Design of Onsite Volume Reduction System (OVRS) for Source-Separated Urine

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1. INTRODUCTION:

In Onsite Wastewater Differentiable Treatment System (OWDTS) wastewater streams are collected separately and each stream is treated properly at household level. Urine Diverting Toilet is used for separate urine collection and subsequent treatment. One of the advantages of urine separation is saving energy cost for composting of feces. As urine contains high concentration of nutrients (N, P, K) but is in small quantity (1% of wastewater flow), therefore, low cost Onsite Volume Reduction System (OVRS) may be needed for pollution control.

Figure 1.1: Onsite Wastewater Differentiable Treatment Systems

This research Paper is based on following 2 Questions which would be resolved in the subsequent discussion.

i) How much volume of urine should be reduced?

ii) How to reduce volume of urine?

To resolve first question, a Case Study of Southern Pakistan was carried out, where cotton is one of major crops requiring 90 kg of N fertilizer /ha, while its cost is 16 US$ (as of 2007). Farmland is located 60 km away from urban area. Unit transportation cost of 1,000 L is 0.0625 US $ /km. (as per market rates as of 2007).

Although urine contains high concentration of nutrients as compared to feces, however, large amount of urine is required to meet crop requirement, for example, for cotton 10,000 L/ha of (=90 kg of N) is required.

Figure 1.2 indicates transportation cost of urine based fertilizer per ha for cotton field. Cost of raw urine proportionate to transportation distance, while it is equal to cost of commercial fertilizer at 22 km distance. When volume of urine is reduced to 50% then required volume to transport gets 5000 L /ha, which is equal to the cost of commercial fertilizer at 42 km. Therefore, higher volume reduction of 80% would be desired for offering incentives to farmers.

Figure 1.2: Comparison of Urine Transportation Cost and Commercial N Fertilizer Cost

By 80% volume reduction, we can recover N (100% = 90 kg), P (3%= 2 kg/ha) and K (20%=10 kg/ha), thereby saving 24% cost/ha, if farmers apply urine based fertilizer (plus commercial. fertilizer = 58 kg P +40 kg K) instead of total commercial fertilizer alone.

ii) How to reduce urine volume?

There are various methods to reduce urine volume such as reverse osmosis, electro-dialysis, freezing and thawing and conventional evaporation with
heating, but they require high operation cost and energy supply. Here, Southern Pakistan has a hot and dry climate and poor piping system, so urine drying with natural energy like sun drying of laundry is expected in that area. Therefore, we proposed the onsite volume reduction system (OVRS) from climate and daily urine load.

2. EXPERIMENTAL METHOD:
Two types of Experiments are required to be performed.

i) Character of Vertical Sheet
ii) Experiments for Evaporation

j) Character of Vertical Sheet:
These experiments were performed to assess how far and how fast does water move upward under capillarity in the vertical sheet. No evaporation was allowed to take place; therefore, air humidity was kept 100%, without any supply of wind velocity. De-ionized water was used as a sample which is a model for urine and virgin gauze sheet was used. Height of Sheet (H) to which water moves up was measured with scale initially at an interval of 10 minutes for first 1-2 hours Subsequently measurement was made at 3 hour interval. Finally maximum height (H_{max}) was also measured.

Table 2.1: Boundary Conditions for Experiment

<table>
<thead>
<tr>
<th>Air Humidity (%)</th>
<th>Air Temp (°C)</th>
<th>Wind Velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>25</td>
<td>0</td>
</tr>
</tbody>
</table>

The Hagen-Poiseuille equation was used to formulate q-Supply Equation. Using the measured speed of water rising to sheet, H_{max}, depth of gauze sheet (d), μ (from temperature) and using Runge Kutta Method, we calculated σ i.e penetration factor (gr. /cm sec²).

q-Supply = \nu \times A

\frac{dH}{dt} = \sigma /\mu \ (H_{\text{max}} - H) /H \ (W \ d) \ldots \text{Equation (1)}

ii) Experiments for Evaporation:
We designed a closed wind tunnel having a long shallow tank (made of PAC), vertical cloth sheet and a fan (capacity of 30 m³/min), as shown in Figure 2.1. Constant Temperature Humidity Chamber is connected to wind tunnel via pipes for recirculation of air supply to maintain constant boundary condition. The humidity and temperature sensor is placed on the wall to check the air condition. The tank weight is automatically measured every 10 minutes to evaluate Evaporation Rate (ER) of sample in the tank through the Sheet.

From drying theory the ER of sample is calculated by the following mass transfer equation:

\text{ER} = \frac{M_{(\text{air})}}{\text{Ky}} (X_i - X) \ A \ldots \text{Equation (2)}

Where \(M_{(\text{air})}\) is molecular weight of air; \(X_i\) is saturated air humidity which depends upon the air temperature; \(X\) is humidity of supplied air; and \(A\) is effective drying area which is a design parameter. In this case \(A\) is product of sheet width and water height. \(A\) also specifies balance of \(q\)-Supply and \(q\)-Evaporation.

Figure 2.1: Lab Scale Onsite Volume Reduction System

The effective drying area is estimated from sheet width and water height to sheet at 2-3 hours intervals. Gauze was preferred over towel and paper sheets as rate of water rising (cm/min) to gauze was found higher than other sheets by an experiment. The boundary conditions for these experiments, suitable to the climate of Southern Pakistan, are specified in Table 2.2:

Table 2.2 Experimental Conditions

<table>
<thead>
<tr>
<th>Constant Air Conditions</th>
<th>Variable Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp(°C)</td>
<td>Humidity (%)</td>
</tr>
<tr>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>W. Velocity (m/s)</td>
<td>Humidity (%)</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
</tr>
<tr>
<td>Air Temp(°C)</td>
<td>W. Velocity(m/s)</td>
</tr>
<tr>
<td>25</td>
<td>5</td>
</tr>
</tbody>
</table>

3. RESULTS AND DISCUSSION
3.1 Experiments for Character of Sheet:

Figure 3.1 shows time course of water rising to the vertical sheet height (cm/min) using gauze. The figure 3.1 shows that rate of water rising initially was high owing to empty sheet. Later speed slowed as water started accumulating and saturation of
water in sheet was achieved during 20 hrs.

The figure 3.2 shows time-course of Evaporation Rate under five wind velocity conditions. For these experiments air temperature and air humidity were kept constant whereas wind velocity was changed five times. Under steady state the ER was 47 grams/hr when wind velocity was 6 m/sec. However, under same conditions initially ER was found 58 g/hr and steady state was achieved within 1-2 hours. In the steady state the ER remains same which is because of balance between water rising to sheet by capillarity and evaporation. Likewise under low wind velocity of 2 m/sec, steady state ER was found 12 gr/hr which is 4 times lower than the one observed in 6 m/sec. This shows that evaporation rate increased when turbulence to wind velocity is increased.

Based on the experimental data of water rising, the values of \( \sigma \) (g/cm. sec \(^2\)) and \( H_{\text{max}} \) are given in Table 3.1.

<table>
<thead>
<tr>
<th>Case</th>
<th>( \sigma ) (g/cm. sec (^2))</th>
<th>( H_{\text{max}} ) (cm)</th>
<th>Sample Liquid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virgin Gauze Sheet</td>
<td>0.00001</td>
<td>30</td>
<td>De-ionized water</td>
</tr>
</tbody>
</table>

3.2 Evaporation Experiments:

Experiments were performed using de-ionized water as a model of urine for establishing relationship between Non Dimensional Numbers. Reason for using de-ionized water is that urine contains high concentration of salts which create problem in assessment of effective drying height due to attachment of salt to sheet.

For making inter-relationship of Non Dimensional Numbers, various experiments were performed to assess effect of wind velocity, air temperature and air humidity, as specified in the Table 2.2. The results obtained from such experiments are discussed in the figures 3.2 to 3.7

The effective drying height which was measured every 2-3 hours is represented in the figure 3.3. Width of sheet used in these experiments is 30 cm which is constant for all conditions. However, effective drying height varies when experimental conditions are changed. Therefore, height is important parameter for calculation of effective drying area. The figure 3.3 shows that effective drying height is 5 cm when wind velocity is 2 m/sec, which is because of low evaporation rate of 12 gr/hr under steady state. When steady state ER is 47 gr/hr, then effective drying height is found 1.9 cm under 6 m/sec wind velocity. This shows that drying height is lower when the ER is high and it is higher when the ER becomes low.
Figure 3.4 shows time-course of MTC under various wind velocities keeping air temperature and air humidity constant. The figure 3.4 shows that MTC is found higher with increase in turbulence to wind velocity. This is mainly due to high ER under high wind velocity.

Further experiments were performed for assessing effect of air temperature and air humidity respectively on ER, as indicated in the Table 2.2. In this case also ER and effective drying height and other parameters were measured. However, the results of Mass Transfer Coefficient are discussed in the below given figures.

The MTC data obtained from all experiments was used to plot inter-relationship between Re, Sc and Sh.

The figure 3.5 shows time-course of Mass Transfer Coefficient (MTC) while changing air temperature five times. The figure 3.5 shows that there is minor difference in values of MTC when we change air temperature. This is mainly because we have used narrow range of air temperature in our experiments.

The figure 3.6 shows time course of MTC using various air humidity while keeping same air temperature and wind velocity. The figure 3.6 shows that value of MTC was found about 1.9 g.mol/cm$^2$.hr in all set of experiments.

4. Design of Vertical Sheet for De-ionized Water:

Comprehensive procedure for design of vertical sheet from climate conditions and daily water load is explained in Figure 4.1. Under this procedure, using the given data in the proposed model, one can calculate value of design parameters for volume reduction unit. In the Figure 4.1 the W stands for total width of sheet, whereas w stands for width of each sheet in case we use more than one sheet for practical purpose.

Keeping in view the dry climate conditions of southern Pakistan, we have estimated size of vertical sheet for a household unit comprising 10 family members which is expected to generate about 10 L of urine per day. The target volume to be reduced per day would become 8 L. Following the design procedure given in the Figure 4.1, the estimated size of vertical sheet for dry climate conditions under various wind velocity is given in Table 4.1.
References


Carolina Schonning (2001), Urine diversion-hygienic risk and microbial guidelines for reuse, Department of Parasitology, Mycology and Environmental Mycology, Swedish Institute of Infectious Diseases Control.


Perry Green (1984), Perry’s Chemical Engineers Handbook (McGraw Hill)


W. Pronk, M Biewbow, M Boller. Assessment of processing alternatives for source separated urine. EAWAG, Swiss Federal Institute of Environmental Science and Technology, Switzerland.

K.M Udert, T.A Larsen, W. Gujer, Fate of Major Compounds in Source Separated Urine. EAWAG, Swiss Federal Institute of Environmental Science and Technology, Switzerland.


Wouter Pronk, Martin Biewbow, Markus Boller. Treatment of source separated urine by a combination of Bipolar Electro dialysis and gas transfer membrane. EAWAG, Swiss Federal Institute of Environmental Science and Technology,

Table 4.1: Estimated Size of sheets for Dry Climate Conditions of Southern Pakistan

<table>
<thead>
<tr>
<th>Wind Velocity (m/s)</th>
<th>MTC (g.mol/cm² .hr)</th>
<th>Required Drying Sheet (80% volume reduction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.90</td>
<td>H:5 W:75 Size:375</td>
</tr>
<tr>
<td>3</td>
<td>1.20</td>
<td>H:3.5 W:80 Size:280</td>
</tr>
<tr>
<td>4</td>
<td>1.5</td>
<td>H:2.9 W:82 Size:238</td>
</tr>
<tr>
<td>5</td>
<td>1.9</td>
<td>H:2.3 W:77 Size:177</td>
</tr>
<tr>
<td>6</td>
<td>2.4</td>
<td>H:1.9 W:74 Size:141</td>
</tr>
</tbody>
</table>
Switzerland.


M. Mourer, P. Schwegler and T. Larsen. Nutrients in urine: energetic aspects of removal and recovery. EAWAG, Swiss Federal Institute of Environmental Science and Technology, Switzerland.


R. Ito, N. Fuamizu, M. Yokota. Energy analysis of composting toilets from full scale demonstration project on onsite differentiable treatment system for annual operation.


Food and Agriculture Organization of United Nations, Rome (2004), Fertilizer use by crops in Pakistan.

World Bank (2005), Road Transport Service Efficiency Study, India.