Paper presented at ISES 2001 Solar World Congress “Bringing Solar Down to Earth”. Adelaide, Australia
25 to 30 November 2001; International Solar Energy Society.

Solar Evaporation of Liquid Effluent from Composting Toilets

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Abstract

This paper presents the results of a study aimed at (a) investigating factors influencing the performance of solar-enhanced evaporators for liquid effluent from composting toilets; and (b) designing and testing a compact, modular, cost-effective and efficient evaporator. Investigations in the laboratory indicated that the use of a wick system and the maximising of both air flow and heat uptake are factors that should be incorporated into a prototype evaporator design. The prototype evaporator has been designed and built and is being used in a series of comparative trials against a simple flat tray with a transparent, ventilated lid (similar to solar-enhanced evaporators now in use). The prototype is achieving almost three times the evaporation rate of the control. The goal, which seems realistic based on laboratory and preliminary comparative trials, is to develop a unit with one quarter to one tenth the base area of existing evaporators, yet achieving similar evaporation rates, with similar maintenance requirements and installed costs also similar to existing systems. Such units would be visually less intrusive, easier to install and provide greater flexibility in siting.

1. INTRODUCTION

This paper introduces an on-going research project into evaporation of liquid effluent from composting toilets operating at remote locations in cool temperate climates. Composting toilets, sometimes referred to as dry or waterless toilets, have proved a popular and effective means of dealing with human waste in remote locations or areas without reliable water supply (for example, see Earthwise Publications 2001; Todd 2001). In warm, dry climates there is little, if any, liquid effluent from these toilets. However, in cool temperate climates where there is less evaporation from the compost pile and lower temperatures mean slower compost rates, liquid effluent can create a serious health risk. Managers of natural areas would like a toilet system that contributes no liquid effluent at all, and only requires occasional removal of solid compost.

The aim of this research program is to develop an evaporator suited to composting toilets that:

- is more efficient than designs now used in Tasmania (the goal is to achieve ten times more evaporation per unit base area, although this might be somewhat optimistic);
- is modular so that it can be added to if effluent discharge increases;
- is small and portable for ease of installation (or removal);
- is reliable, requiring little maintenance; and
- has a comparable or lower capital and installation cost to existing systems used in Tasmania.

Throughout the paper, reference is made to remote toilet systems in Tasmania, Australia. Tasmania has large areas of wilderness that provide many popular walking routes involving overnight stays (see DPIWE 2001). The popular central plateau area (elevation around 800m) is cool-temperate with average minimum temperatures ranging from about 6°C in summer to 0°C in winter and considerably colder at higher elevations.

Composting toilets offer a practical alternative to septic tanks and pit toilets for on-site treatment of human wastes. They are the preferred toilet system in many natural areas with medium to high numbers of tourist or recreational visitors where centralised sewage connection is not viable. However, highly polluted liquid effluent from composting toilets has the potential to contaminate both surface and groundwater and alter the ecology of natural areas. Being a dry toilet system, the liquid effluent has a relatively low volume, of the order of zero to a few litres per day. This lends itself to disposal by solar-enhanced evaporation. The advantages of disposal in an evaporator, rather than an adsorption trench, are that there will be zero emission onto land or into waterways, there is minimal site disturbance, and the system is independent of soil types and topography. These are important benefits in sensitive, low nutrient ecosystems.

Toilets and evaporators in natural areas must not create unnecessary visual intrusion. The systems must be self-contained and require minimal maintenance, especially for more remote locations. The toilet and evaporator must be sized for the local climate and number of visitors. Tasmania’s cool temperate climate, and the fact that many toilets are located at higher altitudes, presents a special challenge in dealing with liquid effluent due to reduced potential for evaporation. These factors, coupled with potential for high demand during the winter months (for recreational activities such as skiing), require a unique approach to liquid waste elimination.

2. THE PROBLEM

Natural areas including National Parks, various types of nature reserves and private land maintained for ecotourism activities are all subject to increasing pressure from visitor numbers. Even remote camping areas, such as those in Tasmania’s South-West wilderness, experience sufficient overnight visitors to make provision of toilet facilities essential.

The selection of remote campgrounds and hut sites is usually based on the criterion of proximity to a reliable water source. This makes appropriate management of human effluent still more necessary to avoid contamination of surface water used for drinking. The toilet system must also prevent transmission of disease through insect and native mammal transmission vectors; otherwise taking water from a location upstream of toilet facilities is no guarantee of safe supply.

2.1 Health impacts

A study of 24 composting toilets in parks in Tasmania in 1992 (Crennan 1995, p.89) indicated that 16 showed no signs of composting and the remaining 8 were only partially composting. Lack of composting activity inevitably means liquid runoff from the toilets. Significant efforts have been made to improve compost performance, but some problems remain. Another study in 1999 (Brassington 1999) found raised faecal coliform levels (above recommended safe drinking levels) in streams supplying drinking water in the vicinity of a remote campsite with composting toilets.

Liquid effluent from composting toilets, having leached through a compost pile, contains many harmful pathogens derived from faecal waste including viruses, bacteria, protozoa and helminths (Crennan 1992, p.14). On contact with humans or other animals these pathogens cause gastrointestinal disease (Brassington 1999).

In 1986, 25 per cent of visitors to the overland track in the Tasmanian Cradle Mountain-Lake St. Claire National Park contracted gastroenteritis (O’Loughlin 1988, p.47-48). This was reduced to 8 per cent in 1987; a result mainly attributed to the education of park visitors on human waste disposal in the Minimal Impact Bushwalking campaign initiated by the Tasmania Parks and Wildlife Division (O’Loughlin 1988, p.47-48). It is obviously desirable to improve toilet facilities and education to the point where few, if any, visitors contract such diseases. A bushwalking experience in which a tourist contracts an illness as a result of ineffectual toilet technology or education is likely to have a detrimental effect on tourism.

In addition to preventing adverse human health impacts, an effective toilet system should prevent nutrients present in human waste from entering sensitive ecosystems. Increased nutrient levels in ecologically sensitive areas facilitate invasion by exotic plant species and affect native vegetation adapted to the low-nutrient soils found throughout Tasmania (Brassington, 1999, p.10).

The most effective means of preventing release of pathogens and nutrients from composting toilets is to operate them with zero liquid effluent. An evaporator able to cope with maximum discharge from a composting toilet is an attractive solution.

2.2 Visual intrusion

Wilderness and remote areas receive visitors wanting to escape their usual built environment. The visual intrusion of toilets and associated technology must be minimised in order to preserve the wilderness experience to which these people are attracted. Evaporators employed for liquid waste removal at the present time are unsightly due to their size, yet matched to toilet loads in such a way as to cause them to operate well below their evaporative capacity. It is desirable to match evaporator size to the demand of a particular site and to maximise efficiency in order to allow a compact, unobtrusive design. The present ‘flat plate’ designs used in Tasmania (there are 5 in use) are relatively large (about $10m^2$). The modular design presented in this study should enable adequate matching of toilet output to evaporator performance and simple handling of change in effluent output through mathematical modelling of liquid output and evaporative capacity.

Any evaporator relying on solar heating is best placed in a location with good solar aspect and no shading. However, the need to minimise visual intrusion suggests a location shielded by vegetation. A system that works effectively in partial shade would, therefore, be advantageous.

2.3 Cost and maintenance

The cost of constructing an evaporator utilising the current Tasmanian Parks and Wildlife Division design is around $2000 (Vaughn pers. com.). The practical success of a new design relates, in part, to the ability to produce it at or below this cost. The prototype materials compare favourably in terms of cost to those used by the Parks and Wildlife Division. Costs of installation can be high because materials must be brought in by helicopter in many locations. Thus, small modular designs are desirable from this perspective as well.

As the evaporator is to be used in remote locations it is necessary to ensure that minimal maintenance is required. Maintenance must be straightforward (i.e. easily done by park rangers without specialised tools) and safe (i.e. not requiring contact with contaminated effluent). The evaporator must also be robust so that deliberate or accidental damage by curious campers is minimised.

Obviously, the evaporator system must be fully self-contained. Moving parts should be kept to a minimum and electricity, if required, should be supplied by photovoltaic cells. Batteries should be avoided because of potential maintenance issues.

3. SOLUTIONS

The quantity of liquid effluent from composting toilets is comparatively small. Vaughn (pers. com. 2001), based on his experience with composting toilets in Tasmania’s National Parks, estimates about 0.1L per day per overnight visitor to an adjacent camp site or hut. At peak periods there might be up to 100 people in the vicinity of one camping area, but for most of the year numbers are well below this. Thus, total effluent could be as high as 10L in one day, but generally would be less than 5L/day and much lower in winter. These volumes mean that solar evaporation is likely to be a viable means of disposing of the liquid effluent.

Solar-enhanced evaporation is an ideal method for the removal of contaminated liquid effluent from composting toilets in sensitive ecosystems. There is zero emission to the soil or surface water. The system will perform better in summer (longer daylight hours, higher air temperatures) when expected loading is greatest, making it easier to keep the system as small as possible. Dissolved solids will remain in the evaporator and will require periodic removal, but quantities are expected to be small.

Literature relating to solar enhanced evaporation (Guinn 1992) and comparative performance of solar stills and evaporators (Satori 1996) has provided useful hints to the design process involved here. The design of solar stills referred to by Sartori can be adapted to solar evaporator design, the main difference being that it is possible to utilise large air flows through the system because it is not necessary to condense and recover the evaporated water.

Water was determined as a satisfactory substitute for urine for evaporative testing. It is assumed that the use of water will provide a proportional, if not direct insight into evaporation potential in the prototype design. Moreover, the use of water eliminates the chance of contracting disease during pre-field testing.

3.1 Laboratory Testing

In order to determine factors that increase the evaporation of water a series of laboratory experiments were conducted under controlled conditions. Initial testing determined evaporation rates from two identical vessels and demonstrated the same rate of evaporation for both. This conclusion was used as the basis for comparative testing, using a control, on the effects of air movement and increased surface area (achieved via a wick system) on evaporation. Tests on several wick materials indicated a distinct advantage in using pure cotton towel material. Both air movement and increased surface area facilitated an increase in the evaporation rate of water. These factors, coupled with the knowledge that increased heat uptake speeds evaporation, provided the basis for designing a prototype evaporator for testing outdoors.

3.2 Prototype design

The current prototype design brings together the three factors identified in laboratory testing as important to evaporation efficiency. The design facilitates air movement via a solar powered ventilator and inlet tubes, increased surface area through the incorporation of a pure cotton wick system and passive solar heat uptake using a transparent north facing side and black plastic construction materials.

The solar powered "Sunvent" ventilator cost approximately $90 and consists of two photovoltaic cells and a fan in a self contained unit capable of extracting up to 19 cubic metres of air per hour in bright sunlight (accompanying information included with product). The ventilator utilises no energy storage medium, a design property employed to achieve low maintenance. In order to increase the amount of sunlight hitting the photovoltaic cells a reflector, incorporating plywood backing coated with aluminium foil, has been employed with a reflective area of 0.1 square metres.

The wick system consists of a multi-rung frame (top and bottom) with the wick material woven through it to create a zig-zag effect when viewed from the side. This is demonstrated in Plate 1.

Plate 1. View from above the wick system used in the prototype evaporator.

The area of the wick material is approximately 2 square metres, however, the evaporative surface area is much larger due to evaporation taking place on all surfaces of the material and it being textured in such a way that fibres extend from the surface.

The containment vessel allows for a water/effluent surface area of $0.18m^2$ making the combined evaporative surface area, when utilising the wick, approximately $4.2m^2$.

The outer shell is roughly dome shaped and constructed of black moulded plastic, a north facing window and three black plastic ventilation tubes with a total air inlet area of $0.0012m^2$. It stands 0.82 metres high (to the top of the ventilator) and has a base area of $0.56m^2$. Plate 2 shows the current prototype evaporator design.

3.3 Control evaporator design

The control evaporator is designed to simulate the evaporators currently utilised by the Tasmanian National Parks and Wildlife Division for some composting toilets. It consists of an identical water containment vessel to the prototype, with a "Laserlite" and timber sloped cover as shown in Plate 3. The lower edge has an air inlet area of $0.0014m^2$ and the upper edge has an air outlet area of $0.0017m^2$. The design relies on a process of heating the air inside the vessel and creating a thermosiphon effect due to the temperature difference between this air and the outside ambient air temperature. No wick is employed in this design and the water surface area is $0.18m^2$.

Plate 2. Prototype evaporator showing north facing transparent window, with wick system behind, and reflector on top which increases sunlight onto solar powered fan.

Plate 3. Evaporator used as a control during testing of the prototype.

4. DATA GATHERING

The measured variable used to monitor the performance of the prototype and control evaporators was the water evaporated every 24 hours. A galvanised steel pointer is attached to each of the plastic water containment vessels. When the pointer just makes contact with the surface of the water the unit is considered to be full. Evaporation rates are determined by measuring the amount of water added until the surface and pointer make contact. Bench tests showed that this method was accurate to within 15mL.

Data loggers were placed inside each of the evaporators to measure internal air temperature and water temperature, logged at 10 minute intervals. Ambient air temperature is also recorded. Manual readings for evaporation and humidity are taken at twenty-four hour intervals. This data is to aid in assessing differences in performance between the control and prototype evaporators, but is not reported here.

Total sky radiation is recorded at the University close to the test site for the evaporators. This was used to compare evaporation rates with solar radiation.

4.1 Prototype Testing

A regime of testing has been undertaken through winter and spring (July to November 2001). Testing began with the prototype evaporator in a simple form; with the water/effluent containment vessel placed inside the windowless black plastic outer shell, the ventilator unit placed at the highest point and one inlet hose directed over the surface of the water. Once the performance of this basic design was determined via comparison with the control, changes were made at regular intervals to assess the effectiveness of increased air inlet area, increased passive solar input, increased air movement and increased evaporative surface area. The control evaporator remained unchanged throughout the testing.

4.2 Results

Experiment one resulted in no evaporation from the prototype and 725mL from the control (i.e. the control outperformed the prototype). The assumption was made that the inlet tube area was restricting air flow. Figure 1 shows a graph of the results from experiment two where three inlet tubes were employed instead of one. A performance ratio of 1.01:1 in favour of the prototype design indicates that the increase in inlet area initiated evaporation from the prototype to a rate roughly equal to that of the control.

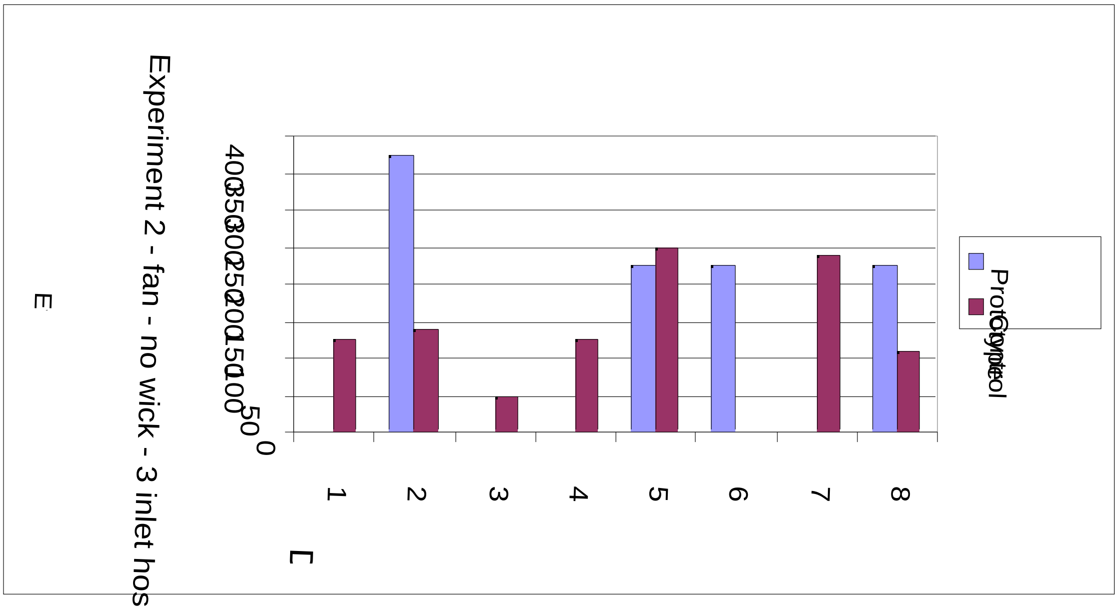

Figure 1. Daily evaporation from the prototype and control. The prototype included the solar powered fan but not other features.

Figure 2 presents the results of a more recent testing period where the prototype is fitted with the wick system and transparent window with no fan. The overall evaporation performance ratio for this testing period is 2.27:1 in favour of the prototype design. The improvement in performance by about a factor of two highlights the performance advantage of increasing surface area with the use of a wick system

The evaporation measurements from the most recent experiment incorporating all design elements are presented in Figure 3. This indicates a performance ratio comparing the prototype to control designs of 2.82:1. In bright sunny conditions the performance ratio was 2.8:1 in favour of the prototype as indicated by the performance on day 5 (Figure 3). Days that are more overcast and cloudy days with few sunny periods, as in day 8, resulted in the control evaporating less than the detection limit, while the prototype has evaporated 600mL. Heavily overcast weather, demonstrated on days 7 and 13, resulted in evaporation of 135mL for the prototype and an undetectable amount for the control in the case of day 7 and no evaporation for either unit on day 13 (day 13 was heavy rain with no sunshine).

Comparing Figures 2 and 3 provides evidence of the difference in performance of the prototype evaporator without and with a solar powered ventilator. The addition of the fan increased the performance ratio almost 25% and ensured that some evaporation occurred in all but the least favourable weather conditions.

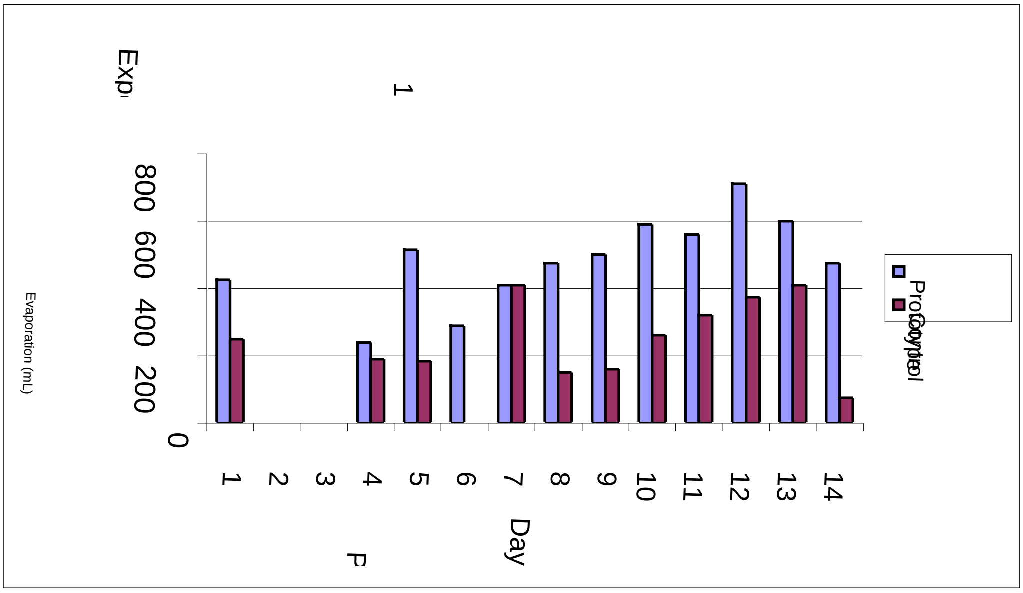

Figure 2. Daily evaporation from the prototype and control with the prototype fitted with the wick and the transparent window.

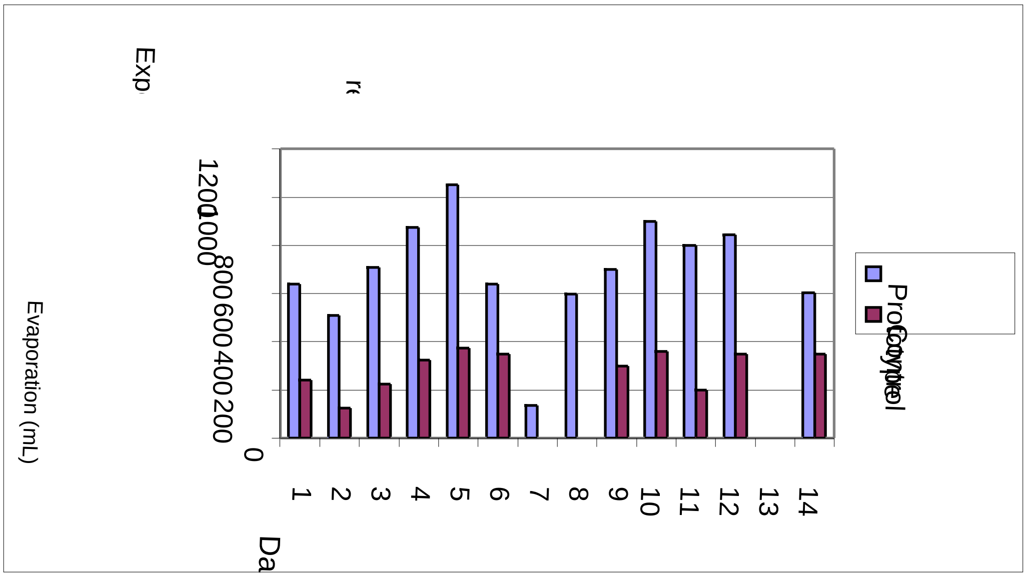

Figure 3. Daily evaporation from the prototype and control with the prototype fitted with the wick, the transparent window, the solar powered fan and the reflector.

4. CONCLUSIONS

The graphs presented above provide a comparison between the three prototype design components and indicate that the most effective performance ratios have been achieved with a combination of increased surface area (the wick), heat uptake (the transparent window) and air movement (the solar powered fan). It appears that the current prototype design performs on certain overcast and cold days when the control design does not. In remote Tasmanian highland conditions this may have a significant bearing on comparative performance. The assumption is that in these conditions the control, relying more on heat to create air movement, and thus evaporation, does not gather enough heat to begin thermosyphoning. The prototype appears to continue evaporating through minimal passive solar heat gain conditions with the use of added surface area and increased air movement. In the context of conducting several months of testing over winter and spring it has become apparent that the prototype, in its current guise, ensures evaporation in all but the most extreme of weather conditions. Only one day has been recorded with no evaporation from the prototype design in this configuration representing an extreme combination of heavy rain, high humidity and low temperature. These performance comparisons indicate a possibility for the prototype to be positioned in discrete vegetated areas to reduce visual intrusion, even if this results in some shading.

Research in Progress

This study is undertaken as part of the Master of Environmental Management Degree at the University of Tasmania, Hobart. The research is still in progress and will result in a thesis to be completed by mid to late 2003. In order to facilitate progress toward the projected tenfold evaporation efficiency increase, further refinement of the prototype design and an in depth analysis of "in the field" performance will be conducted.

Acknowledgements

We would like to acknowledge the support of Oliver Vaughn of the Tasmanian Parks and Wildlife Division.

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