# ROTATING DISC SEWAGE TREATMENT SYSTEMS FOR SUBURBAN DEVELOPMENTS AND HIGH-DENSITY RESORTS OF HAWAI'I

by

Garry T. Griffith
Reginald H.F. Young
Michael J. Chun

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ROTATING DISC SEWAGE TREATMENT SYSTEMS FOR SUBURBAN DEVELOPMENTS AND HIGH DENSITY RESORTS OF HAWAI'I

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Principal Investigators: Michael J. Chun
Reginald H.F. Young
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## ABSTRACT

*Present experience with extended aeration plants in high density resort and suburban developments in Hawai'i has been generally unsatisfactory due to (1) inadequate system management resulting from insufficient manpower resources, and (2) high energy input required for aeration. A large scale pilot rotating disc unit was developed and field tested as a practical alternative to such extended aeration systems.*

*A literature review on rotating disc systems provided information on the basic theory of operation, pilot plant sizing and configuration, pilot system operation and data-gathering techniques, and hydraulic and organic loading rates. Laboratory operation of a bench-scale (6-in. diameter discs) unit led to the conclusion that movement of solids within the unit would be a major problem.*

*A large-scale pilot unit (2-ft diameter discs) was designed and fabricated to remove 85% BOD from 1000 gpd raw domestic sewage. The unit provides for primary settling, four-stage bio-disc biological treatment, final clarification and capacity for 50-day sludge storage and anaerobic digestion. The pilot unit has been installed and operated at the City and County of Honolulu's Pacific Palisades Wastewater Treatment Plant.*

*Results from loading rates of 2.2 and 4.0 gpd/ft$^2$ are encouraging with 80-90% BOD and better than 90% SS removed. Further evaluation of the data as well as performance studies at other loading rates are continuing.*

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# INTRODUCTION

## Rotating Disc Concepts

A literature review documenting pilot and full-scale rotating disc operations was performed to provide information concerning various aspects of the theory, design, operation and evaluation of the rotating disc treatment system. This data was evaluated and used in the design and field testing of a large scale pilot unit.

Several theoretical concepts of the rotating disc process can be incorporated into the design of a unit to increase its efficiency. Process removal efficiency is dependent upon producing contact between the biomass attached to the disc, and the organics, nutrients, and dissolved oxygen in the waste water. The greater the concentration of materials in the waste water, the greater the driving force for absorption of the material into the biomass (at concentration levels found in domestic waste water). This "effective" concentration can be increased over that found in a single disc reaction chamber, by separating the reaction chamber into sections or "stages" containing groups of discs (EPA 1974). As the amount of staging is increased, the amount of disc surface area providing an equivalent level of removal is decreased (EPA 1974). In addition, the volume of the disc reaction tank must provide sufficient detention time for absorption to occur (Grieves 1972).

The microorganisms (fixed to the rotating discs) which are most responsible for the removal of waste water contaminants are the filamentous and nonfilamentous bacteria (Antonie 1972; Tropey 1971). The bacterial species on the disc change through a multistage operation. Bacteria which utilize carbonaceous material are predominant on the discs in the initial stages where the concentration of carbonaceous material is relatively high (Antonie 1972, 1974*b*). Nitrifying bacteria are found attached to the discs in the later stages where the concentration of carbonaceous material is removed to a level where the nitrifiers can successfully compete for space on the disc surface (Weng and Wolf 1974; Tropey 1971).

The rotational movement of the disc through the waste water does more than just provide contact of the attached biomass with the substrate, nutrients and dissolved oxygen (DO) in the waste water. This rotation also provides for continued removal of "excess" biomass growth from the disc through the creation of a shear force (Antonie 1974*a*, 1974*b*). The sloughed biomass and other solids are kept in suspension through the agitation created by the disc movement. As the disc rotates through the atmosphere, oxygen dissolves into the waste water film adhering to the disc or biomass surface. The amount of oxygen, which dissolves into the waste water and which is thus available to the biomass, is directly proportional to the speed of rotation (Popel 1964). The net effect of increased rotational velocity is to increase the removal efficiency of the process (Popel 1964; Weng and Wolf 1974); however, the power requirements are also increased (EPA 1974).

## LITERATURE REVIEW

Pilot and full-scale rotating disc treatment systems of various sizes and configurations are documented in the literature. The characteristics of waste water to be treated and the degree of treatment desired dictate such treatment system parameters as: number of stages, speed of disc rotation, reaction tank volume, disc spacing, and pretreatment. Systems treating municipal waste water usually provide for two to four stages for secondary treatment (EPA 1971, 1974; Antonie et al. 1974*a*; Hao and Hendricks 1975), and up to 10 stages if further treatment is required (Weng and Wolf 1974; Federal Water Pollution Control Administration 1969; Tropey 1971). Disc rotation velocities of 1 fps (peripheral velocity) are common for initial stages (EPA 1974; Hao and Hendricks 1975), with lower velocities (0.5 fps) used in later stages (EPA 1974), as the oxygen demand in the waste water is reduced. Disc reaction tank volumes which provide 0.12 gal/ft$^2$ of disc (including disc volume), or 1-hr detention time, at a hydraulic loading rate of 0.06 m$^3$/day/m$^2$ (1.5 gpd/ft$^2$) of disc area are common (EPA 1971; Victor 1975). A wide range of hydraulic and organic loading rates have been reported for systems treating domestic waste water. Hydraulic loading rates ranging from 0.004 to 0.17 m$^3$/day/m$^2$ (0.09-4.1 gpd/ft$^2$) of disc surface area and organic loading rates of 0.20 to 6.0 lb BOD per day/1000 ft$^2$ of disc surface area are documented (EPA 1971, 1974; Weng and Wolf 1974; Tropey 1971; Antonie et al. 1974*a*; Hao and Hendricks 1975). Systems having discs aligned parallel to the direction of flow and perpendicular to direction of flow are both documented (EPA 1971; Tropey 1971; Antonie et al. 1974*a*; Hao and Hendricks 1975; Victor 1975). Contouring of the disc reaction tank to the shape of the discs is generally used (Tropey 1971; Hao and Hendricks 1975). This provides for better mixing of the waste water within each stage. Documented disc materials (Tropey 1971; Antonie et al. 1974*a*; Victor 1975) include aluminum, polystyrene, polyethylene, and Plexiglas, to name a few. The basic properties desired of a disc material are that they have a low density and be rigid in shape. Disc diameters range from 6 in. to 12 ft with spacing between discs ranging from 3/8 to 3/4 in. (EPA 1971, 1974; Hao and Hendricks 1975; Victor 1975). Depth of immersion of the disc into the waste water is generally between 40 to 50% of the disc diameter, the only criterion being that all the surface of the disc becomes wetted (EPA 1971, 1974; Weng and Wolf 1974).

Enclosure of the disc sections has been reported to be required for various reasons, the basic reason being to protect the biomass from rain, wind, cold temperature and direct sunlight (Antonie 1974*b*). In addition, some installations have been covered to reduce the amount of odor emitted from the disc process (Antonie 1974*b*).

Domestic waste water usually requires pretreatment in the form of solids removal through settling and flow equalization. However, pH adjustment to within the range 6.5 to 9.5 may also be required.

Final solids settling and removal facilities are generally incorporated into the total treatment scheme. Biomass generation in the order of 0.4 lb dry solids/lb biochemical oxygen demand (BOD) removal has been reported (EPA 1971). Systems used to transport the settled biological solids to storage and treatment facilities include screw conveyors, scraper/bucket schemes and pumps (EPA 1971, 1974; FWPCA 1969; Victor 1975).

Two systems of pilot unit operations have been reported in the literature. The more widely used technique is operation under steady-state conditions (EPA 1971, 1974; Weng and Wolf 1974; FWPCA 1969; Tropey 1971; Hao and Hendricks 1975). A steady-state operation can exist through application of a constant flow or hydraulic loading rate (expressed as gpd/$ft^2$ of disc area) to a given system.

Evaluation of a rotating disc treatment system to determine the optimum rate of operation can be accomplished for a system under steady-state operation. The individual aspects of a system, such as the number stages, rotation velocity, disc reaction tank volume, can be optimized through varying a parameter while operating at one steady-state flow rate (EPA 1971, 1974; Weng and Wolf 1974; Tropey 1971). Another means of steady-state evaluation is also available. In this method, the rotating disc system is operated at a range of steady-state flow rates to determine the optimum flow rate or loading at which the desired level of treatment is achieved (EPA 1971; FWPCA 1969; Hao and Hendricks 1975). Both evaluation methods depend upon the sampling and analysis of various waste water parameters along the path of the treatment scheme to determine net removals and accumulations.

Pilot system operations under nonsteady-state conditions have also been reported (Antonie 1974*a*, 1970). Cyclic and intermittant flows, and hydraulic and organic surge situations have been studied to determine rotating disc treatment system response. This response is usually compared to system performance under steady state conditions. Evaluations may conclude that nonsteady-state flow conditions alter system performance to below desired treatment levels necessitating system alterations or further pretreatment.

## Bench-Scale Pilot Test

Laboratory testing of a bench scale (6-in. diam disc) pilot system was performed following the literature study and prior to the design of the large-scale pilot system. The bench scale system had been previously constructed and operated by Victor in 1975 as a Master's thesis project at the University of Hawaii. The laboratory operation of the unit confirmed the evaluation made by Victor in his thesis. The major problem area in the design was the poor solids conveyance facilities provided. This was basically due to the large sloughed solids size compared to the size of openings in the screw conveyor used to transport settled secondary sludge to the primary clarifier for digestion. Such problems could be avoided in a larger scale system.

## Pilot-Test Design

A large-scale pilot rotating disc treatment system was designed and constructed for the purpose of treating domestic sewage under field conditions in Hawai'i. The unit was designed to remove approximately 85% of the $BOD_5$ from a design flow of 1000 gpd. This approximation was based on removal rates documented in the literature.

The pilot unit includes primary settling, four-stage rotating disc treatment system, and final clarification with sludge storage and anaerobic sludge digestion. The primary clarifier is designed to provide 1-1/2 hr detention time at the design flow. At this loading, practically all of the settleable solids and about 50% of the suspended solids present in the screened, degritted domestic waste water entering the clarifier, are expected to settle out of the waste water. The clarifier tank is an Imhoff tank system and is housed inside the sludge storage area, as shown in Figure 1. This configuration allows for continous removal of the settled solids from the primary clarifier through gravity flow. The clarifier effluent discharges into the rotating disc system through a 1-1/2-in. hose located 6 in. below the surface level.

The rotating disc treatment system consists of two two-stage units, connected in series, positioned in a parallel configuration (Fig. 2). The waste water flow through the system is in a horseshoe-shaped pattern, with the system effluent discharging into the final clarifier, aligned adjacent to the sludge storage basin. Each of the four stages in the rotating disc system contains eleven, 1.8 ft diam by 1/8 in. thick, high-density polyethylene discs. The design hydraulic loading of 4.0 gpd/ft$^2$ is produced on the near 225 ft$^2$ of disc area. The discs are mounted on 3/4-in. centers by use of plastic spacers located on the shaft and at six points along the periphery. The central stainless steel shaft extends on either end of the disc assembly and rests in self-aligning sealed bearings. The two disc assemblies are placed, with shafts horizontal, into half-formed cylindrical stainless steel tanks so that about 40% of the disc diameter is submerged into the waste water which passes through the tank perpendicular to discs. The contour of the half-formed cylindrical tank containing the waste water is such that a space of about 1/2 in. is provided between the periphery of the discs and the inside surface of the tank. Both of the two parallel tanks are divided in the center by a plate creating the two individual stages. A 1-in. diam hole located about mid-waste water depth in the divider plates, allow the waste water to move from connecting stages through the rotating disc system. The total waste water volume available in the rotating disc system provides about 40 min of contact time at the design flow. The two parallel shafts are equipped with gears and are connected to a third shaft by chain. A belt drive system connects the third shaft to a variable speed 1/4 hp d-c motor. With this arrangement, the two disc sys-

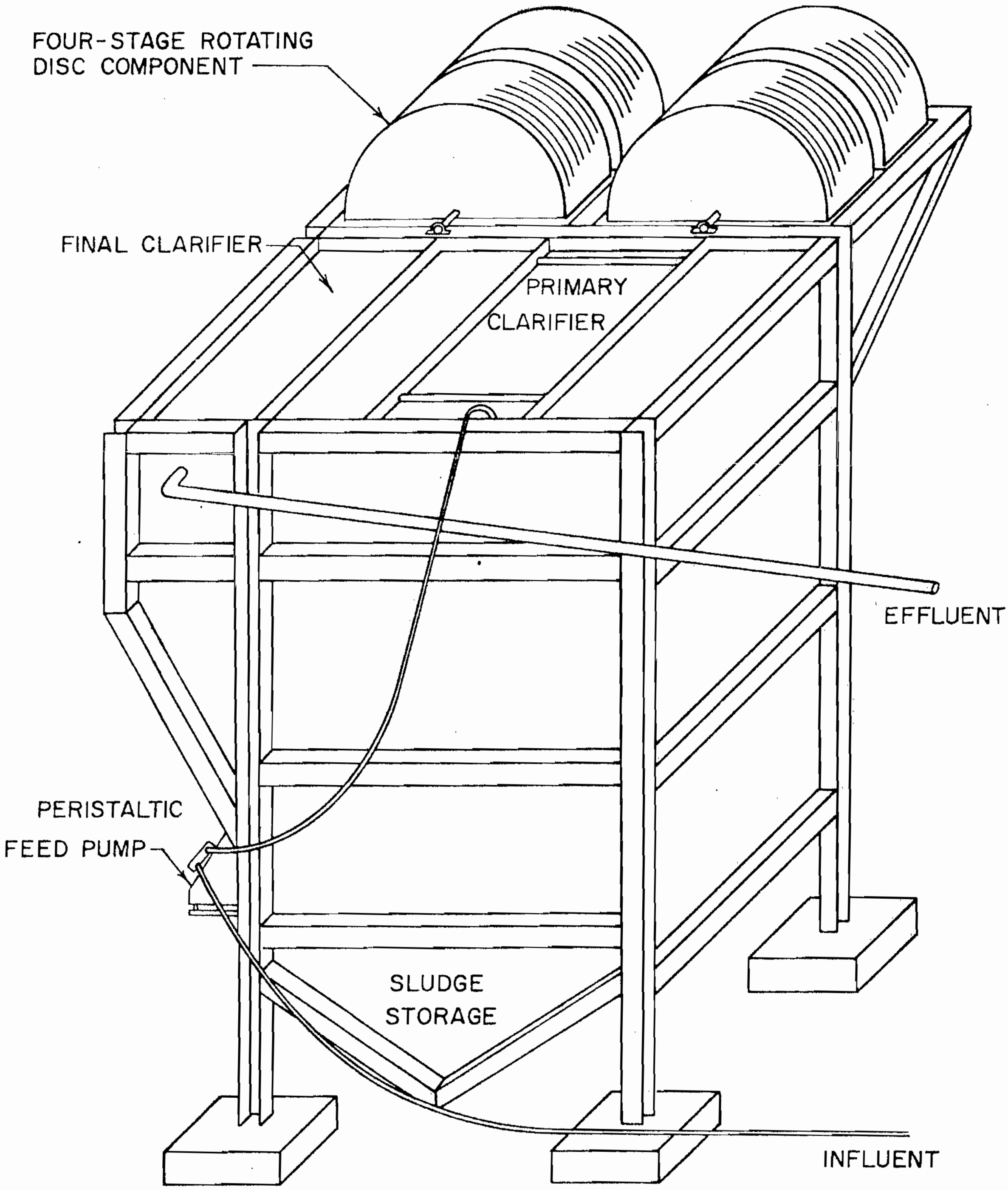


FIGURE 1. ROTATING DISC TEST UNIT

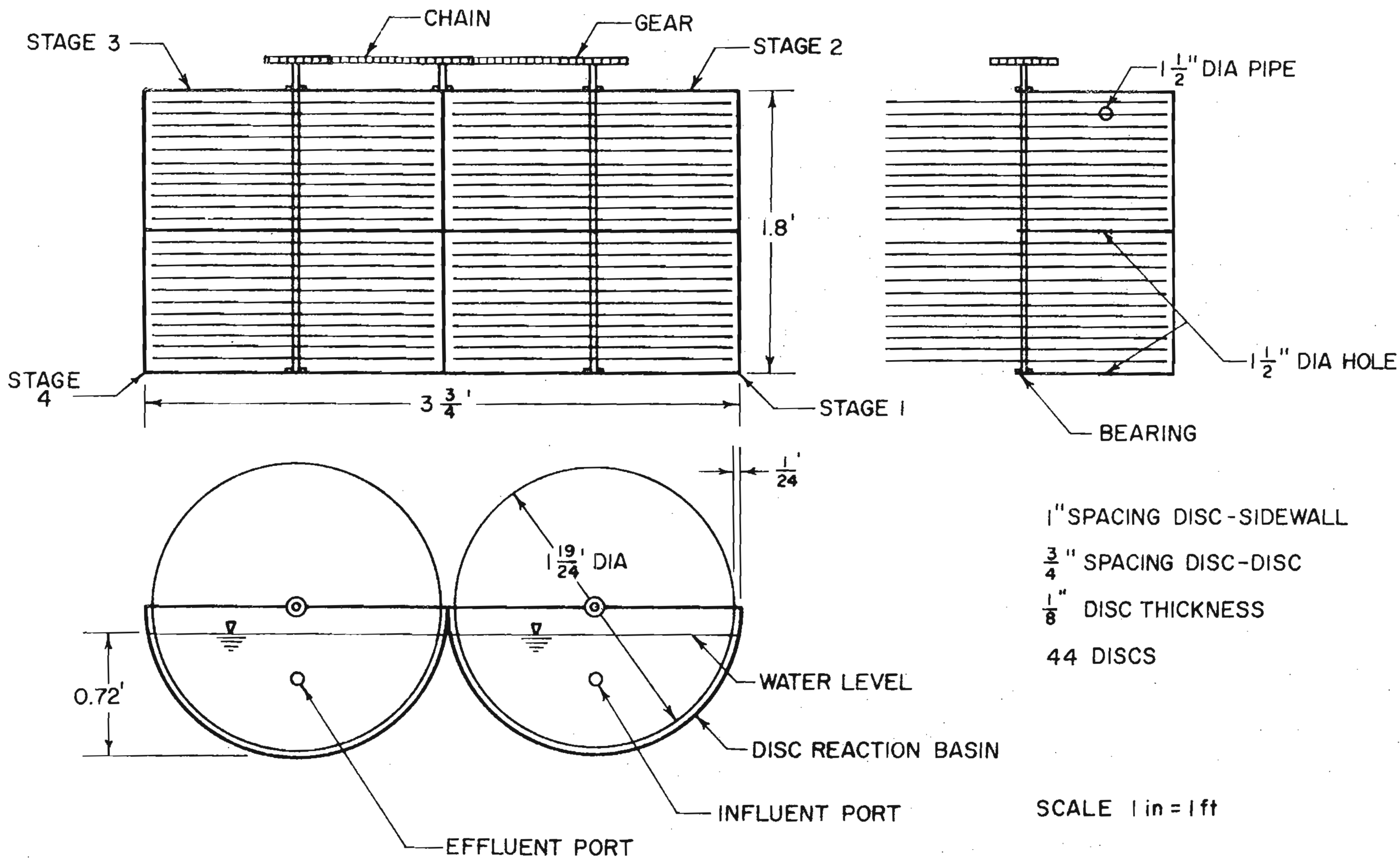


FIGURE 2. SCHEMATIC OF PILOT ROTATING DISC TREATMENT SECTION

tems can be rotated at equal or different velocities, through use of different size gears.

The fourth stage disc effluent enters the final clarifier through a 1-1/2-in. diam hose located at mid-waste water depth in the disc section. The rectangular-shaped final clarifier has a capacity of 62 gal and provides 1-1/2 hr detention during design flow. Under this loading, essentially all of the biological solids generated in the rotating disc process are expected to be removed, producing a final effluent quality which meets secondary standards. The final effluent discharges from the final clarifier through a 3-in. diam circular weir.

Initially, the final clarifier and sludge storage facility were hydraulically connected through an 8-in. wide opening, running the length of the clarifier. It was thought that the solids entering the final clarifier would settle to the clarifier basin bottom and then continue into the sludge storage basin due to the extreme slope of the clarifier basin. This configuration was abandoned when "short-circuiting" of raw waste water into the final clarifier occurred. The final clarifier was then sealed off from the primary clarifier and sludge storage basin through means of a rigid stainless steel plate bordered with high-density neoprene rubber. Daily removal of the plate to allow for settling of the solids into the storage basin was required. Complete sealing of the final clarifier from the sludge storage basin was never certain, and led finally to the complete bypass of the final clarifier basin through connection of the clarifier influent and effluent ports by means of a 1-1/2-in. diam PVC (polyvinyl chloride) pipe. Clarification of the biodisc effluent was performed on a batch basis following sample collection.

## Field Test of Pilot Unit

Field operation of the large-scale pilot unit is presently being carried out at the Pacific Palisades Municipal Wastewater Treatment Facility. This field operation includes two work areas: (1) steady-state operation at four or five specific hydraulic loading conditions, and (2) optimization of the process for BOD and solids removal efficiency and determination of the treatment limitations of the unit using data from the initial operating period. Each of the steady-state trials are to be approximately one month in duration, with one week proceeding each trial for stabilization of the system.

The pilot unit is installed adjacent to the aerated grit chamber at the City and County of Honolulu, Division of Sewers Pacific Palisades Facility. The entire unit is covered with a wooden roof with the disc area enclosed on the three outside surfaces by wooden panels.

An initial 4-mo period (March-June 1977) of operation was required for process debugging and modifications. During this time influent feed line location was established in the aerated grit chamber. A variable speed, peristaltic type pump was selected to supply the influent to the pilot unit. A two-stage screen system was developed for the feed line intake to reduce line and pump clogging. The modifications listed above, for the final clarifier were also completed during this period.

Following the debugging period, steady-state operation was initiated at a hydraulic loading rate of 2.25 gpd/ft$^2$ of disc area. This initial loading rate was maintained during 22 July to 23 August followed by operation at 4.07 gpd/ft$^2$ until 15 October. Disc rotation velocity was maintained at 10.5 rpm or 1.0 fps peripheral velocity during this period.

The pilot unit is presently operated at a hydraulic loading of 6.67 gpd/ft$^2$ of disc area. Upon completion, at least one additional steady-state trial will be performed.

Waste water samples taken during the trial periods were collected on a grab basis at the following four sampling locations: the raw waste water influent line, primary clarifier effluent port, second stage rotating disc effluent, and fourth stage rotating disc effluent. Laboratory analyses were performed as listed in Table 1. Procedures employed in these analyses were in accordance with *Standard Methods for the Examination of Water and Wastewater* (APHA, AWWA, WPCF 1975). All analyses performed on samples collected from the rotating disc second and fourth stage effluents (except dissolved oxygen, pH temperature, and suspended solids) were done on sample supernatant following 3/4 to 1 hr of settling.

## RESULTS

The data collected during the two steady-state operations is summarized in Tables 2 and 3. All values listed are arithmetic average values.

Analysis of treatment efficiencies and comparison between the operation

TABLE 1. SAMPLING AND ANALYSIS PROGRAM

| PARAMETER | SAMPLING POINTS | FREQUENCY (per wk) |
|---|---|---|
| Temperature | 2,3 | 5 |
| pH | 2,3,4 | 5 |
| Dissolved Oxygen (DO) | 2,3,4 | 5 |
| Biochemical Oxygen Demand ($BOD_5$) | 1,2,3,4 | 1 |
| Chemical Oxygen Demand (COD) | 1,2,3,4 | 1 |
| Total Organic Carbon (TOC) | 1,2,3,4 | 5 |
| Total Suspended Solids (Total SS) | 1,2,3,4 | 2 |
| Total Volatile Suspended Solids (Total VSS) | 1,2,3,4 | 2 |
| Total Kjeldahl Nitrogen (TKN) | 2,3,4 | 2 |
| Nitrite Nitrogen ($NO_2^-N$) | 2,3,4 | 2 |
| Nitrate Nitrogen ($NO_3^-N$) | 2,3,4 | 2 |
| Total Phophorus | 2,3,4 | 2 |

TABLE 2. RESULTS FROM OPERATION OF ROTATING DISC TREATMENT UNIT AT LOADING RATE OF 2.25 gpd/ft$^2$, 22 JULY TO 23 AUGUST 1977

| PARAMETER | SAMPLE LOCATION | | | | |
|---|---|---|---|---|---|
| | Raw Infl. | Rotating Disc Infl. | Rotating Disc 2d Stage Effl. | Rotating Disc 4th Stage Effl. | Final Effl. |
| Temp. (°C) | -- | 27.4 | 23.9 | -- | -- |
| pH (units) | -- | 6.8 | 7.3 | 7.0 | -- |
| DO (mg/ℓ) | -- | 0.1 | 3.8 | 4.1 | -- |
| $BOD_5$ (mg/ℓ) | 200 | 145 | 26 | 34 | -- |
| (% removal) | -- | 28 | 87 | 83 | -- |
| COD (mg/ℓ) | 475 | 295 | 62 | 46 | -- |
| (% removal) | -- | 38 | 87 | 90 | -- |
| TOC (mg/ℓ) | 129 | 115 | 28 | 18 | -- |
| (% removal) | -- | 11 | 78 | 86 | -- |
| SS (mg/ℓ) | 202 | 149 | 57 | 62 | 10 |
| (% removal) | -- | 26 | 72 | 69 | 95 |
| Total N (mg/ℓ) | -- | 37 | 28 | 29 | -- |
| (% removal) | -- | -- | 24 | 22 | -- |
| TKN (mg/ℓ) | -- | 33 | 26 | 14 | -- |
| (% removal) | -- | -- | 21 | 58 | -- |
| Nitrogen, $NO_2^-N$ (mg/ℓ) | -- | 0.0 | 1.0 | 4.3 | -- |
| $NO_3^-N$ (mg/ℓ) | -- | 0.0 | 1.4 | 9.4 | -- |
| Total P (mg/ℓ) | -- | 7.1 | 4.8 | 3.7 | -- |
| (% removal) | -- | -- | 32 | 48 | -- |

NOTE: Arithmetic averages of biweekly samples.

TABLE 3. RESULTS FROM OPERATION OF ROTATING DISC TREATMENT UNIT AT LOADING RATE OF 4.07 gpd/ft$^2$, 24 AUGUST TO 15 OCTOBER 1977

| PARAMETER | SAMPLE LOCATION | | | | |
|---|---|---|---|---|---|
| | Raw Infl. | Rotating Disc Infl. | Rotating Disc 2d Stage Effl. | Rotating Disc 4th Stage Effl. | Final Effl. |
| Temp. (°C) | -- | 28.1 | 27.0 | -- | -- |
| pH (units) | -- | 6.7 | 7.2 | 7.2 | -- |
| DO (mg/ℓ) | -- | 0.1 | 1.8 | 3.5 | -- |
| $BOD_5$ (mg/ℓ) | 182 | 128 | 33 | 17 | -- |
| (% removal) | -- | 30 | 82 | 91 | -- |
| COD (mg/ℓ) | 495 | 260 | 88 | 47 | -- |
| (% removal) | -- | 47 | 82 | 91 | -- |
| TOC (mg/ℓ) | 117 | 113 | 36.3 | 22.0 | -- |
| (% removal) | -- | 3 | 69 | 81 | -- |
| SS (mg/ℓ) | 160 | 125 | 71 | 62 | 11 |
| (% removal) | -- | 22 | 56 | 61 | 93 |
| Total N (mg/ℓ) | -- | 41 | 32 | 34 | -- |
| (% removal) | -- | -- | 22 | 17 | -- |
| TKN (mg/ℓ) | -- | 41 | 32 | 31 | -- |
| (% removal) | -- | -- | 22 | 24 | -- |
| Nitrogen, $NO_2^-N$ (mg/ℓ) | -- | 0.0 | 0.0 | 2.8 | -- |
| $NO_3^-N$ (mg/ℓ) | -- | 0.0 | 0.0 | 0.4 | -- |
| Total P (mg/ℓ) | -- | 8.0 | 6.9 | 6.9 | -- |
| (% removal) | -- | -- | 14 | 14 | -- |

NOTE: Arithmetic averages of biweekly samples.

during the two steady-state operations are discussed in the following paragraphs.

The temperature of the waste water decreases to approach the ambient temperature with increased detention time in the rotating disc section.

The pH of the waste water remains at a relatively constant level throughout the treatment system. The dissolved oxygen content increases, from zero in the primary clarifier, to 3 to 4 mg/ℓ in the disc unit. The residual oxygen levels measured in the second and fourth stage effluents reflect the organic loading applied.

Overall removal of carbonaceous material (expressed as $BOD_5$, COD, and TOC) is near equal in the two steady-state operations. However, the location within the rotating disc system, where this removal occurs is significantly different between the two operations. Under the 2.25 gpd/ft$^2$ loading, 76% (of the total 84% total organic carbon [TOC] removal by the rotating disc system only) was removed during the first and second stages, as compared to only 68% TOC removal (of a total 81% TOC removal) during the first and second stages under the higher, 4.07 gpd/ft$^2$ loading. The removals achieved in $BOD_5$ and COD show similar patterns. The relative density and appearance of the biological growth on the discs of the four treatment stages is consistent with the stated removals. The dense, filamentous growth associated with carbonaceous removal appeared only mid-way through the second stage during the first steady-state trial, while the characteristic growth continued through the third stage during the second trial. The $BOD_5$ levels measured in the second and fourth stage effluent are somewhat inconsistent (higher) when compared to corresponding TOC and COD values. It is thought that Nitrobacter and Nitrosomonas (bacteria capable of oxidizing ammonia to nitrite and nitrate, respectively) are present in the waste water in significant numbers to produce a measurable oxygen demand during the $BOD_5$ test period.

Solids removal characteristics were comparable during the two steady-state operations. Suspended solids removals reported for the primary clarifier (26% and 22%) are approximately half of the design removal anticipated. Resuspension of settled solids, which stick to the clarifier floor and thus do not settle through the Imhoff bottom of the clarifier into the sludge storage basin, is thought to be responsible for the low solids removals reported. Scraping of the clarifier floor on a daily basis may be required. The solids remaining in the waste water following the rotating disc unit are observed to be comprised to a large extent of biomass sloughed from the disc surfaces. These solids are filamentous in nature, but settle readily under quiescent conditions (80-85% removal over a settling period of 45 to 60 min). Removals to levels of less than 10 mg/ℓ can be achieved under proper conditions.

The organic and ammonia nitrogen removals (expressed as total Kjeldahl nitrogen, TKN) during the first steady-state operation (2.25 gpd/$ft^2$) were about twice the removals measured during the second trial (4.07 gpd/$ft^2$). In addition, significantly more nitrite and nitrate nitrogen ($NO_2^-$ and $NO_3^-N$) was measured in the disc fourth state effluent under the initial phase of operation (4.3 mg/ℓ $NO_2^-N$ and 9.4 mg/ℓ $NO_3^-N$ compared to 2.8 mg/ℓ $NO_2^-N$ and 0.4 mg/ℓ $NO_3^-N$, respectively). This observation is consistent with the relative disc area supporting carbonaceous removing biomass described for the two trials.

Phosphorous removals of 50% were reported during the first trial compared to only 14% during the second.

The research results will be used to determine the practicality of using a rotating disc treatment unit as an alternative to the extended aeration process in providing secondary treatment of domestic waste water from Hawaiian communities. Of special significance, should adequate treatment effectiveness be demonstrated, are the low energy and operational skill requirements characteristic of the process. Criteria for the design and operation of rotating disc units in tropical climates will also be provided and, thus, will be useful to consultants, operators, and regulatory officials.

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