Abridgment

Evaluation of a Water-Reuse Concept for Highway Rest Areas

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Most of the water used at rest areas is used for flushing toilets. Therefore, if toilet-flushing needs can be met without using potable water, the potable-water supply needed for a rest area can be drastically reduced. In addition, if the water used for flushing the toilets can be returned to them, the waste-treatment objective becomes that of renovating the water for reuse rather than that of meeting water-quality standards.

The object of this work was (a) to develop a water-reuse concept for flushing toilets and (b) to evaluate this concept by using a bench-scale model.

WATER AND WASTEWATER AT REST AREAS

Studies in Virginia and other states have shown that the total water used at rest areas is 19 to 20 L (5 to 5.5 gal)/rest-room user (1). If this water is to be recycled and reused for flushing toilets, it is first necessary to identify the amount of potable water needed versus the amount of water that can be of a lower quality. A system that recycles and reuses water for flushing toilets must also take into account the amount of water wasted from lavatories and drinking fountains, which is another water input to the system. This input is one of the factors that control the amount of water that must be wasted from the system and was estimated from field observations to be between 5 and 10 percent of the total water use. This is within the range that can be calculated by using either (a) 11 to 19 L (3 to 5 gal)/flush/toilet plus 2.8 to 5.7 L (0.75 to 1.5 gal)/lavatory user or (b) 19 to 20 L (5 to 5.5 gal)/rest-room user with one-third to one-half of the rest-room users actually using the lavatory at a rate of 2.8 to 5.7 L (0.75 to 1.5 gal)/lavatory user.

Analyses of wastewater at rest areas have shown that both the 5-d biochemical oxygen demand (BOD_5) and the suspended solids are in the range of 150 to 180 mg/L (1). These results imply that the quality of rest-area wastewater is comparable to that of domestic wastewater; however, the total Kjeldahl nitrogen (TKN) of rest-area wastewater is between 75 and 100 mg/L, which is three to four times higher than that of domestic wastewater. Because the biological and chemical changes associated with nitrogen can have important effects on wastewater treatment processes as well as on the receiving streams, this high content of ammonia and organic nitrogen is very significant.

CONCEPT OF WATER RECYCLE AND REUSE

The basic requirements for a flushing fluid are the following: (a) no objectionable odor, (b) no objectionable color, (c) no foaming, (d) no suspended solids, (e) chemical and biological stability, and (f) low bacterial count. Fluids meeting these requirements can be produced by extended aeration or by aerated lagoons followed by filtration.

At present, there appear to be only two recycling systems for flushing fluids. These are the water-recycling system, in which the water from fountains and lavatories enters the system as a water input and becomes part of the recycled flushing water, and the mineral oil system, in which the fountain and lavatory wastewaters are either evaporated or separately treated. In either system, the water to the fountains and lavatories must be potable water and must be handled in the total treatment scheme. In a water-recycling system, this water from the fountains and lavatories can be used to maintain an equilibrium dissolved-solids concentration in the recycled water by wasting an equal volume of recycled water. Obviously, both water reuse and mineral oil recycling require that a volume of water equal to that produced from fountains and lavatories must be disposed of.

Originally designed for use on ships, the mineral oil-incineration system basically replaces flushing water with a colored mineral oil and either evaporates drinking-fountain and lavatory wastewaters or provides a separate treatment system for these wastes. A recycling system that is now in operation in Virginia can be added directly to rest areas that are already equipped with extended-aeration biological treatment. Approximately 90 to 95 percent of the water use at rest areas is for flushing toilets, and extended aeration followed by sand filtration produces a water of sufficient quality for this purpose. The advantages to this system are greatly reduced requirements for potable water and a reduced discharge of wastewater to streams. The cost-effectiveness of this type of system will be maximized when the system is added to rest areas that already have extended-aeration systems or aerated lagoons.

In a water-recycling system in which the mineral content is not reduced, there must be a waste of water from the system to limit the buildup of dissolved solids in the water. In a biological system, the effect of the dissolved solids on the microbial reactions must be taken into account. Solids inert to biological activity will build up to an equilibrium level that is controlled by the make-up water, i.e., the wastewater from lavatories and fountains. However, many organisms can adapt to a high salinity and efficiently degrade the organic constituents present in the wastewater.

The conceptual flow scheme shown in Figure 1 is based on the known performance of the extended-aeration system with high dissolved solids and the acceptability of applying settled extended-aeration effluent to a sand filter.

RESULTS OF BENCH-SCALE STUDIES

The bench-scale system used to study the recycle and reuse of wastewater included extended aeration followed by sedimentation and sand filtration. The sand filtration and recycling lines would be the only modifications necessary for the conversion of a conventional extended-aeration system to a water recycle-and-reuse system.

In the bench-scale study, recycled wastewater could not be used; therefore, a synthetic waste similar to rest-area wastes was formulated to duplicate certain specific parameters found in rest-area wastewater. The synthetic wastewater used in previous kinetic studies of bacterial growth was modified so that it would be similar to field wastewater in chemical oxygen demand (COD), pH, alkalinity, TKN, and chloride, calcium, and phosphorus concentrations (2). Because most of the compounds used to produce the COD were biodegradable organics, which is not the case in rest-area wastewater, the BOD_5 of the synthetic wastewater was greater than that of field wastewater. The total fixed-solids concentration in the synthetic waste was similar to that in the actual wastewater, but because the organics that determined the BOD_5 and COD also provided the volatile solids, the total solids were significantly higher in the synthetic wastewater.

Table 1. Quality of laboratory pilot-plant effluents at various recycle rates.

Parameter	Recycle Rate (%)			
	90[a]	0[a]	95[b]	95 With Color[b]
BOD_5, mg/L	14	9	15	12
COD, mg/L	155	109	875	846
Total dissolved solids, mg/L	5920	486	7644	7152
Total of fixed solids dissolved, mg/L	3860	365	5980	5572
Percent of dissolved solids fixed	65.2	75.1	78.2	77.9
TKN, mg/L	128	45.5	–	210
Ammonia nitrogen, mg/L	83	38.5	–	102
Mixed-liquor suspended solids, mg/L	7100	1726	7362	7846
Mixed-liquor, volatile suspended solids, mg/L	5900	1505	5936	6528
Percent volatile of mixed liquor	83.1	87.2	80.6	83.2
pH	5.4	5.6	6.2	6.2
Alkalinity, mg/L	10	26.3	346	314
Sludge-volume index	36.0	35.3	38.7	38.9
Chlorides, mg/L	597	–	1170	–
Efficiency of BOD removal[c]	99.5	96.9	99.7	99.8
Efficiency of COD removal[c]	96.1	72.8	89.1	89.4

[a] Synthetic-wastewater formula 1.
[b] Synthetic-wastewater formula 2.
[c] Based on weight of component in system effluent that was wasted.

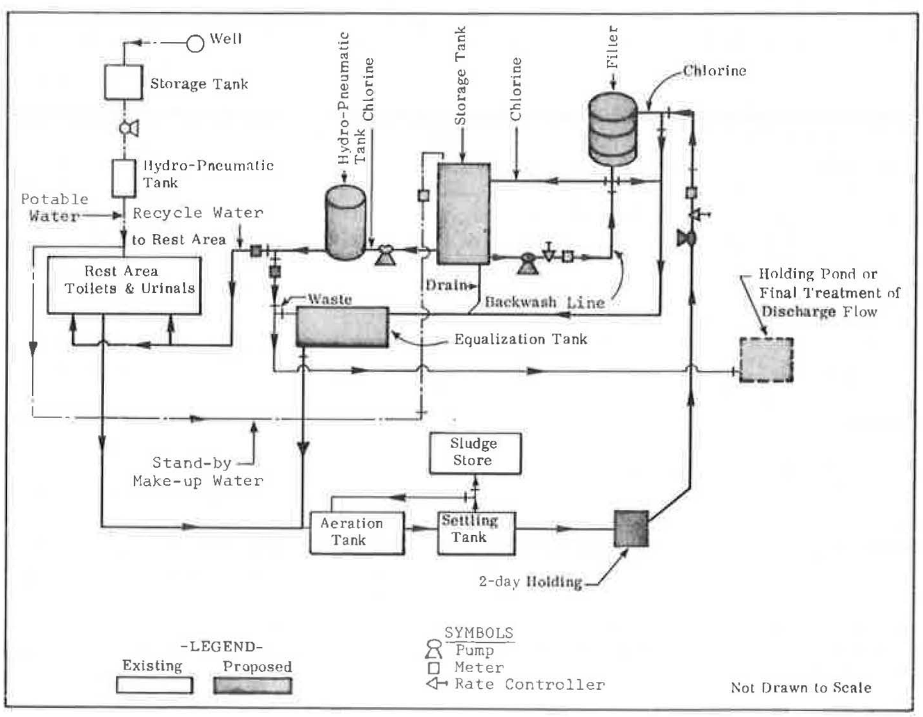
At the start-up, the biological system was seeded with a biomass obtained from a field extended-aeration unit. A recycle rate of zero percent was used to provide baseline information on the performance of the bench-scale system and to compare the system with a field-operated extended-aeration system.

At the zero recycle rate, the effluent from the bench-scale system contained 109 mg/L COD, 9 mg/L BOD_5, and 83 mg/L TKN. For comparison, an extended-aeration system at a rest area was found to be producing an effluent that contained 73 mg/L COD, 8 mg/L BOD_5, and 3 mg/L TKN from an influent raw wastewater containing 310 mg/L COD, 175 mg/L BOD_5, and 92 mg/L TKN. The effluents from the two systems compare favorably when it is considered that the BOD_5 of the synthetic wastewater had been made purposely higher to match the COD concentration so that the bench-scale system had a higher biodegradable organic load. Under these conditions, comparable nitrification was not expected.

Table 1 presents data obtained at different recycle rates. These data indicate that a buildup of nondegradable organics and inorganics will occur, but that there will not be a very large increase in biodegradable organics. Table 1 also includes the results from the use of sodium fluorescein to color the recycled water. The final steady-state water had a slight color, but appeared completely acceptable for flushing toilets. Chemically, biologically, and physically the system performed without difficulty and produced water that could be reused to transport human wastes. The biological system adjusted to the recycled water and did not show any signs of deterioration.

Synthetic wastewaters 1 and 2 in Table 1 differed only in the amount of alkalinity in the formulation. The increased alkalinity of formulation 2 was to enhance nitrification. Because pH, alkalinity, dissolved oxygen, and temperature greatly affect nitrification, a field recycling system should have increases in pH and in ammonia nitrogen during the winter when temperature will control the nitrification rate. During the summer, the rate-limiting parameters for the nitrification reactions will

Figure 1. Flow diagram for modifying typical extended-aeration system.



probably be pH, alkalinity, and dissolved oxygen; therefore, the ammonia buildup will depend on adjustments of these parameters. If the system is run in the summer without any adjustments in pH and alkalinity, the pH and the alkalinity will decrease, and the ammonia will increase. The winter pH should approach 8.3 and the summer pH should be between 5.5 and 6.0.

In addition to the satisfactory performance of the biological system, the sand filtration system adequately removed the suspended solids and required only infrequent backwashing.

Sodium fluorescein appeared to be an acceptable dye for coloring the flush water in all respects except for its greenish yellow color. It deteriorates in sunlight and is easily removed by activated carbon. Because blue is normally an appealing color, a blue food coloring such as FDC blue No. 1 may be more acceptable. This color can also be removed by activated carbon.

Evaporation as a means of producing zero discharge from a water-reuse system was evaluated by the study of a typical rest area in Virginia that treats 37 900 L (10 000 gal)/d, recycling 90 to 95 percent of the water, and having a final holding pond with a surface area of 500 m^2 (5380 ft^2). The data compiled indicate that, if holding ponds of the size currently used at rest areas in Virginia are appropriately covered, zero discharge is feasible. In addition to solar evaporation, the application of evaporation technology may be an acceptable means for producing zero discharge.

The Virginia Department of Highways and Transportation has constructed a prototype water-recycling system that is now operating at a rest area on I-81 in Rockbridge County. When compared with other alternatives for treating wastewater and conserving water, this system has an estimated saving of $30 000 annually.

CONCLUSIONS

Rest areas can use extended aeration followed by sand filtration in a scheme such as the one shown in Figure 1 to recycle and reuse water for flushing toilets. The system should be capable of recycling 90 to 95 percent of the water used. Water from water fountains and lavatories can provide the 5 to 10 percent of additional water necessary to ensure a steady-state dissolved-solids composition in the recycled water. The system will have a wastage of 5 to 10 percent of the average daily flow; however, evaporation of equivalent volumes may be a means of producing zero discharge. In certain locations, solar evaporation may be used to produce zero discharge.

The wastewater treatment described is applicable to areas with deficient water supplies and to areas where there are problems with wastewater disposal. It will not meet the needs of all rest areas, but in certain locations it can provide a viable alternative to current practice. The system can be added to existing extended-aeration systems, or it can be incorporated in the design of new facilities.

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Simplified Method for Design of Curb-Opening Inlets

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The purpose of this paper is to expand on and simplify the method of designing curb-opening inlets given in the Hydraulic Engineering Circular 12. A reanalysis of the experimental data has shown that the performance of a curb-opening inlet can be represented by a single dimensionless graph of the interception ratio of the curb-opening inlet (Q_i/Q) as a function of the length of the curb-opening inlet (L_i) divided by the product of the Froude number of the flow at the outer edge of the inlet depression (F_w) and the width of the spread of uniform flow in the street. The unit discharge of the inlet, up to a value of Q_i/Q defined by the cross slope alone, conforms closely to the unit discharge of the same inlet for the sump condition if the effective length of the weir crest and same total head are used in the latter case. Above this value of Q_i/Q, the required length of inlet varies as the 0.4th power of the ratio of L_i to 1.65 $F_w T$, regardless of cross slope. A design method is presented that enables computation, with reasonable confidence, of the required length of inlet for any cross slope, any grade, any width of depression, any spread of flow on the pavement, and any pavement roughness. The results agree well with the experimental data on subcritical and supercritical slopes. The analysis disclosed a number of deficiencies in the experimental data. Recommendations for remedying these deficiencies are given.

The data on curb-opening inlets first reported by Bauer and Woo (1) and their subsequent design charts (2) have been widely reproduced in hydraulic design manuals. Unfortunately, these charts are confined to a maximum longitudinal slope of 4 percent, a fixed manning n-value of 0.016, inlet lengths of 1.5, 3.05 4.6 m (5, 10 and 15 ft), and a range of flow spread up to 3.05 m (10 ft).

The original experimental data for supercritical slopes were reported by Karaki and Haynie (3). The experiments were full-scale and made on longitudinal