PERFORMANCE AND OPERATION OF SMALL ACTIVATED SLUDGE PLANTS IN TOURIST AREAS

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ABSTRACT
Small scale activated sludge plants are used extensively in tourist areas for the treatment of wastewaters from hotels and other tourist establishments. A recent survey carried out in a big tourist island of Greece showed that the majority of small plants did not perform satisfactorily. The most important problems identified were associated with diurnal flow fluctuations, inadequate control of air supply and sludge return rates, accumulation of grease and fats in the plant and bad design. Another important problem appeared to be the lack of trained personnel for the operation and maintenance of the plant. These problems are discussed in detail and possible measures are presented. Experimental results from the monitoring of two small extended aeration plants confirmed the bad effect of sudden surges of flow on effluent quality. Moreover it was found that the time required for the startup of the plant was approximately six weeks.

KEYWORDS
Extended aeration, package plants, wastewater treatment, performance, operational problems.

INTRODUCTION
Small scale treatment plants are usually defined as those serving populations of up to 3000 people, ranging from individual establishments, i.e., hotels, restaurants etc. to groups of houses and small communities. Several types of installations are in use having as their main units septic tanks, biological filters, rotating biological contactors and activated sludge units.

Installations based on the activated sludge principle and particularly extended aeration plants are by far the most common type in use in tourist areas. They are constructed either as prefabricated units known as "package plants" or are individually built on site. The main design features of these plants are (a) the long period of aeration provided which ensures good stabilization of surplus sludge and (b) the absence of a primary sedimentation tank which renders the process simpler and minimizes sludge handling and disposal problems.

A recent survey carried out in an important tourist island of Greece showed that the majority of tourist establishments had installed individual sewage treatment plants to treat all wastewaters before they were discharged to the
These consisted in most cases of extended aeration plants or oxidation ditches with the exception of some hotels that used septic tanks of long retention times. Although the plants were designed and constructed in accordance to well established design criteria almost all experienced operation and maintenance problems so that the performance of the plants was not satisfactory in most cases.

This paper deals with the design, performance and operation of small extended aeration plants used in tourist areas and discusses some of the possible measures of control of effluent quality.

**REVIEW OF DESIGN CRITERIA AND CONSTRUCTION METHODS FOR EXTENDED AERATION PLANTS**

**Design**

The extended aeration activated sludge process is a modification of the conventional activated sludge process, and exploits more fully than any other modification the endogenous metabolism of synthesized cellular material. Unlike all other systems this is not designed for daily wasting of secondary sludge and synthesized material undergoes extended periods of aeration. Hence the name of the process. Basically, extended aeration systems incorporate an aeration tank for treating crude B.O.D. and stabilizing secondary sludge, and a settling basin from which all of the removed solids are returned to the aeration compartment. The contents of the sewer discharge directly into the aeration tank through, if required, coarse bar screens or comminutors. If a bar screen is provided, it should be of the submerged type to avoid accumulation of solids above water level. Such accumulation encourage flies and can be a source of odour.

The aeration time is generally 24 hours or more, but lesser periods are practicable at the expense of aerobic digestion and sludge storage. All the secondary sludge from the settling tank is collected and returned to aeration compartment by gravity or air-lift pump to undergo endogenous metabolism. Thus the aeration tank serves the dual purpose of substrate B.O.D. and synthesized sludge treatment.

The activated sludge should be evenly distributed across the whole tank length. This is essential in order that the active solids can be introduced to the polluting load efficiently. The ratio of applied BOD to MLSS is much smaller than in any other treatment process.

**Construction**

Prefabricated package plants are usually constructed in 6 mm steel plate, shot-blasted and painted with epoxy resin. For the smallest plants serving populations of up to 200 people, rectangular tanks are used, whereas for larger plants circular tanks are preferred. These larger units consist of concentric circular tanks, the outermost being used for aeration and the inner as a secondary sedimentation basin. Plants built on site are normally made of concrete to any design. Oxidation ditches, operated either discontinuously (fill or draw) or continuously with external settlement tanks, have an oval ring shape and are constructed of concrete.

**Aeration equipment**

In extended aeration plants, aeration is normally achieved with compressed air, using either coarse-bubble or fine-bubble diffusers. Fine bubble diffusers have a greater aeration efficiency (e.g. 1.8-2.2 kg O₂/kW·h) as opposed to 1.0 kg O₂/kW·h for coarse bubble but their overall construction and maintenance costs are higher due to their frequent blockage. Aeration equipment is designed to provide 2.0-2.5 Kg O₂ per Kg BOD or 180 m³ air/Kg BOD assuming an oxygen transfer efficiency of 45% in the aeration system. Standby equipment of capacity of at least up to 50% of the duty is essential. Three blowers, each rated at 50% of the total design requirement are in some cases provided to cope both with underloading and overloading situations.
Mechanical surface aerators are also being used in some installations. A particular example is the TNO horizontal brush aerator. The aeration time is generally 24 hours or more but lesser detention times are practicable at the expense of aerobic digestion and sludge storage.

Final settlement and sludge recycle

Final settlement may be carried out in a quiescent zone within the aeration tank i.e., separated from the latter by a partition, or in a separate clarifier. For smaller plants, serving up to 1000 persons, an upward flow clarifier, with a 60° degrees sidewall slope is used. Larger installations employ radial flow tanks with mechanical scrapers. In all cases upward flow velocities should not exceed 0.9 m²/m²·h to overcome the problem of solids washout. Sludge recycle is accomplished by hydrostatic head in the case of small plants or by air lift or an external pump in larger plants. One problem with recycling sludge by gravity is that pockets adhere to the sides of the tank and may cause rising sludge problems, due to denitrification.

The rate of sludge recirculation is normally in the range of 0.5–2.0 times the average daily flow. The minimum recycle ratio is given by:

\[ r = 1 / \left( \frac{X}{X_r} - 1 \right) \]

where \( X_r \) and \( X \) = solids concentration in return sludge and aerator respectively.

Summary of design criteria

The most common basis of design of extended aeration units, developed from experience, are summarized in Table 1.

<table>
<thead>
<tr>
<th>TABLE 1. Design criteria of extended aeration plants</th>
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<tbody>
<tr>
<td>Design flow, l/head·d</td>
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<tr>
<td>Aeration time, h</td>
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<tr>
<td>Sludge loading, Kg BOD/Kg MLSS·d</td>
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<tr>
<td>Organic loading, Kg BOD/m²·d</td>
</tr>
<tr>
<td>Settling rate, m³/m²·day</td>
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<tr>
<td>Air supply</td>
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<tr>
<td>1) Diffused air, m³/Kg BOD</td>
</tr>
<tr>
<td>- Aeration depth of 1.8 m</td>
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<td>- Aeration depth of 2.7 m</td>
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<tr>
<td>2) Mechanical aeration, Kg O₂/Kg BOD·h</td>
</tr>
<tr>
<td>- Sludge recirculation rate</td>
</tr>
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</table>

COMMON PROBLEMS OF SMALL PLANTS IN TOURIST AREAS

The types of problems encountered and reported in the survey mentioned in the introduction are typical of all small plant installations. These were categorized as follows:

- Diurnal fluctuations in hydraulic loading
- Inadequate control of return sludge rates
- Inadequate control of air supply
- Accumulations of grease and fats
- Discharge of scouring powders and disinfectants
- Accessibility of plant components
- Startup of the plant

Variations in hydraulic loadings

Small treatment plants are sensitive to fluctuations in hydraulic loading which may be caused by:

- the small number of contributing population and the similar pattern of activities of individuals served
- the close proximity of the plant to the establishment served

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Intermittent introduction of sewage to the plant by pumping.

Diurnal flow fluctuations may reach up to 10 times the average flow in some cases. Care must be taken in the selection of the design flow so that the plant is not severely over or underdesigned.

Intermittent pumping of sewage in the aerator creates instantaneous surges of flow, particular in cases where a large size pump has been selected operating at relatively long intervals. Such surges may cause the sludge blanket in the aerator to rise and large quantities of solids to be lost in the effluent, thus impairing effluent quality. Intermittent introduction of sewage also affects biological operation. In order for microorganisms to be maintained at a constant growth rate it is essential that the feed is continuous and approximately constant throughout the day.

The key to the solution of this problem appears to be the regulation of pumping frequency and rates of pumping. Selection of smaller pumps or variable flow pumps in the design stage of the plant is recommended.

Where site availability permits, the provision of an equalizing basin may provide an alternative.

Inadequate control of return sludge rates

In plants where sludge return is by gravity, the rate of sludge recycling cannot be externally controlled and is in most cases unsatisfactory. This results in the formation of sludge pockets in the settling tank, and a gradual loss of solids from the aeration tank. For this reason this type of sludge recycling should be avoided.

Problems have also being reported in plants utilizing air-lift pumps for the recycle of sludge. In this case return sludge rates are controlled by controlling the air volume applied to the air lift pumps but in most instances the means provided for accomplishing this end are inadequate. Thus when the air flow rate is decreased to within reasonable limits, the lines clog instantly and the return flow is interrupted. Very often excessive rates of sludge recirculation are observed which have an adverse effect on settling in two ways, firstly they disturb the quiescent conditions in the tank by turning over its entire volume several times each hour and secondly flocs are torn apart and their settling ability is reduced.

Inadequate control of air supply

Inadequate control of the air being supplied to the unit is one of the major mechanical problems confronting the operator of a small unit activated sludge plant. The majority of the units are equipped with positive displacement air blowers on a fixed base. Therefore, the only available means of varying the air is by changing the sheaves on the blower. This does not provide adequate control and has the added disadvantage of being time-consuming.

Excessive turbulence in the aeration tank resulting from inadequate air control has a detrimental effect on clarification when the aeration and settling sections are housed in a single tank and separated only by a baffle. The energy imparted to the mixed liquor due to this turbulence is carried over into the settling section and results in poor clarification.

A second problem is denitrification. Denitrification occurs in the settled sludge causing nitrogen gas to be formed and on its release bringing the sludge to the surface. Denitrification must be preceded by nitrification and since excess oxygen is the cause of nitrification the solution, obviously, is to decrease the quantity of air being supplied. This problem will be encountered most frequently at an installation operating below the organic design load of the plant. The most satisfactory solution appears to be the incorporation of an automatic timer into the diffuser system, or use of a turbine blower. With these the amount of air being supplied can be controlled within loosely defined limits.
Grease and fats

The troubles caused by grease and fat at small treatment plants are many and varied, some of them being of rather common occurrence. Grease tends to clog the screens and thus to increase the cost of maintenance. It forms unsightly scum and fat balls on the surface of the aerator and it coats side-walls of channels and tanks. Scum balls accumulate behind baffles and weirs, interfering with final settlement of wastewater. Accumulations of grease are likely to cause offensive odours if left for long periods. Usually scum accumulated in the settling tank is returned to the aerator by means of surface eductors or scum removal devices. The best way to deal with grease problems is the removal of grease and fat in grease traps before it arrives at the plant and the daily collection and removal of floating material from the surface by manual skimming.

Scouring powders and disinfectants

This is a problem inherent to all small plants as large quantities of materials used for cleansing and disinfecting of the premises are discharged to the plant in slug doses thus poisoning microbial populations. The only method to cope with this problem is care in the use of these materials.

Bad design

Small treatment plants in tourist areas, particularly those built on site, are usually buried in the ground and covered by concrete slabs, leaving only small manholes for sampling and operation purposes. This fact renders the plant very difficult to operate and maintain properly. Thus, in many cases, it is impossible for the operator to reach weirs and baffles and remove scum and other accumulated materials. Even visual inspection of the process is impossible.

It is essential therefore to design small plants as "open" as technically feasible and to install them in a separate building in order to prevent visual and other impacts to the close environment.

EXPERIMENTAL

An experimental investigation of the performance of two small plants, serving a motel with a restaurant and a small hotel respectively was carried out during the summer period, in order to evaluate the efficiency and operational characteristics of typical extended aeration units. The design criteria of the two plants are shown in table 2.

Plant "A"

The first plant, referred to as plant "A", was of a very simple design, employing gravity return of settled sludge. A schematic representation is shown in figure 1. Crude sewage was collected in a sump of 36 m³ and was pumped to the aeration tank intermittently approximately every 20 minutes.

Table 3 shows typical performance results of plant A. As it can be seen plant A achieved a high percentage removal of BOD and organic Nitrogen and the BOD concentration in the effluent was always lower than 20 mg/l. The SS concentration in the effluent however was high, rising on occasions to 60 mg/l. A close relationship between BOD and SS in the effluent was observed and this is shown in figure 2. The suspended solids in the effluent was of a non-biodegradable nature which was a consequence of the long time of aeration provided.

High effluent SS concentrations was always an effect of low MLSS levels. Once MLSS were established in the order of 1700 mg/l effluent SS concentration dropped to 20-30 mg/l.
Fig. 1. Schematic layout of plant "A"

Table 2. Design criteria of plants surveyed

<table>
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<tr>
<th></th>
<th>Plant &quot;A&quot;</th>
<th>Plant &quot;B&quot;</th>
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<tbody>
<tr>
<td>Design population</td>
<td>80.00</td>
<td>80.00</td>
</tr>
<tr>
<td>Aeration Volume, m³</td>
<td>65.00</td>
<td>12.50</td>
</tr>
<tr>
<td>Settling Volume, m³</td>
<td>9.00</td>
<td>2.10</td>
</tr>
<tr>
<td>Settling surface area, m²</td>
<td>11.50</td>
<td>3.50</td>
</tr>
<tr>
<td>Detention time in aeration, h</td>
<td>30.00</td>
<td>16.00</td>
</tr>
<tr>
<td>Detention time in settling, h</td>
<td>5.30</td>
<td>2.80</td>
</tr>
<tr>
<td>Average flow, m³/h</td>
<td>0.76</td>
<td>0.77</td>
</tr>
<tr>
<td>Maximum flow, m³/h</td>
<td>2.18</td>
<td>2.30</td>
</tr>
<tr>
<td>Sludge storage, m³</td>
<td>36.00</td>
<td></td>
</tr>
<tr>
<td>Sewage sump, m³</td>
<td></td>
<td></td>
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</tbody>
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Table 3. Performance results of plant "A"

<table>
<thead>
<tr>
<th></th>
<th>Influent</th>
<th>Effluent</th>
<th>E%</th>
</tr>
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<tbody>
<tr>
<td>BOD, mg/l</td>
<td>150</td>
<td>80-20</td>
<td>86-92</td>
</tr>
<tr>
<td>SS, mg/l</td>
<td>175</td>
<td>20-60</td>
<td>67-91</td>
</tr>
<tr>
<td>Organic N, mg/l</td>
<td>75</td>
<td>4</td>
<td>95</td>
</tr>
<tr>
<td>Ammonia, mg/l</td>
<td>50</td>
<td>10-14</td>
<td>72-80</td>
</tr>
<tr>
<td>Oxidized N, mg/l</td>
<td></td>
<td>13-15</td>
<td></td>
</tr>
<tr>
<td>MLSS, mg/l</td>
<td></td>
<td>1500-1700</td>
<td></td>
</tr>
<tr>
<td>Specific resistance of sludge, m/Kg</td>
<td>4.4 x 10¹³</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Occasionally up to 300 mg/l
Small activated sludge plants

The interesting finding of this investigation was the acute effect of intermittent pumping of sewage on the quality of effluent. This was observed on several occasions particularly during the busy hours of the hotel when the pumps operated every 10 minutes, causing a 4-fold increase in the rate of flow. A typical result is shown in Figure 3. The direct pumping of raw wastes in the aeration tank caused a rise of the sludge blanket and subsequent loss of solids to the effluent.

Bearing in mind that the duration of the pump operation was approximately 1 min, the actual instantaneous overflow rate was 45.4 m³/m², about twice the recommended overflow rate.

The increase in SS was observed 5 minutes after the operation of the pump. The rise of the sludge blanket was visually apparent. The time required for the plant to recover from severe disturbance was approximately 2 hours.
The settling and dewatering characteristics of the sludge were very good throughout the experimental period.

Another problem also detrimental to effluent quality, was the problem of rising sludge. As it can be seen from table 3, only 50% of the initial total nitrogen was removed in the effluent, indicating that the rest was lost to the air as nitrogen gas due to denitrification.

Good effluent quality was always dependent on daily plant maintenance. A constant problem observed was the formation of fat balls in the aeration tank and the accumulation of grease and scum behind the baffles and weirs, which required daily surface skimming and brushing. The time spent daily for maintenance was approximately two hours.

Plant "B"

The second plant "B", consisted of two concentric tanks, the inner serving as a settling basin and the outer as an aeration tank, figure 4. Sludge was recycled by means of an air lift pump, while surplus sludge was wasted at a controlled rate and stored in a separate aerobic digesting tank. The plant was fed continuously by gravity flow.

Plant B which was of a more sophisticated design was monitored during the period of start-up. The start-up consisted simply of directing the wastewater into the plant and starting the aeration and sludge recycle pumps.

Fig. 4. Layout of plant "B"
Figure 5 shows the progress of the plant performance during this period. The time required for plant "B" to reach optimum performance was approximately 6 weeks. However the biological processes were greatly speeded up after the second to the third week. During this period no severe foaming of the plant was observed.

The general performance of this plant after the start up period was satisfactory. This plant had approximately the same maintenance requirements as plant "A".

CONCLUSIONS

Small plants can be used successfully in tourist areas for the treatment of sewage provided that care is taken in the design stage to minimize problems caused by surges of flow, inadequate control of air supply, and sludge recycle. The importance of correct maintenance schedules cannot be overstated. A daily maintenance routine should include cleaning of baffles and weirs, removal of fats and scum, checking of air flow and air lift pumps, measurement of MLSS and SVI. Regular removal of surplus sludge, at monthly intervals is essential for correct MLSS concentration. Finally all mechanical equipment should be checked and maintained properly at least once every year.