A method for treating wastewater comprising the steps of subjecting the wastewater to an anaerobic settling step for at least 6 hours and passing the liquid effluent from the anaerobic settling step through a filter cell in an upflow manner, wherein the effluent is subjected first to the action of anaerobic and facultative microorganisms and then to the action of aerobic microorganisms and the roots of at least one vascular aquatic plant.

17 Claims, 3 Drawing Figures
METHOD FOR TREATING WASTEWATER USING MICROORGANISMS AND VASCULAR AQUATIC PLANTS

ORIGIN OF THE INVENTION

The invention described herein was made by an employee of the U.S. Government and may be manufactured or used by or for the Government for governmental purposes without payment of any royalties thereon or therefor.

TECHNICAL FIELD

This invention relates to a process for the purification of wastewater for recycling or discharge to groundwater sources.

BACKGROUND ART

Recent wastewater regulations promulgated by the U.S. Environmental Protection Agency (EPA) require secondary treatment as the minimum acceptable level of treatment prior to discharge of surface waters. Increases in industrial wastes discharged into domestic sewage treatment plants has also increased significantly the need for improved wastewater treatment methods to remove hazardous chemicals and to meet the secondary treatment standards.

In many parts of the country, the available supply of fresh groundwater has become contaminated with toxic chemicals or the groundwater table has been drastically lowered by effects of inadequate rainfall. In these areas, advanced wastewater treatment and reuse of wastewater will become a necessity in the foreseeable future.

Seidel has proposed, in U.S. Pat. No. 3,770,623, incorporated by reference, a system for purifying wastewaters polluted with oily pollutants, coarse suspended materials, slime, colloidal material, dissolved inorganic compounds and/or pathogenic organisms by a three-stage process, in the first stage of which gravitational separation of floatable oily pollutants and heavy sediment is accomplished, in the second stage of which the remaining aqueous material is treated in filtration beds containing plants having nodes to remove slime and colloidal material by filtration and in the third stage of which the effluent from the second stage is passed into a bed containing plants which can use the dissolved impurities as nutrients. For waters heavily contaminated with pathogens, plants with bacterial nodules will be used in the second or third stages.

Serling et al. have proposed, in U.S. Pat. No. 4,169,050, to treat wastewaters using pollution-consuming, floating aquatic plants which have high surface area, submerged, activated bio-web substrates of high fixed bacterial film area and activity.

Carothers has proposed (U.S. Pat. No. 3,728,254) a process for recycling waste products, which utilizes conventional activated sludge aeration tanks and a "trickling filter effect" to enhance aeration and bacterial growth in the aeration tank.

Wolverton, "New Hybrid Wastewater Treatment Systems Using Anaerobic Microorganisms and Reeds," presented at a Seminar on Innovative Wastewater Treatment Technology, Louisville, Ky. (Apr. 23, 1981), incorporated herein by reference, has reviewed the art with respect to the separate uses of anaerobic microorganisms and vascular aquatic plants for the treatment of wastewaters and has proposed an improved treatment system combining the foregoing to treat wastewaters after a preparatory anaerobic settling step.

It will be apparent that higher standards required for recycle or discharge of wastewaters require the development of improved wastewater treatment technology. Present economic conditions in the United States make highly desirable the development of technology which consumes less energy and is more cost effective and more efficient than wastewater treatment methods presently available.

It is the object of this invention to provide a simple and effective method for purifying wastewaters, which method is low in energy requirements and economical in operation.

DISCLOSURE OF THE INVENTION

This invention relates to a method for purification of wastewater comprising the steps of subjecting the wastewater to an anaerobic settling step for at least 6 hours and passing the liquid effluent from the anaerobic settling step through a filter cell in an upflow manner, wherein the effluent is subjected first to the action of anaerobic and facultative microorganisms and then to aerobic microorganisms and the roots of at least one vascular aquatic plant.

In another aspect, this invention relates to a system for treating wastewater, comprising a preliminary vessel in which is carried anaerobic settling and a hybrid filter for the effluent from the preliminary vessel, the hybrid filter having a lower portion inoculated on the surface thereof with anaerobic and facultative microorganisms and having an upper portion the surface of which is inoculated with aerobic microorganisms and in which is growing vascular aquatic plants, wherein means for transferring effluent from the preliminary vessel feed the effluent upwardly through the lower portion of the hybrid filter toward the upper part of the hybrid filter.

Preliminary treatment of wastewaters (shown as 1 in FIG. 1) in accordance with the present invention can be carried out in any sludge collecting and digesting chamber, for example, a simple septic tank, a covered anaerobic lagoon, a primary settling/digestion tank, or an Imhoff tank arrangement, shown as 2 in FIG. 1. The sludge collecting chamber will normally be provided with means for venting carbon dioxide, methane and other gaseous products from the system and may be provided with means for the removal of collected sludge. In the practice of this invention, a minimum of 6 hours treatment in the sludge collecting chamber will normally be required. However, longer residence times, preferably greater than 12 hours, are preferred. Although there is no theoretical upper limit on the residence time in the sludge collecting chamber, practical considerations, including limitations on the size and number of chambers needed to process a given volume of sewage or other wastewater, will normally favor selecting the shortest residence time permitting settling of 30-50% of the total suspended solids (TSS) and removal of about the same amount of 5-day biochemical oxygen demand (BOD5).

In the second step of the process, supernatant liquid from the sludge collecting chamber (anaerobic settling tank, designated '2' of FIG. 1) is treated in a hybrid filter system (3' in FIG. 1) consisting of a filter bed to which is fixed a film of anaerobic, facultative and aerobic microorganisms and in which is growing one or more vascular aquatic plants. The filter bed can be con-
structured from rocks of varying sizes or from vinyl core media. In either case, the top layer of the filter bed is preferably pea gravel (0.25-1.5 cm particles shown as 11 in FIG. 2) to serve as a support for the vascular aquatic plants, a sealer, and a final aerobic microbial surface area for final polishing and oxidation of odorous volatile sulfides to non-volatile sulfates. When rocks are used to construct the filter bed, an intermediate layer of rocks (2.5-7.5 cm, 12 in FIG. 2) and a base layer of 7.5-15 cm rocks (shown as 13 in FIG. 2) is preferably employed. Vinyl core media are available commercially. These materials have been used in trickling filter type systems and can contain up to 214 square meters of surface area per cubic meter of media. This is approximately four times that of a rock filter, because rocks create 40%-50% voids while vinyl core media create a 96% or less voids. Vinyl cores are lightweight and easier to transport and install than rocks, but vinyl cores cost more per system than rock. It will be understood that the choice of core material will be based on cost considerations and the relative convenience of the two types of filter bed constructions.


The anaerobic filter provides a high surface area for the attachment and growth of bacterial and fungal with growth patterns considered slow relative to those of aerobic microorganisms associated with waste treatment. Because of the filter, large R's (mean cell residence times) of approximately 100 days can be achieved with short hydraulic retention times. In the bottom and middle zones of the filter, a two-step decomposition of the organic matter takes place.

The first step occurs (21 in FIG. 2) mostly with facultative or obligate anaerobic bacteria, which hydrolyze and convert complex organic compounds into simple organic acids such as acetic or propionic acid. Examples of microorganisms which normally accomplish this first step are Clostridium spp., Peptococcus anaerobus, Bifidobacterium spp., Desulphoribio spp., Corynebacterium spp., Lactobacillus, Actinomyces, Staphylococcus, and Escherichia coli.

The second step (22 in FIG. 2) involves the conversion of the simple organic acids into methane, carbon dioxide, and trace amounts of hydrogen and hydrogen sulfide. The bacteria which accomplish this final conversion are strict anaerobes, the majority of which belong to the following genera: Methanobacterium, Methanobacillus, Methanococcus, and Methanosarcina.

In the top zone (23 in FIG. 2) aerobic microorganisms, which aid in the oxidation of odoriferous sulfides to sulfates and facultative bacteria performing aerobic processes exist. Facultative bacteria normally associ-
below ground plant mass. The ability of reeds to develop aquatic roots and absorb nutrients and other elements directly from water is advantageous and is an important reason why this plant is preferred for wastewater treatment.

The phosphorus removal potential of reeds is 10-80 kg/ha for above-ground plant mass and 38-74 kg/ha for below-ground plant mass. Reeds are salt-resistant plants, seldom taking up sodium. The sodium removal potential of the common reed is 4.6-49.3 kg/ha.

Reeds have an inherently high transpiration rate, but a low unit mass of leaves moderates the overall transpiration rate of reed beds. In Poland the transpiration of Phragmites communis has been measured as 30-100 cm/yr.

Biomass production reported for reeds in the U.S. range from 6,540 to 39,990 kg/ha. Combined above ground and below ground production in hydropic culture ranges from 8,230 to 74,010 kg/ha/yr in 1- to 3-year old cultures.

Rush appear about or nearly as effective as reeds in the context of this invention.

A prototype small hybrid wastewater treatment system consisting of a settling tank in series with an anaerobic filter-reeed (Phragmites communis) treatment cell (1', 2', 3' in FIG. 1) was evaluated and compared with a similar plant-free system (1, 2, 3 in FIG. 1). Combination of anaerobic filters (attached film filters) and vascular aquatic plants downstream of the component of the system. The plant-free system reduced the BOD5 from 93 to 25 mg/l in 6 hours, compared to a reduction of 103 to 9 mg/l in the anaerobic filter-reeed system in the same length of time. The BOD5 and TSS after 24 hours in each component of the plant-free systems were reduced from 93 to 17 mg/l and 47 to 17 mg/l, respectively. Under the same conditions, the hybrid system reduced the BOD5 from 103 to 4 mg/l and the TSS from 82 to 3 mg/l.

In the hybrid system, the contaminants of most concern in wastewater treatment were reduced after 24 hours in each component as follows: ammonia nitrogen (NH$_3$-N) from 10.8 to 0.8 mg/l, total Kjeldahl nitrogen (TKN) from 16.4 to 3.4 mg/l, and total phosphorus (TP) from 4.7 to 2.1 mg/l.

Use of an anaerobic settling tank alone reduced the TSS during two different sets of experiments from 144 to 34 mg/l and 85 to 26 mg/l following 6 hours' settling time.

It will be appreciated that the EPA standard for each of BOD5 and TSS following secondary treatment is 30 mg/l. Use of the method set forth herein provides a feasible, simple, economically competitive way of meeting, if not exceeding, these standards.

The hybrid reed-rock filter system uses a combination of anaerobic, facultative and aerobic microorganisms, along with the roots of vascular aquatic plants, to treat wastewater and remove minerals. In the lower anaerobic portion of the filter, complex organic contaminants are converted to carbon dioxide, methane, and simple organics. Odorous volatile sulfides are removed by the plant roots or oxidized and/or assimilated by the aerobic microorganisms near the surface of the filter component. The combination of microorganisms and vascular aquatic plants permits the removal of phosphorus, ammonia and potassium impurities, not normally removed by treatment with microorganisms alone.

This system disclosed herein will be cost effective in both installation and operation and more versatile than presently available systems. The system disclosed can be installed in modules. Expansion can be accomplished by adding more modules. Advanced wastewater treatment can be provided by including additional modules in the system.

The process and system disclosed herein does not, once installed, require highly trained personnel for operation. The system can be installed without having any moving parts. Once wastewater enters the system, gravity flow can complete the process.

**BRIEF DESCRIPTION OF THE DRAWINGS**

In FIG. 1 is shown a schematic comparison of the process of this invention with a process using no treatment with plants.

In FIG. 2 is shown a preferred configuration for the anaerobic filter reed cell used in the process of this invention.

In FIG. 3 is shown a top view of a plastic anaerobic filter which can be used.

**DESCRIPTION OF MOST PREFERRED EMBODIMENT**

In a most preferred case, the anaerobic, facultative and aerobic organisms on the filter bed are established to a high mean cell residence time, $t_o$, of approximately 100 days and the vascular aquatic plant is reed or rush.

Without further elaboration, it is believed that one skilled in the art can, using the preceding description, utilize the present invention to its fullest extent. The following preferred specific embodiments are, therefore, to be construed as merely illustrative and not limitative of the remainder of the disclosure in any way whatsoever. In the following Examples, the temperatures are set forth uncorrected in degrees Celsius. Unless otherwise indicated, all parts and percentages are by weight.

**EXAMPLE 1**

The anaerobic settling step was done in plastic-covered containers (113 liter capacity), into which raw sewage was pumped and allowed to settle under anaerobic conditions for 6 or 24 hours.

The supernatant liquid from the settling tanks was pumped into the bottom of a metal trough 50.5 cm wide, 30.5 cm deep and 298 cm long, which was filled to a height of 16 cm with 2.5-7.5 cm diameter railroad rocks, over which there was a layer (5 cm deep) of 0.25-1.3 cm diameter pea gravel. Some troughs contained reeds (Phragmites communis), grown on the surface of the rock filters. The wastewater retention time, also under anaerobic conditions, in these troughs was 6 or 24 hours. The rock filter was "matured" by several weeks of biweekly additions of anaerobic supernatant from anaerobic settling tanks to the filters. This process of maturation allowed a balanced community of anaerobic, aerobic, and facultative microorganisms of the species described above to become established at high concentrations on the rock surfaces. Therefore, high mean cell residence times, $t_o$, of approximately 100 days could be maintained with short hydraulic retention times of 24 hours or less.

The experimental set up, with or without treatment by reeds in the second stage, is as shown in FIG. 1. Raw sewage from NSTL (National Space Technology Laboratories, NSTL Station, Miss. 39539) was used...
as the source of sewage for all experiments. The sewage was analyzed for 5-day biochemical oxygen demand (BOD₅), total suspended solids (TSS), total Kjeldahl nitrogen (TKN), total phosphorus (TP) and ammonia nitrogen (NH₃—N) before and after treatment.

The initial and final volumes of wastewater were measured to determine water loss from the rock troughs by evaporation and from the rock-reed troughs by evapotranspiration. Minimum and maximum daily greenhouse temperatures averaged 19°C and 35°C, respectively.

Data given in the table below represent an average of at least 6 or more separate samples.

In one series of experiments (Series A), BOD₅ was reduced from about 95 mg/l to 82 mg/l by 24 hr in the anaerobic settling tank. Further reduction to 35 and 13 mg/l was accomplished by treatment for 6 and 24 hr, respectively, in a plant-free rock filter.

As shown by the results of Series D, use of the reed-containing rock filters in series with anaerobic settling for 24 hr, gave reduction of BOD₅ to 9 and 4 mg/l after 6 and 24 hr, respectively in the filter. The effluents obtained have contaminant levels significantly below those of effluents obtained using plant-free filters.

The experiments in Series E show that concentrations of Kjeldahl nitrogen, ammonia nitrogen and phosphorus were reduced insignificantly, if at all, by a combination of anaerobic settling and treatment for 24 hr in a plant-free rock filter. However, marked reduction of the concentrations of these impurities was demonstrated (Series F) by a combination of 24-hours' anaerobic settling and 24 hours' residence in a rock-filter planted with reeds.

The preceding examples can be repeated with similar success by substituting the generically or specifically described reactants and/or operating conditions of this invention for those used in the preceding examples.

From the foregoing description, one skilled in the art can easily ascertain the essential characteristics of this invention and, without departing from the spirit and scope thereof, can make various changes and modifications of the invention to adapt it to various usages and conditions.
organisms disposed on a particulate media in a lower portion of said bed and then to the action of aerobic microorganisms disposed on a particulate media in an upper portion of said bed and the roots of at least one vascular aquatic plant.

2. The method of claim 1, wherein the vascular aquatic plant is a reed.

3. The method of claim 1, wherein the vascular aquatic plant is a rush.

4. The method of claim 1, wherein the filter bed comprises rocks and has a top layer of pea gravel, a middle layer of rocks 2.5-7.5 cm in size and a base layer of rocks 7.5-15 cm in size.

5. The method of claim 1, wherein the filter bed comprises vinyl core medium as support and has as a top layer pea gravel.

6. The method of claim 1, wherein aerobic, anaerobic, and facultative microorganisms are provided with a high surface for attachment and growth under conditions producing mean cell residence times of approximately 100 days.

7. The method of claim 1, wherein the aerobic, anaerobic and facultative microorganisms are on the surface of the filter bed to a level of microorganisms with a mean cell residence time of approximately 100 days, the aerobic microorganisms are Achromobacter, Flavobacterium, Pseudomonas, Alcaligenes, Fusarium, Mucor, Penicillium, Geotrichum, or Sporotrichum; the anaerobic microorganisms are Methanobacterium, Methanobacillus, Methanococcus, or Methanosarcina; and the facultative microorganisms are Clostridium spp., Peptococcus anaerobus, Bifidobacterium spp., Desulphovibrio spp., Cornebacterium spp., Lactobacillus, Actinomyces, Staphylococcus or Escherichia coli.

8. The method of claim 7, wherein the vascular aquatic plant is a reed.

9. The method of claim 7, wherein the vascular aquatic plant is a rush.

10. The method of claim 1, wherein the anaerobic settling step is at least 12 hours.

11. The method of claim 1, wherein sludge accumulated during the anaerobic settling step is collected and removed periodically.

12. A system for the treatment of wastewater, comprising a preliminary vessel in which is carried out anaerobic settling, inlet means entering said vessel, a hybrid filter having a bed of particulate material, a lower portion of said bed being inoculated with anaerobic and facultative microorganisms and an upper portion thereof being inoculated with aerobic microorganisms and having vascular aquatic plants growing therein, fluid communication means between the preliminary vessel and said hybrid filter for conveying the effluent from the preliminary vessel to a bottom level of said hybrid filter for upflow therethrough, and outlet means from the hybrid filter.

13. The system of claim 12, wherein the preliminary vessel is a covered anaerobic lagoon.

14. The system of claim 12, wherein the hybrid filter is a rock bed and wherein the vascular aquatic plant growing in the filter bed is reed.

15. The system of claim 12, wherein the hybrid filter is a rock bed and wherein the vascular aquatic plant growing in the filter bed is rush.

16. The system of claim 12, wherein the hybrid filter comprises a bed of rocks and has a top layer of pea gravel, to serve as a support for the vascular aquatic plants; a middle layer of rocks 2.5-7.5 cm in size and a base layer of rocks 7.5-15 cm in size.

17. The system of claim 12, wherein the hybrid filter comprises vinyl core medium as support and has as a top layer pea gravel.