A SYSTEM FOR ON SITE TREATMENT AND DISPOSAL OF WASTEWATERS FROM TOURIST RESORTS

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ABSTRACT

A system for on-site treatment and disposal of wastewaters from tourist resorts was evaluated and compared to conventional package plants on the basis of experimental results obtained from a laboratory scale simulation of the system and reported data. The system was found to produce an effluent comparable to package plant effluents with respect to BOD5 and suspended solids but superior with respect to reliability and fecal coliforms. Disposal of the treated effluent to the soil through absorption trenches or to the sea through a short outfall are the most appropriate disposal methods, although reuse for irrigation after disinfection can also be practiced. The initial capital cost of the system is at most half the cost of the conventional package plants and the operation and maintenance expenditure negligible. The system is particularly suited to recreational facilities with seasonal operation.

KEYWORDS

On site systems; package plants; tourist resorts wastewaters; sand filtration; effluent disposal; cost; operation and maintenance of on site systems.

INTRODUCTION

In sparsely populated areas, where the distances between houses are great, the cost of sewers and water supply lines may so dominate the other costs of centralized facilities as to make them economically infeasible. (Goldstein, 1977). This is often the case with facilities in coastal recreational areas, such as camp grounds, motels, hotels, restaurants and bars, which are usually located along the coastline at considerable distances from each other.

The simplest and cheapest on-site treatment and disposal system is the conventional septic tank-absorption trench system. A basic drawback of this system is the need for long trenches as a result of the low capacity of the soil to transmit the wastewater, due to the formation of an organic crust along the wetted perimeter of the trench (Healey and Laak, 1974; Bouma, 1975). Soil characteristics and depth may lead to further limitations. Gravel and coarse sand are considered unsuitable while at the other end of the spectrum, clays may lead to problems due to possible damage of their structure during construction (EPA, 1980). With respect to depth, 60-120 cm of unsaturated
soil should exist between the bottom of the system and the seasonally high
water table or bedrock (EPA, 1980). Since these constraints are rarely
satisfied in coastal tourist areas, the conventional septic tank-absorption
trench system can not be widely applied.

Alternatively, biological treatment systems can and have been used. These
include biological filters, rotating biological contactors, contact stabiliza-
tion systems and occasionally even anaerobic packed beds; in all cases
usually in the form of preconstructed package plants. However the extended
aeration package plant is by far the most widely used system. This is
probably due to the lower initial capital cost and the fact that relatively
few commercially produced fixed film systems are currently available for
onsite applications (EPA, 1980).

These package systems are designed to operate under low loading conditions
in order to produce good quality effluents suitable for discharge to surface
waters. Generally they achieve production of reduced amounts of stabilized
excess sludge. The high hydraulic and solids retention times result also in
a high degree of nitrification. Reductions of phosphorus are normally less
than 25%. The removal of indicator bacteria in onsite extended aeration
processes is highly variable and not well documented. Reported values of
fecal coliforms appear to be about two orders of magnitude lower in extended
aeration effluents than in raw sewage (Seymour, 1972; EPA, 1980); such
fecal coliforms concentrations are usually too high to allow direct discharge
to surface waters, or to sea through a short outfall, without disinfection.

Despite their advantageous treatment capabilities, biological units for
onsite treatment are susceptible to upsets. Without regular supervision and
maintenance, the units may produce low quality effluents. A wide diversity
of factors that can adversely affect biological onsite treatment units and
particularly the extended aeration system has been reported (Seymour, 1972;
WPCF, 1985). Shock loads, sludge bulking, abuse or neglect of the plant,
over aeration or under aeration and mechanical malfunctions are among the
most common reasons for poor performance. In general, the uncontrolled loss
of solids from the system is the major cause of effluent deterioration. It
should also be noted that biological units are not very suitable for seasonal
operation, due to the necessary period required for the development of the
biomass. During this period, which often lasts several weeks, a low quality
effluent is produced.

The effect of the above mentioned reasons for poor performance is particularly
strong in small units, serving up to a few hundred inhabitants, a case which
is typical of most tourist resorts in Greece, with the exception of some of
the bigger hotels. A survey of the field performance of small onsite
extended aeration package systems showed that the mean effluent BOD₅ con-
centrations ranged between 30 and 150 mg/l, while the range of the reported
concentrations was from 1 to 800 mg/l (EPA, 1980). It is possible that the
situation is different with units installed in big hotels, where the economy
of scale may allow a greater degree of operator attention and often, in
addition to this, the adoption of alternative systems typical for small
communities, such as the oxidation ditch system. Given that the high flow
rates of sewage from tourist resorts are combined with high temperatures,
an oxidation maturation ponds system may also be cost effective, depending on
the cost of land and soil permeability.

This paper describes an alternative on site system consisting of a septic tank,
a gravel and two sand filters. The system has been experimentally evaluated
at the Sanitary Engineering Laboratory of the National Technical University

DESCRIPTION OF THE SYSTEM

The system under consideration consists of a septic tank, a gravel filter and
two sand filters operated alternately. Further treatment of the septic tank
effluent prior to disposal is achieved by filtration by means of the upflow
gravel filter followed by the two submerged sand filters operated alternately.
A schematic representation of the system is shown in figure 1.

A laboratory scale model of the system was constructed at the Sanitary Engineering Laboratory of the N.T.U.A. The operation of the septic tank was simulated by settlement of raw sewage in containers over a period of 3-4 days. Gravel and sand columns were used to simulate the filters. A detailed description of the experimental set up can be found elsewhere (Andreadakis and Christoulas, 1982; Christoulas and Andreadakis, 1987). The system was experimentally evaluated with respect to hydraulic performance and organic matter and nitrogen removal efficiencies. The results have been presented analytically in previous publications (Andreadakis and Christoulas, 1982; Christoulas and Andreadakis, 1987), and can be summarised as follows:

- The gravel filter did not show any trend for clogging. The coefficient of permeability of the sand filter decreased to about one-third of the original value at the end of a two weeks loading period, but full recovery was observed after two weeks of resting. Permanent clogging of the sand filter due to crust formation may be thus prevented by adoption of two sand filters operating alternately.

- The gravel filter achieved a variable BOD$_5$ removal efficiency (25-70%) so that the effluent BOD$_5$ was in the range 75-80 mg l$^{-1}$ for influent BOD$_5$ ranging from 100 to 250 mg l$^{-1}$ and for hydraulic loadings as high as 5.6 m$^3$ m$^{-2}$ d$^{-1}$. On average, 40% of the suspended solids were removed but the efficiency did not correlate with the sewage strength. The removal of BOD$_5$ by the sand filter depended on the hydraulic loading applied and the degree of compaction of the sand. For hydraulic loading $q = 1.5$ m$^3$ m$^{-2}$ d$^{-1}$, and a filter with an initial coefficient of permeability of 3 m$^{-1}$ day$^{-1}$, the BOD$_5$ removal efficiency was approximately 75% and the corresponding suspended solids removal efficiency about 50%. The observed organic matter removals by the gravel filter and the sand filter resulted in an effluent with BOD$_5$ and SS concentrations around 20 and 15 mg l$^{-1}$ respectively, which is comparable to a typical secondary treatment effluent.

- The sand filter was able to retain about 50% of the influent nitrogen by adsorption of the NH$_4^+$, oxidise to NO$_3$ during the resting period and denitrify most of it (85%) during the subsequent new flooding cycle, leading to nitrogen removal of approximately 40-45%.

On the basis of these results and relevant literature data (U.S. Public Health Service, 1967; Ramar and Chakladar, 1972; Sauer and Boyle, 1977), the following criteria can be adopted for the design and operation of the proposed system.

The septic tank may consist of one compartment, although two compartments with the first twice the size of the second have been reported to give better results, especially for bigger tanks (U.S. Public Health Service, 1967). For widths greater than 1.20 m it is recommended that the outlet has the form of an overflow weir along the width of the tank. In this case a baffle placed at a distance of 0.15 m before the weir will prevent the exit of floating solids. The bottom of the baffle will be at a depth equal to 0.30 H0, where H0 is the depth of the liquid in the tank. For narrower tanks a T piece outlet configuration may be adopted. Proper ventilation of the tank can be achieved by a vertical pipe placed on the tank or at some part of the sewage collection network.

A septic tank volume equal to twice the daily sewage flow allows for liquid detention times equal to or greater than one day, and adequate space for sludge storage. Suspended solids and BOD$_5$ removal efficiencies are about 60-65% and 35-40% respectively; sludge removal may be performed every 2 to 3 years.

The gravel filter is a submerged, anaerobic, upflow filter with a slotted base which permits the passage of the sewage but retains the gravel. The depth of the filter media is 0.50 m. The bottom 0.40 meters consist of gravel with sizes 12-15 mm, while the top 0.10 m consist of gravel with size approximately 0.6 mm.

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The area of the upflow gravel filter can be determined by adoption of a hydraulic loading equal to 2 m³m⁻²day⁻¹. The maximum head loss due to clogging will be approximately 0.15 m after two years of continuous operation. Every two years backwashing, by passing high pressure water downwards, will restore the permeability of the gravel filter. The water used for backwashing can be collected (space A in figure 1) and pumped out of the system together with the contents of the septic tank.

The sand filters are submerged, anaerobic, downflow filters, with intermittent operation. The filter media has a depth of 0.50 m and consists of sand of effective diameter \( D_e \) 0.6 mm and uniformity coefficient of 1.70. Filling is carried out by compaction of subsequently added sand layers (approx. 5 cm thickness each) so that the initial coefficient of permeability will be approximately 3 m day⁻¹. Underneath the sand layer, a sublayer of gravel, 0.30 m in thickness, is necessary to retain the sand and to act as a drainage system.

The area of each sand filter can be determined for a loading rate equal to 1.5 m³m⁻²day⁻¹. During each period of operation the decreasing permeability of the sand layer will lead to an increasing head loss. After two weeks, at the end of the operation period, the coefficient of permeability will be approximately 1 m day⁻¹ (one third of the initial). For a sand layer with a depth of 0.50 m, and a flow equal to \( 1.5 \frac{m^3}{16} \cdot 2.25 \frac{m^3}{day^1} \) (assuming that the sewage is produced over 16 hours each day), the Darcy equation gives a head loss equal to 1.125 m. Allowing for hourly peak flows a total head of 1.40 m can be safely adopted. When this head loss is reached, the gravel filter effluent is introduced to the second sand filter, while the first is left to drain and reset in order to recover its initial permeability. During the resting period drainage of the filter in order to ensure aerobic conditions should be practiced. This can be achieved by a pump placed in space B (Figure 1). The passages between gravel and sand filters (manifolds or gates) should be adequately wide in order to keep the velocity lower than 0.10 m sec⁻¹. Due to the high head loss at the start of each operation period, the introduction of the gravel filter effluent to the sand filter should be carefully exercised in order to avoid scour of the surface sand layers. One solution could be the diversion of the gravel filter effluent to space B (Figure 1) and subsequent return to the septic tank by means of the filter drainage pump.

The system described, when properly designed and operated, can achieve a final effluent which is comparable to the effluents produced by well operated package biological treatment systems, with respect to BOD₅ and suspended solids concentrations. Only partial nitrification can be achieved (≤5%) instead of the nearly complete nitrification obtained by extended aeration package plants. This may be a crucial difference for disposal into streams and torrents but not for subsurface and sea disposal practices.

The efficiency of the system to remove coliforms has not been experimentally evaluated. There is however evidence that it is superior to biological treatment plants. Fecal coliforms in concentrations \( 10^6-10^9 \) organisms per 100 ml have been reported for raw sewages (EPA, '80). For Mediterranean countries a value close to \( 10^6 \) per 100 ml has been suggested (WHO et al., 1982). This value is one to two orders of magnitude higher than the values usually reported for North Europe and the United States, but it is doubtful whether it corresponds to a proportionally increased concentration of pathogens.

Aerobic package plants result in fecal coliform removal efficiencies in the range 90-99% (Seymour, 1972) and a two log reduction seems to be a maximum value (EPA, 1980). Biologically treated effluents can therefore be expected to have concentrations of fecal coliforms not lower than \( 10^6/100 \) ml. There are uncertainties about the removal efficiency of the septic tank–gravel filter system. Reported efficiency values for primary sedimentation vary between 3 -72% (Hudson and Fennell, 1980). Taking into account the longer retention times employed in septic tanks and the probable contribution of the gravel filter, it is reasonable to accept a value 50-90% for the combined system.
Sauer, Boyle and Otis (1976) found concentrations of fecal coliforms in effluents of intermittent sand filters loaded at 0.6-1.7 m\(^3\)m\(^{-2}\)day\(^{-1}\) in the range 140 to 4900 per 100 ml, values which represent a 2 to 4 log reduction, when compared to the concentrations found in the septic tank effluent of their system. Similarly EPA (1980) reported that intermittent filters are capable of reducing fecal coliforms by 2 to 4 logs, producing effluent values ranging from 100 to 3000 per 100 ml. Comparable reductions were observed in column experiments with loamy unsaturated flow conditions and therefore are expected, resulting in an effluent concentration of the order of \(10^4\) organisms per 100 ml, with a maximum value around \(10^5\) organisms per 100 ml. These findings refer to unsaturated flow conditions and therefore are not directly applicable to the sand filters of the system, which are flooded during the operation period. It has been shown that high moisture contents of the filtering media prolong the survival of the retained bacteria (Geros et al., 1975; Watson, 1980). However, on the basis of the reported literature data, a 2 log reduction of fecal coliforms by the system septic tank-gravel filter-sand filters can be expected, resulting in an effluent concentration of the order of \(10^4\) organisms per 100 ml, with a maximum value around \(10^5\) organisms per 100 ml. Clearly further research and experimentation is needed to determine the efficiency of the system with respect to pathogens removal.

DISPOSAL ALTERNATIVES

When the system (septic tank-gravel filter-sand filter) is combined with subsurface disposal through absorption trenches, the low concentration of organic matter in the sand filter effluent will result in slower build-up of the soil crust and the ultimate crust infiltration rate can be expected to be approximately two times higher than the ultimate infiltration rate of a crust formed by septic tank effluents (Laek, 1977). In addition, due to the pretreatment offered by the system, the danger of unacceptable ground water pollution by short circuiting of the flow due to cracks of the soil crust, or channels formed by worm activity, is reduced.

Despite these advantages, the required total length of trenches is still considerable, approximately 5 m per person served. A modified subsurface disposal method, through trenches which operate alternately was experimentally investigated in the Sanitary Engineering Laboratory of the N.T.U.A. It was found (Andreadakis and Christoulas, 1982; Andreadakis, 1987) that under an alternating operation, similar in mode to the operation of the sand filters, a soil of moderate permeability (~1 m.day\(^{-1}\)) could transmit the effluent at rates approximately equal to half the rate for clean water transmission, without tendency towards permanent clogging. This finding indicates that for a moderately permeable soil, the alternating operation of two trenches may lead to reduction of the required total trench length by more than one order of magnitude, in comparison to the conventional system. The system can, therefore, be applied to areas fairly dense in population, provided that soil characteristics and depths meet the same criteria as those described earlier for the conventional system. Experiments by means of soil columns with depths of 0.5 m, indicated that the leachate to the groundwater can be kept consistently below 10 mg.l\(^{-1}\) for both BOD\(_5\) and suspended solids concentrations (Christoulas and Andreadakis, 1984; Andreadakis 1987). The degree of further fecal coliforms retention by the soil layer depends on the soil characteristics, but in most cases the concentrations in the leachate should be limited to less than 200 per 100 ml (Lance et al., 1980). In cases where the groundwater in the vicinity of the trenches is used as a source of potable water, disinfection of the sand filter effluent should be practiced. The possibility of high concentrations of nitrates should also be examined in such cases, although unacceptably high concentrations are not very likely, as the proposed system in combination with subsurface disposal can remove 50-70% of the nitrogen of the sewage (Andreadakis, 1987).

Whenever subsurface disposal is not feasible, disposal to the sea through a short outfall can be adopted as an alternative solution. Disposal at a depth of around 10 m can be achieved in most cases on Greek coasts, through a short outfall, usually not more than 200 m in length. According to Abraham (1963), for diffuser orifices 5 cm in diameter, a dilution factor of 200 can be obtained, resulting in fecal coliform concentrations at the
on the order of $10^2$ per $100$ ml (for $10^4$ per $100$ ml in the sand filter effluent). The EPA standard (U.S. Env. Pr. Ag. 1976) for swimming is $200/100$ ml (log mean value), while according to the EEC (Comm. Official Paper, 1976) the suggested maximum concentration for $80\%$ of the samples is $100/100$ ml, and the mandatory maximum concentration for $95\%$ of the samples is $2000/100$ ml. It appears, therefore, that disposal of the sand filter effluent to the sea through a short outfall can be practiced in most cases without disinfection, unlike the case of package treatment plants, where the concentration of fecal coliforms in the effluent is at least one order of magnitude higher. With respect to other pollutants (BOD, NH$_3$, etc.) it is certain that their concentrations after dilution will be lower than the maximum permitted values.

An interesting disposal alternative may be the utilization of the sand filter effluent after disinfection for irrigation purposes on a perennial or seasonal basis.

**ECONOMIC CONSIDERATIONS**

The area occupied by the system is approximately $0.60-0.70$ m$^2$ per capita, which is about three times larger than the area required by typical package plants ($0.20-0.25$ m$^2$ per capita without drying beds. In most cases the area around the recreational facility (hotel, motel, etc.) suffices for the construction of the proposed system, which can be completely underground.

The authors performed a detailed cost analysis for various flow rates and derived a relationship between initial capital cost ($C_0$ in drachmas, prices of 2nd quarter 1977) and the daily flow ($Q$ in m$^3$.day$^{-1}$). It should be noted that local conditions may cause deviations from the estimated costs, however, the relationship can be reliably used for preliminary design purposes.

$$C_0 = 200000Q^{0.74}$$

Using rather limited data concerning initial costs of package plants in Greece, it was found that these costs are approximately 2 times higher when compared to the costs given by equation 1. This finding is supported by literature data concerning package plants in the U.S.A. Lamp (1974) reported a cost study of 33% package plants constructed in the U.S.A. He found a relationship similar to equation 1:

$$C_0 = AQ^B$$

Using the EPA Construction Cost Index, for SCCT (Small City Conventional Treatment), the prices were updated for the 2nd quarter of 1987, and it was found that they were approximately twice the prices given by equation 1. Three to four times higher costs were estimated by using the cost analyses reported by Bechtel Corporation (1979), Mitchell et al (1970) and Tchobanoglous (1973), for community sizes in the range 100-500 persons.

The major advantage of the described system lies in its operational simplicity. A reliable performance with minimum surveillance and operational procedures can be achieved. Operational and maintenance procedures are limited to a few general inspections, alternating the flow and draining the filter every two weeks, emptying the septic tank content every 2-3 years and maintaining the surface of the filters by raking the sand surface and possibly replacing the top layer of the sand (5 cm layer) every 1-2 years. Practically no energy is required with the exception of the possibility of pumping the filter effluent after draining. The annual operation and maintenance cost is negligible when compared to the operation and maintenance costs of the package plants. One daily visit to the package plant by the operator is recommended (W.P.C.F., 1965) for a minimum duration of 3 hours (EPA, 1977). For extended aeration plants, the energy required for aeration is estimated to be about 50 kWh per person per year. Thus labor and energy costs, which are the two major components of the total operation and maintenance cost, add up to about 5-10% of the initial cost. This range compares favourably to the costs reported by Bechtel Corporation (1970) and Tchobanoglous (1973) for community sizes in the range 100-500.
persons, and recent estimates of Englehardt and Ward (1986) for extended aeration package plants serving 20-100 persons. In rotating biological disks the annual running costs are significantly lower (about 20-25% of the cost of an extended aeration plant), but still much higher than the running costs of the examined system.

CONCLUSIONS

An alternative system for on-site treatment and disposal of wastewaters from tourist resorts, consisting of a septic tank, an upflow gravel filter and a submerged sand filter operating intermittently (two beds), is able to produce an effluent characterized by BOD₅ and Suspended Solids concentrations close to 20 mg.l⁻¹ and 15 mg.l⁻¹ respectively. This effluent quality is comparable to the effluents produced by biological package plants.

Subsurface disposal of the effluent through alternately operated absorption trenches, leads to total trench length approx. one order of magnitude shorter in comparison to the length required in the case of the conventional septic tank-absorption trench system.

For disposal to the sea through a short outfall, the system is comparable, if not superior to the conventional package plants. It gives comparable but more consistent effluent quality with respect to BOD₅ and Suspended Solids. As far as fecal coliforms are concerned, their concentration in the effluent seems to be at least one order of magnitude lower than the concentrations found in package plants effluents, thus enabling, in general, disposal without disinfection. Further research is needed with respect to the efficiency of the system to remove pathogens. The system under investigation is cheap to construct and operate. Initial capital costs were estimated to be at most half the costs for package plants. A reliable performance with negligible operation and maintenance cost can be achieved. The system is particularly suited for seasonal operation, with high efficiencies throughout the operation period, in contrast to biological package plants, which during the start up period suffer from reduced efficiency for up to several weeks.

REFERENCES


