavated material can be re-laid and compacted to form the lagoon bund walls. This design is robust enough so there is no need to worry about the forces generated by the mechanical aerator. The lining also prevents bank erosion by any wave action induced. The lagoon can be shaped to reduce hydraulic short-circuiting, and is designed as an extended aeration, complete mix system. The lagoon would need only very occasional desludging.

Design of the greywater recycling system

Considerable water savings maybe made if expensive water bowsering operations are being used to provide the camp with sufficient daily potable water. Up to 95% recovery is common for a MBR system. It is advocated that greywater produced is first chlorinated using a simple chlorine doser and then stored, before being pumped to a high level mixing tank where it is premixed with fresh water to give a better nitrate and colour dilution since microfiltration is not good at removing these contaminates (see Fig. 4). Theoretically this greywater would be good enough to be utilised as a potable supply but whether it is ethical to do so is another issue as well as the attitude of the refugees themselves towards this. However this greywater can be used as a secondary water quality source designed for clothes washing, body bathing and flushing of pour flush latrines.

If activated sludge is not available in-country to seed the works then bioaugmentation can be used to allow a rapid build up in heterotrophic bacteria which digest the wastewater BOD organics. This commercially available seed material comes either as a liquid preparation or in solid pellet form so can be pre-stocked beforehand. The following further points have to be considered when deciding whether to install a system of this type: power supply requirements and reliability of supply, length of duration of the refugee camp, sludge handling and disposal methods, and the critical issue of maintenance of mechanical equipment, spare parts availability and standby capacity.

Flow train for Design Option C) - Pre-fabricated Kit Version using Oxfam Storage Tanks & Aerated Lagoon Design with Butyl Rubber Lining & Floating Mechanical Aerator

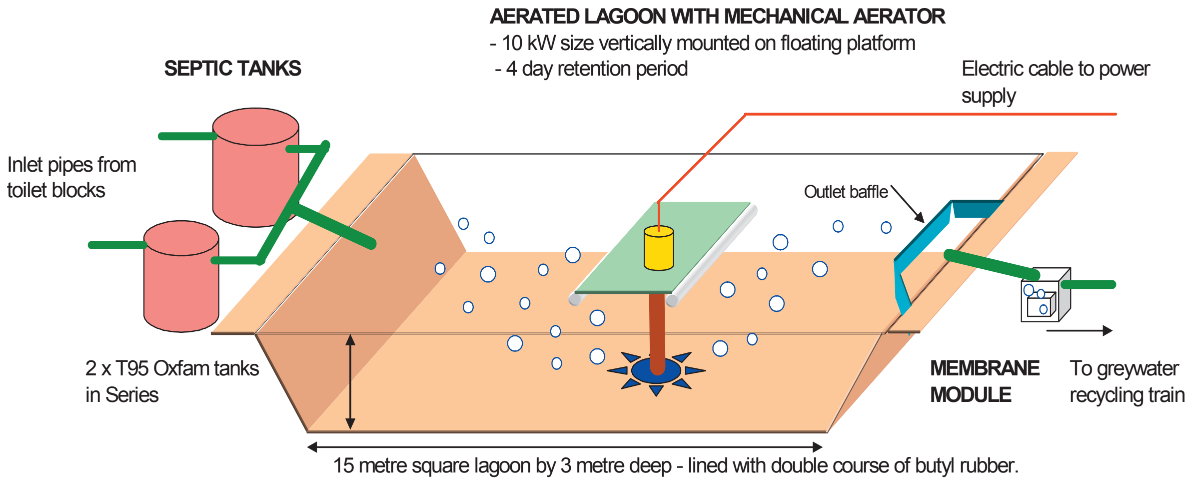

Figure 3. Recommended Oxfam rapidly deployable emergency sanitation design system

Source: Paul, 2003

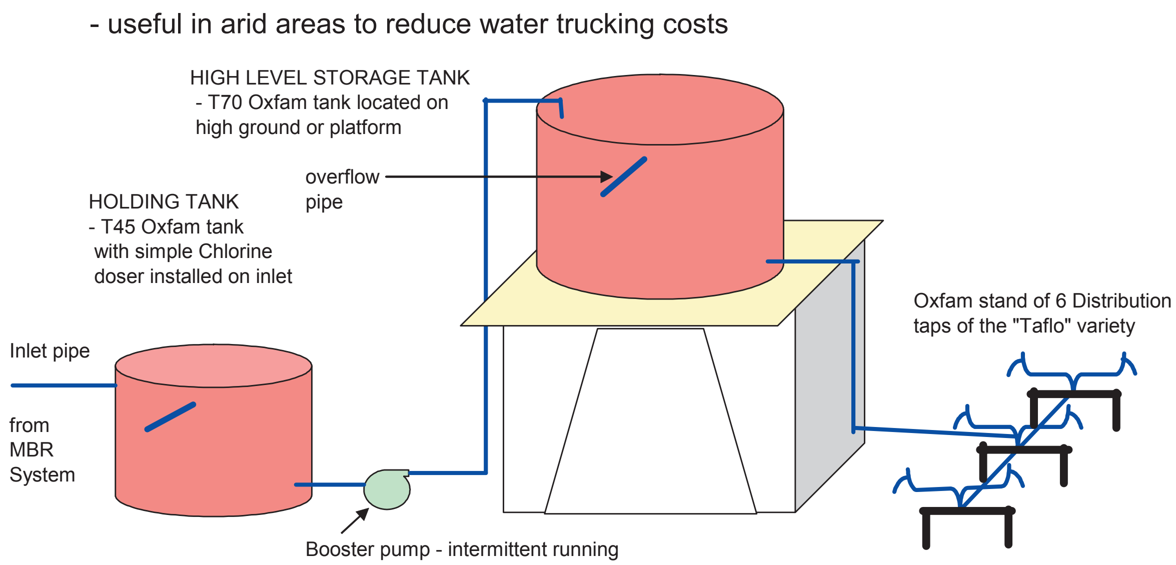

Figure 4. Proposed greywater recycling system

Source: Paul, 2003

The military camp situation

Where a system of this type is certainly cost effective is when used by a military expeditionary force. By contrast to the usual refugee camp scenario, a military camp normally has heavy moving equipment to allow easy plant installation, a readily available fuel supply, more money to run the system, and technical expertise on-hand to operate it. However, the influent characteristics could be far different in terms of BOD flow rates per Capita than for a refugee camp, and would be more comparable to that produced by a small package treatment works. Hence a military camp design would have to be altered accordingly.

Conclusions

In terms of selecting a rapidly installable system for an emergency context which can start producing good quality effluent straightaway; where speed of sanitary treatment is more essential and money is a lesser issue, then a septic tank system coupled to an MBR system via an aeration basin could be the only quick option capable of handling the type of population build-ups that occur in refugee camps, whilst still being relatively easy to maintain. Further compared to other aerobic treatment methods, since a submerged MBR effectively divorces the hydraulic retention time from the sludge age, then the process is extremely robust in process control terms. On the other hand conventional activated sludge processes (ASP) are much more easily upset with flow and load variations, and complicated further by recirculation flows. In comparison a submerged MBR is only a single, simple flow-train with the operator not having to worry so much about what's happening in the aeration basin so long as sufficient aeration is taking place.

In conclusion, the basic argument being presented here is that a rapid onset emergency situation developing into a possible catastrophe is unique and can break the normal rules applied to long-term sustainable development or any transitional phase of post reconstruction works, since the speed and rapidity of sanitation coverage is what is required, and sustainability is of lesser concern due to the temporary nature of the situation. However, as there have never been kit versions before that can be rapidly assembled, that are portable, and more importantly reusable at different sites, then careful testing in the field has to be conducted to verify this concept. It would initially involve pilot plant testing to measure flow and load data into the works. Several toilet block and sewer system designs, which connect into the plant, would also be simultaneously tested and investigated to obtain the optimal system configurations and operating ranges of this plant.

Hence it is anticipated that a system of this type will be used:

1) by agencies like Oxfam in a refugee camp setting, or by a military force in an expeditionary camp setting; and

2) that this design will give Oxfam a greater flexibility and responsiveness when it comes to meeting the sanitary needs of refugee camp communities in future complex emergency situations; and

3) it will also give the sanitary engineer a greater selection of sanitary options particularly when facing technically challenging topography and/or soil conditions.

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