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PATENT SPECIFICATION

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(54) METHOD OF TREATING WASTE WATER AND SLUDGE PRODUCT THEREOF

(71) We, AIR PRODUCTS AND
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Allentown, Pennsylvania 18105, United States
of America, a Corporation of the State of
Delaware, United States of America, do
hereby declare the invention, for which we
pray that a patent may be granted to us, and
the method by which it is to be performed,
to be particularly described in and by the
following statement:—

This invention relates generally to improve-
ments in the treatment of municipal sewage
and/or industrial wastewater by the activated
sludge process. It is particularly concerned
with the control of operating conditions to
enhance selective production and maintenance
in the system of a highly active biomass
essentially free from filamentous growth, where
the attained sludge has favorable settling
characteristics and is capable of substantial
removal of phosphate values from the in-
coming wastewater.

The activated sludge process has been used
for many years for the removal of biological
oxygen demand (BOD) from wastewater.
This process consists of maintaining an
aeration basin in which wastewater is fed to a
suspension of microorganisms to form a mixed
liquor. The mixed liquor is aerated to furnish
oxygen for the respiration of biomass which
sorbs, assimilates and metabolizes the bio-
logical oxygen demand of the wastewater.

After a suitable period of aeration, the
mixed liquor is introduced to a clarifier in
which the biomass settles and the treated
wastewater overflows into the receiving stream.
A major portion of the settled biomass, which
is concentrated at the bottom of the clarifier,
is recycled to the aeration basin, and a minor
portion purged in order to maintain the
constant biosolids inventory within the system.

Despite the versatility and effectiveness of
this process and its many modifications, there
remains a major problem. It is the prolifera-
tion at times of high surface area and/or
filamentous species, such as sphaerotilus,
which do not settle adequately in the clarifier.

Thus, one consequence of filamentous biomass
is the inability to disengage the biomass from
the treated wastewater.

Another problem is effectiveness of removal
of phosphate values from the wastewater. The
reasons for such removal are obscure and the
process has been unable to be extrapolated
to biological wastewater treatment plants in
general. Thus, to date, there are no reliable
or satisfactory methods in which the control
of phosphate removal by biological action
alone has been generally established.

There have been several modifications of
the basic activated sludge process aimed at
avoiding filamentous and/or high surface area
species which result in a phenomenon known
as "bulking". One method is to distribute the
influent wastewater to different sections of the
aeration basin in order to spread out the
oxygen demand. Another is to decrease the
loading of BOD to the aeration basin. A
third is to add poisons to the system in order
to selectively kill off the high surface area
filaments. Another is to temporarily make the
system totally anaerobic and thus kill off the
filamentous biomass which is composed largely
of obligate aerobes. Another is to maintain
a high dissolved oxygen and high steady state
BOD level in an initial liquid stage or its
hydraulic equivalent in order to promote the
selective growth of an active, non-filamentous
biomass which outgrows or precludes the
development of filamentous species of higher
surface area.

A number of techniques have been proposed
in recent years aimed at modification of the
conventional activated sludge process to effect
or improve removal of nitrogen and/or phos-
phorus values. Among the various methods
disclosed are those including nitrification-
denitrification systems, one form of which is that
described by Barnard, J. L., *Water and Waste
Engineering* (1974) 33. In this process, desig-
nated "Bardenpho", four completely mixed
activated sludge basins are operated in series
followed by a clarifier from which sludge is
returned to the first basin. The first and third

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basins are operated under anoxic conditions, and receive mixed liquor containing nitrates and nitrites (hereinafter referred to as NO_x^-) from the second and fourth basins in the series which are aerated. While periodic good removal of phosphorus and nitrogen in pilot plant operation is reported, when operating at fairly high influent retention time, the production of a dense, easily filterable sludge is not achieved.

None of the methods heretofore proposed are capable of both avoiding bulking biomass and effecting phosphate removal. The process of the invention produces an active, dense biomass which concentrates readily in secondary clarification.

It has now been found that the desired selective production of species which are capable of removing phosphate values and producing a non-bulking biomass population of highly active, dense and rapidly settling microorganisms can be promoted and sustained by strictly maintaining anaerobic conditions during an initial state where incoming wastewater and recycle sludge from secondary clarification are mixed. The result is that: (1) the proliferation of filamentous biomass is inhibited and in particular proliferation of undesired high surface area microorganisms, such as *sphaerotilus*, is avoided; and (2) substantial quantities of incoming BOD are sorbed from the incoming wastewater by microorganisms which have the capability of doing so under anaerobic conditions. It is hypothesized without being bound thereby, that the energy for active transport of BOD values to within cell walls is derived from hydrolysis of polyphosphates, and that those species most capable of storing polyphosphates will proliferate under these conditions.

According to the present invention, there is provided a method of treating wastewater to reduce the BOD thereof, which method comprises:

(a) subjecting said wastewater to a preliminary treatment comprising mixing recycled activated sludge with BOD-containing wastewater influent; said mixture being maintained under anaerobic conditions such as to be substantially free of NO_x^- and to contain a concentration of less than 0.7 ppm dissolved oxygen; thereby effecting selective production of non-filamentous microorganisms capable of sorbing BOD;

(b) oxidizing BOD in mixed liquor resulting from step (a) to cause removal of BOD by contact with oxygen-containing gas by maintaining therein a dissolved oxygen content of at least 1 ppm;

and (c) separating purified supernatant liquid from sludge, the recycled activated sludge used in step (a) comprising sludge formed by subjecting wastewater to treatment steps corresponding to steps (a) and (b).

Preferably, in carrying out the process of

the invention, step (a) is carried out in at least one initial contact zone; step (b) is effected by oxidizing liquor from step (a) in at least one subsequent oxygenated zone; the oxidized mixed liquor from the or each oxygenated zone is transferred to at least one settling zone wherein purified supernatant liquid is separated from settled sludge and at least a portion of said settled sludge is recycled to an initial contact zone operated in accordance with step (a) to provide the activated sludge admixed therein with the wastewater influent.

Thus, for example, the wastewater may be treated by:

(a) mixing in an initial contact zone recycled activated sludge with BOD-containing wastewater influent; said initial contact zone being maintained under anaerobic conditions such as to be substantially free of NO_x^- and to contain a concentration of less than 0.7 ppm dissolved oxygen; thereby effecting selective production of non-filamentous microorganisms capable of sorbing BOD;

(b) oxidizing BOD in the mixed liquor in a subsequent oxygenated zone to cause removal of BOD by contact with oxygen-containing gas admitted to said oxygenated zone, said oxygenated zone having maintained therein a dissolved oxygen content of at least 1 ppm;

(c) transferring the oxidized mixed liquor from said oxygenated zone to a settling zone wherein purified supernatant liquid is separated from settled sludge;

and (d) returning a portion of said settled sludge to said initial contact zone to provide the activated sludge admixed therein with the wastewater influent.

In accordance with one embodiment, step (a) is carried out in an initial anaerobic zone, followed by an oxygenated aerobic zone in which step (b) is conducted and where the BOD sorbed in the anaerobic zone is oxidized, and where any remaining BOD is sorbed and oxidized. During this aerobic stage, the energy lost by hydrolysis of polyphosphates is recouped, and polyphosphate is reformed and stored within the aerated biomass, and phosphate values are thus removed from the mixed liquor.

In accordance with another embodiment, as will hereinafter appear, an anoxic zone for effecting denitrification, is interposed between the anaerobic and the oxygenated aerobic zone.

The nature of storage of phosphorus values within the biomass is such that only minor bleed back of phosphate occurs, thus permitting phosphorus values to be discarded from the system with waste activated sludge.

The invention will now be described in more detail with particular reference to the accompanying drawings in which:

Figure 1 of the accompanying drawings is a schematic and diagrammatic side view of

a simplified system for practice of the invention; and

Figure 2 is a similar view of a modified embodiment.

Referring to Figure 1 of the drawings, a modified activated sludge treating facility is represented, provided with the usual inlet 11 for the wastewater to be treated. Typically, this wastewater is settled sewage from a primary sedimentation tank or clarifier (not shown) but primary sedimentation is not a necessary condition. The influent wastewater initially enters an anaerobic mixing zone A wherein it is stirred and admixed with recycled sludge settled in the sedimentation tank or clarifier 12 and recycled to zone A by line 13. A portion of the settled sludge from clarifier 12 is removed by line 14, while the purified supernatant liquid is sent to receiving streams or reservoirs with or without further treatment as need be.

As indicated, zone A is maintained under strictly *anaerobic* conditions. The terms "anaerobic" and "anoxic" are not clearly or consistently defined in the literature wherein these terms are used. For the purpose of the present application, the term "anaerobic" is defined as the state existing within a sewage treating zone which is substantially free of NO_x^- (i.e. less than 0.3 ppm and preferably less than 0.2 ppm expressed as elemental nitrogen) wherein conditions are maintained such that the dissolved oxygen concentration (DO) is less than 0.7 ppm and preferably less than 0.4 ppm. The term "anoxic", as employed in the present application, is defined as the condition existing within a sewage treating zone wherein BOD is metabolized by nitrates and/or nitrites in initial total concentrations higher than 0.5 ppm expressed as nitrogen, and dissolved oxygen is at less than 0.7 ppm, preferably at less than 0.4 ppm.

To assure that zone A is maintained under anaerobic conditions, any one or more of the following steps may be followed. The vessel constituting zone A may be provided with a blanket of nitrogen, carbon dioxide or other inert gas at the liquid surface to avoid access thereto of atmospheric air; or a loose-fitting cover may be provided at or above the liquid surface, or a rigid cover may be provided above the liquid surface. Instead, or in addition thereto, nitrogen purge gas may be admitted into and bubbled up through the mixed liquor in zone A to strip any oxygen present. The latter option is illustrated in Figure 1 by the line 15 introducing nitrogen into the bottom of zone A.

Wastewater normally contains little or no NO_x^- due to the reducing power of BOD in the presence of microorganisms in the influent. A potential source of NO_x^- is from recycle sludge from the secondary clarifier and recycle mixed liquor from the aerobic treatment zone from nitrifying biological

systems, i.e. those which effect oxidation of ammoniacal BOD to NO_x^- .

The concentration of NO_x^- in the initial section of the anaerobic zone where the recycle sludge is mixed with incoming wastewater is maintained at less than 0.3 and preferably less than 0.2 ppm of NO_x^- , expressed as elemental nitrogen, by avoiding introduction of mixed liquor from the aerobic zone of the nitrifying system and controlling the NO_x^- content in the recycle sludge from the clarifier underflow. The NO_x^- concentration in the sludge recycle may be controlled by providing sufficient residence time in the clarifier and the sludge recycle system to permit adequate reduction of NO_x^- to elemental nitrogen by the oxygen demand of the biomass in the sludge recycle liquor.

While not necessarily limited thereto, zone A is preferably partitioned into two or more liquid treating sections to afford plug flow of the liquid through the anaerobic zone. It has been found that by the provision of physically partitioned sections or their hydraulic equivalent, there is better assurance of achieving the desired freedom from filamentous growth and thereby attaining development of dense sludge characteristics under even adverse conditions. Such adverse conditions, for example, include operating with low concentrations of BOD wherein high surface area biomass would have an advantage in competing for the sorption of a sparse food supply. By liquid staging, bypassing of untreated BOD from the anaerobic zone is precluded.

In the embodiment illustrated in Figure 1, zone A is shown as partitioned into two sections or chambers 16 and 17, each equipped with stirring means 19. The liquid passes in approximate plug flow through the several sections of zone A and is discharged into an oxygenation zone designated B. While zone A is shown as having two partitioned sections 16 and 17, it will be understood that three or more such sections may be employed.

Zones A and B may be separate interconnected vessels, or a single basin of any desired construction may be utilized, provided with suitable means for partitioning zone A from zone B while permitting unidirectional flow of liquid from zone A to zone B without recycling. Aeration of the liquid is effected in oxygenated zone B in known manner. Thus, as shown, compressed air may be admitted into the bottom of the oxygenated zone by spargers 20. If desired, instead of, or in addition to spargers, the oxygenated zone may be provided with mechanical aerators. Instead of air, oxygen of any desired purity may be admitted to zone B, in which event suitable means for covering all or part of the zone may be considered.

In practice, the dissolved oxygen content of zone B should be maintained above about 1

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ppm and preferably above 2 ppm, to assure adequate oxygen presence for metabolism of BOD and for phosphate uptake.

As illustrated in Figure 1, zone B is partitioned into two liquid treating sections 26 and 27, although it will be understood that a larger number of such sections may be employed, if desired. One reason for staging is that phosphate uptake is observed to be first order with respect to soluble phosphate concentration; thus low values of phosphate in the effluent are best obtained with a plug flow configuration.

In operating the system illustrated in Figure 1, it is emphasized that the initial zone of contact and admixture of incoming wastewater with recycled sludge must be maintained under anaerobic conditions. It was unexpectedly found that under such conditions there is selective production of species of microorganisms which not only are capable of removing phosphate values, but that the obtained biomass is made of essentially non-filamentous organisms producing a highly active, dense and rapidly settling sludge.

Production of filamentous microorganisms which are obligate aerobes is avoided since their proliferation is favoured only under aerobic conditions. Under the anaerobic conditions maintained there is promoted the selective production and proliferation of a species of microorganisms capable of storing unusually high amounts of polyphosphate within their cell walls. This is done by permitting those species which are capable of hydrolyzing phosphate to provide energy for active transport to do so and, thus, have a preferred access to influent BOD. Conversely, those species which would normally sorb food by active transport in which energy is derived from aerobic oxidation of BOD, are rendered relatively noncompetitive. The net effect is to promote proliferation of those species which can store polyphosphate during oxidation and hydrolyze polyphosphate during anaerobic feeding. Conditions which favor such microorganisms also promote relatively low sludge volume indices (Mohlmann), and relatively high zone settling velocities (ZSV). Species which assimilate and oxidize BOD most effectively ultimately dominate the biomass population. Thus, the method of this invention promotes the development of active, nonfilamentous, phosphorus-storing species to the competitive disadvantage of others. These species are capable of storing high amounts of phosphorus and proliferating in the system to the extent that the sludge has been observed to contain 6% phosphate values, expressed as elemental phosphorus on a dry basis. It has been discovered that a substantial portion of BOD is removed from the mixed liquor within the anaerobic stage described above, and further that polyphosphate is hydrolyzed as evidenced by release

of soluble phosphate to the mixed liquor in the anaerobic zone.

After the initial anaerobic contact, the mixed liquor is subjected to aeration in zone B, to oxidize sorbed BOD and to complete removal and oxidation of any remaining BOD. During this period of aeration, the energy of oxidation is partially utilized for cell growth and partially utilized to energetically upgrade soluble phosphate values in the mixed liquor to stored polyphosphate within the cells of biomass. This phenomenon is observed in this aerated zone in that the concentration of soluble phosphate is rapidly reduced. After the aerobic stage, which results in both phosphate and BOD removal and stabilization, the mixed liquor can be discharged into the secondary clarifier, wherein the clear supernatant is discharged either to further treatment or directly to receiving waters. Preferably, the total influent detention time in initial contact zone A and aeration zone B substantially does not exceed three hours.

In the embodiment illustrated in Figure 2, provision is made for denitrification of nitrogen values in the wastewater, while maintaining the desired production of nonfilamentous, dense sludge, with accompanying removal of phosphates, and without excessive extension of the overall treating time required. Thus, three separate treating zones are provided in the illustrated embodiment: an anaerobic zone C, followed by an anoxic zone D, and an aerobic oxygenated zone E. As in the embodiment previously described, the BOD-containing wastewater to be treated enters the modified activated sludge system of Figure 2 by line 31, wherein it is admixed in initial treating basin or vessel 34 with recycled activated sludge returned from settler or clarifier 32. Vessel 34 is maintained under anaerobic conditions as heretofore defined; that is, precautions are observed to maintain during the initial treating stage in zone C substantially complete absence of dissolved oxygen as in the case of zone A. That is, the dissolved oxygen concentration is maintained below 0.7 ppm and preferably below 0.4 ppm.

In vessel or basin 34, the mixed liquor is stirred under strictly anaerobic conditions to permit as in the previous described embodiment incorporation of BOD values by organisms which are provided by the recycled activated sludge and thus give those species which can effect this transfer a preferential chance to obtain food and thus outgrow other species. Energy for the transfer is provided by the hydrolysis of polyphosphates contained in the biomass of the sludge recycle. In this manner, growth of species which preferentially store phosphate is encouraged. As before, substantial freedom from dissolved oxygen is assured by covering vessel 34 or otherwise preventing access thereto of atmospheric air

and/or by stripping the liquor therein by bubbling nitrogen gas therethrough as indicated at 38.

As illustrated in Figure 2, approximate plug flow is maintained in vessel 34 by partitioning that vessel for staged liquid flow through two or more physically separated or hydraulically distinct liquid stages.

From vessel or chamber 34 the mixed liquor passes into the anoxic treating zone D, represented at 35. This may be a separate vessel or may be part of a continuous treating basin suitably partitioned from the preceding zone C to permit concurrent unidirectional liquid flow without backmixing. Freedom from dissolved oxygen in zone D can be achieved as heretofore described for zone C. In Figure 2, nitrogen gas is introduced into zone D through line 38 to strip the mixed liquor of any dissolved oxygen and prevent entry of oxygen from the atmosphere. From zone D, the mixed liquor next flows into and through the aerobic oxygenated zone E wherein it is aerated to oxidize BOD, including ammonia values and effect phosphate uptake. The oxidized mixed liquor from E flows into clarifier 32 wherein the supernatant purified liquor is separated from the settling sludge a portion of the latter being returned in controlled amount to vessel 34 by line 33.

In anoxic zone D, nitrates and nitrites (NO_x^-) are admitted in concentrations higher than 2 ppm expressed as elemental nitrogen and are reduced to elemental nitrogen and discharged as such. To effect this purpose, a portion of the mixed liquor from the oxygenated zone E is returned to zone D by line 40. These nitrates and nitrites are formed in zone E by oxidation of nitrogen values (considered as ammonia) contained in the influent wastewater which entered the system by line 31. In the oxygenated zone E, the balance of the BOD is metabolized and the ammonia is oxidized to nitrites and ultimately, at least in part, to nitrates. The oxidized mixed liquor from the last stage of zone E is returned to an initial stage of zone D, wherein the nitrate and nitrite content is brought into contact with incoming BOD. Care must be taken to avoid introduction of NO_x^- into the anaerobic zone (C).

By operating in accordance with the scheme illustrated in Figure 2, not only is the selective production of nonfilamentous biomass with desired removal of phosphate obtained as in the embodiment of Figure 1, but also substantial removal of nitrogenous nutrients is also achieved. Moreover, the desired removal of nitrogen values can be effected without substantially prolonging the overall treating time requirements. Desirably, the influent detention time in the initial anaerobic zone, the anoxic zone and the aerating zone substantially does not exceed three hours.

The amount of mixed liquor recycled from

the oxygenated zone E to the anoxic zone D may, in practical operation, constitute from 100 to 400% of the raw influent volumetric flow entering the system through line 31. The amount of sludge recycled by line 33, as well as in the case of line 13 (Figure 1), may be in the order of from about 10 to 50%, preferably 20 to 30% of the raw influent.

Oxygenated zone E is operated in substantially the same manner as zone B previously described. The treated liquor is passed from the oxygenated zone (B or E) to the clarifier. To assure good removal of BOD and effective nitrification, the aeration zone should be operated throughout at a minimum D.O. level of 1 ppm and preferably greater than 2 ppm. When higher dissolved oxygen levels at the discharge end of the oxygenated zone are required, they may be imposed without adverse effect on the system.

In the practice of the invention, the mixed liquor is passed in approximate plug flow through the entire treating system constituted by zones A and B in the embodiment of Figure 1 or zones C, D and E in the embodiment of Figure 2. It has been observed that the rate of denitrification varies directly with NO_x^- concentration when such concentration is below about 2 ppm and therefore, a plug flow configuration is preferred to attain low NO_x^- values in the effluent from zone D. Moreover, in the preferred practice, each of these zones C, D and E, is operated in liquid staged pattern, each such treating zone being physically partitioned into two or more separate treating stages or their hydraulic equivalent, as determined by residence time distribution via tracer experiments (see Levenspiel, "Chemical Reaction Engineering", John Wiley and Sons, New York, 1962, pages 242-308).

The need for inclusion in the system of an anoxic zone for nitrogen removal will depend upon the content of ammonia values in the influent wastewater and the limitations imposed upon the permissible nitrogen content of the purified water effluent discharged. As a rule, without being necessarily limited thereto, the incorporation of the intermediate anoxic zone is generally indicated whenever the influent wastewater contains in excess of about 10 parts per million of ammonia nitrogen expressed as elemental nitrogen.

EXAMPLE 1.

A system operating on the principle of the embodiment of Figure 1 was tested over a period of several months in the treatment of municipal wastewater from Allentown, Pennsylvania. The system employed an anaerobic zone of 6 liters subdivided by partitions into 5 equal stages (1.2 liters each) followed by an oxygenated zone of 10 liters subdivided by partitions into 5 equal stages (2 liters each) into which air was sparged. Nitrogen gas was sparged through the

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5 anaerobic zone, which was fitted with a loosely-sealed rigid cover. From the last stage of aeration, the oxidized mixed liquor was passed into a clarifier, from which a portion of the settled sludge was recycled to the initial anaerobic stage, in the amount of about 20% by volume of the wastewater influent. The results reported in Table 1 below are the averages over a period of ten days operation.

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It will be seen from the reported results

in Table 1 that a desirable sludge volume index was maintained, indicative of a dense, easily settling sludge, while more than 90% removal of phosphate was attained. BOD

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The sludge retention time in the clarifier and sludge recycle was about 1.7 hours, which was adequate to effect reduction of NO_3^- from 11.26 ppm as estimated from the clarifier effluent, to 0.18 ppm in the sludge recycle liquor.

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TABLE 1

		In Fresh Influent	In sludge Recycle	In Clari-fied Liquid
MLVSS mg/L	4082			
COD (filtered) influent, mg/L	286			
COD (filtered) effluent, mg/L	48.88			
BOD ₅ (filtered) influent mg/L	127.4			
BOD ₅ (filtered) effluent mg/L	5.72			
Influent detention time, hrs.	2.86			
Sludge recycle, % influent	20.73			
Nominal residence time				
Anaerobic zone, hrs.	0.89			
Aeration zone, hrs.	1.48			
Phosphorus (as P) mg/L		6.1	3.85	0.44
NH ₃ (as N) mg/L		18.35	0.82	0.43
NO ₃ ⁻ (as N), mg/L		0.08	0.18	11.26
ZSV, ft/hr	6.44			
SVI, ml/g TSS	69			
D.O. in anaerobic zone, mg/L	0.29- 0.32			
D.O. in aerobic first zone, mg/L	6.41			
D.O. in aerobic last zone, mg/L	6.16			

25 The content of nitrates and nitrites (measured as NO_3^- nitrogen) in the five sections of the anaerobic zone remained below 0.16 mg/L. The phosphate concentrations expressed as mg P/L in the ten sections were respectively. 9.35, 12.87, 13.55, 13.63, 13.07, 6.64, 3.65, 1.78, 1.05 and 0.72. These values indicate phosphate release in the first five anaerobic sections and exponential phosphate uptake in the last five aerobic sections.

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EXAMPLE 2.

A system operating in accordance with the flow scheme of Figure 2 was used in the treatment of municipal wastewater from Allentown, Pennsylvania. The system comprised three separate vessels providing an anaerobic zone (I) of 7.2 liters divided by partitions into 3 equal chambers of 2.4 liters each; an anoxic zone (II) of 3.6 liters divided by partitions into three equal chambers of

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5 1.2 liters each; and an oxygenated zone (III) of 12 liters divided by partitions into 4 chambers respectively of 1.2, 2.4, 3.6 and 4.8 liters. Nitrogen gas was admitted to each chamber of the anaerobic and anoxic zones to maintain substantial freedom from oxygen. The mixed liquor from the last chamber of the aeration vessel (III) flowed into a clarifier from which the purified supernatant liquor was withdrawn, while a portion of the settled sludge was recycled to the first chamber of the anaerobic zone, in which it was contacted and mixed with the influent wastewater. The mixed liquor thus passed successively through the system in plug flow and in staged liquid sequence in each of the zones. A portion of

the mixed liquor from the last chamber of the oxygenated zone (III) was withdrawn and recycled to the first chamber of the anoxic zone (II). Oxygen was supplied to the oxygenated zone by sparging air through the mixed liquor.

The operating conditions and results are reported in Table 2 below, based on the average over a week of operation.

The sludge retention time in the clarifier and sludge recycle was about 1.4 hours, which was adequate to effect reduction of NO_x^- from 4.85 ppm, as estimated from the clarifier effluent, to 0.07 ppm in the sludge recycle liquor.

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TABLE 2

	In fresh feed	In sludge recycle	In clarified liquid	In (III-II) Internal Recycle	In flow I to II	In flow II to III
MLVSS, mg/L	3399					
COD (unfiltered) influent, mg/L	285.5					
COD (filtered) influent, mg/L	155.0					
BOD ₅ (filtered) influent, (avg.) mg/L	42.24					
BOD ₅ (filtered) effluent (avg.) mg/L	2.07					
Sludge recycle, % influent	30.52					
Internal Recycle, III to II, % influent	182.9					
Influent detention time hrs.	2.95					
Phosphates as P, mg/L-% removed	86.48	3.33	4.13	1.39	15.34	8.19
Ammonia Nitrogen as N, mg/L % removed	97.03	13.51	2.34	0.69	8.58	4.88
NO _x Nitrogen as N, mg/L % removed	61.34	0.7	0.07	5.51	0.06	1.29
SVI, (avg.) mL/g TSS	154.0					
SVI, stirred mL/g	51.79					
Zone Settling Velocity, ft/hr	4.40					

The nitrogen and phosphorus concentrations in Table 2 is given in Table 3 below, together in each of the sections of the system reported with the DO levels.

TABLE 3

Section	ZONE I			ZONE II			ZONE III			
	1	2	3	4	5	6	7	8	9	10
NO_x^- , mg/L	0.05	0.05	0.06	2.1	1.69	1.29	2.23	3.71	5.21	5.51
$\text{NH}_3\text{-N}$, mg/L	10.43	10.04	8.58	5.32	5.05	4.88	3.92	2.44	1.16	0.69
$\text{PO}_4^{3-}\text{-P}$, mg/L	10.46	14.11	15.34	10.24	8.49	8.19	6.33	4.53	2.60	1.39
DO, mg/L	0.14	0.12	0.13	0.43	0.35	0.43	7.47	7.14	5.29	3.54

The system provides favorable economics not only resulting from the savings in the cost of chemicals otherwise required to effect desired removal of phosphates, but also from the standpoint of the high rates of wastewater throughput per unit of fluid volume capacity, with excellent removal of BOD and COD values. Thus, even in instances or vicinities in which the phosphate content of the influent wastewater does not pose a problem, the system of the invention offers important economic advantages because of the high throughput rates. Embodiments of the type illustrated in Figures 1 and 2 attain excellent results when operating on typical municipal wastewaters at an influent detention time in the order of about three hours at about 20°C. A somewhat higher influent detention time may be required in industrial wastewater systems wherein the soluble BOD is in excess of about 150 ppm. Existing activated sludge systems can be readily modified, at low cost, to operate in accordance with either of these embodiments.

Contributing importantly to the economic advantages of systems operating in accordance with the invention is the high density of the clarifier underflow liquid, indicative of good settling velocity and virtual absence of filamentous biomass (confirmed by microscopic examination). Thus, solids concentration in the clarifier underflow of 3.6% volatile suspended solids (VSS) was had in operations according to the invention, whereas conventional systems operate at about or below 1% VSS in the clarifier underflow. The thickened underflow and high zone settling velocities attained thus afford cost advantages even in areas where neither phosphorus removal nor nitrification is required. In addition, the systems of the invention attain reduction of phosphate (as P) in the influent wastewater to 1 ppm or less, reduction of influent BOD to less than 10 ppm, with complete removal of ammonia and reduction in total nitrogen values (as N) to less than 25% of that in the influent.

The system described in Figure 2 may also be desirable where neither phosphate removal

nor nitrification is required, because of the good sludge properties obtained. Another factor contributing to the advantages of the system is the savings in oxygen requirements where nitrification is required, since the oxygen in NO_x^- effects metabolism of BOD in the anoxic zone. Further, reduction of NO_x^- values in the mixed liquor entering the clarifier minimizes the release of nitrogen at that point. Thus, "floating sludge", caused by nitrogen release in the clarifier, commonly observed in nitrification effluents, is avoided.

The systems described in Figures 1 and 2 also have the advantage of producing a biomass that contains up to 6% or more of phosphorus by weight. Thus, a method is provided wherein a high phosphorus content can be attained. This may be advantageous for industrial use. An obvious application is enhanced fertilizer quality of waste biomass and consequently sludge produced in accordance with the process of the invention and fertilizer comprising said sludge constitute further aspects of the invention.

WHAT WE CLAIM IS:—

1. A method of treating wastewater to reduce the BOD thereof, which method comprises:

(a) subjecting said wastewater to a preliminary treatment comprising mixing recycled activated sludge with BOD-containing wastewater influent, said mixture being maintained under anaerobic conditions such as to be substantially free of NO_x^- and to contain a concentration of less than 0.7 ppm dissolved oxygen, thereby effecting selective production of non-filamentous microorganisms capable of sorbing BOD;

(b) oxidizing BOD in liquor resulting from step (a) to cause removal of BOD by contact with oxygen-containing gas by maintaining therein a dissolved oxygen content of at least 1 ppm;

and (c) separating purified supernatant liquid from sludge; the recycled activated sludge used in step (a) comprising sludge formed by subjecting wastewater to treatment steps corresponding to steps (a) and (b).



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TABLE 3

Section	ZONE I			ZONE II			ZONE III			
	1	2	3	4	5	6	7	8	9	10
NO _x ⁻ , mg/L	0.05	0.05	0.06	2.1	1.69	1.29	2.23	3.71	5.21	5.51
NH ₃ -N, mg/L	10.43	10.04	8.58	5.32	5.05	4.88	3.92	2.44	1.16	0.69
PO ₄ ⁻³ P, mg/L	10.46	14.11	15.34	10.24	8.49	8.19	6.33	4.53	2.60	1.39
DO, mg/L	0.14	0.12	0.13	0.43	0.35	0.43	7.47	7.14	5.29	3.54

The system provides favorable economics not only resulting from the savings in the cost of chemicals otherwise required to effect desired removal of phosphates, but also from the standpoint of the high rates of wastewater throughput per unit of fluid volume capacity, with excellent removal of BOD and COD values. Thus, even in instances or vicinities in which the phosphate content of the influent wastewater does not pose a problem, the system of the invention offers important economic advantages because of the high throughput rates. Embodiments of the type illustrated in Figures 1 and 2 attain excellent results when operating on typical municipal wastewaters at an influent detention time in the order of about three hours at about 20°C. A somewhat higher influent detention time may be required in industrial wastewater systems wherein the soluble BOD is in excess of about 150 ppm. Existing activated sludge systems can be readily modified, at low cost, to operate in accordance with either of these embodiments.

Contributing importantly to the economic advantages of systems operating in accordance with the invention is the high density of the clarifier underflow liquid, indicative of good settling velocity and virtual absence of filamentous biomass (confirmed by microscopic examination). Thus, solids concentration in the clarifier underflow of 3.6% volatile suspended solids (VSS) was had in operations according to the invention, whereas conventional systems operate at about or below 1% VSS in the clarifier underflow. The thickened underflow and high zone settling velocities attained thus afford cost advantages even in areas where neither phosphorus removal nor nitrification is required. In addition, the systems of the invention attain reduction of phosphate (as P) in the influent wastewater to 1 ppm or less, reduction of influent BOD to less than 10 ppm, with complete removal of ammonia and reduction in total nitrogen values (as N) to less than 25% of that in the influent.

The system described in Figure 2 may also be desirable where neither phosphate removal

nor nitrification is required, because of the good sludge properties obtained. Another factor contributing to the advantages of the system is the savings in oxygen requirements where nitrification is required, since the oxygen in NO_x⁻ effects metabolism of BOD in the anoxic zone. Further, reduction of NO_x⁻ values in the mixed liquor entering the clarifier minimizes the release of nitrogen at that point. Thus, "floating sludge", caused by nitrogen release in the clarifier, commonly observed in nitrification effluents, is avoided.

The systems described in Figures 1 and 2 also have the advantage of producing a biomass that contains up to 6% or more of phosphorus by weight. Thus, a method is provided wherein a high phosphorus content can be attained. This may be advantageous for industrial use. An obvious application is enhanced fertilizer quality of waste biomass and consequently sludge produced in accordance with the process of the invention and fertilizer comprising said sludge constitute further aspects of the invention.

WHAT WE CLAIM IS:—

1. A method of treating wastewater to reduce the BOD thereof, which method comprises:

(a) subjecting said wastewater to a preliminary treatment comprising mixing recycled activated sludge with BOD-containing wastewater influent, said mixture being maintained under anaerobic conditions such as to be substantially free of NO_x⁻ and to contain a concentration of less than 0.7 ppm dissolved oxygen, thereby effecting selective production of non-filamentous microorganisms capable of sorbing BOD;

(b) oxidizing BOD in liquor resulting from step (a) to cause removal of BOD by contact with oxygen-containing gas by maintaining therein a dissolved oxygen content of at least 1 ppm;

and (c) separating purified supernatant liquid from sludge; the recycled activated sludge used in step (a) comprising sludge formed by subjecting wastewater to treatment steps corresponding to steps (a) and (b).

(18)



2. A method according to Claim 1 which comprises:

5 (a) subjecting said wastewater to a preliminary treatment comprising mixing recycled activated sludge with BOD-containing waste-
water influent in at least one initial contact zone, said initial contact zone being main-
tained under anaerobic conditions such as to
10 be substantially free of NO_x^- and to contain a concentration of less than 0.7 ppm dissolved oxygen, thereby effecting selective production of non-filamentous microorganisms capable of sorbing BOD;

15 (b) oxidizing BOD in the liquor from step (a) in at least one subsequent oxygenated zone to cause removal of BOD by contact with oxygen-containing gas, said oxygenated zone or zones having maintained therein a dissolved oxygen content of at least 1 ppm;

20 (c) transferring oxidized mixed liquor from the or each oxygenated zone to at least one settling zone wherein purified supernatant liquid is separated from settled sludge;

25 and (d) recycling at least a portion of said settled sludge to an initial contact zone operated in accordance with step (a) to provide the activated sludge admixed therein with the wastewater influent, the recycled activated
30 sludge used in step (a) comprising sludge formed by subjecting wastepaper to treatment steps corresponding to steps (a) and (b).

3. A method according to Claim 1, which comprises:

35 (a) mixing in an initial contact zone recycled activated sludge with BOD-containing wastewater influent; said initial contact zone being maintained under anaerobic conditions such as to be substantially free of NO_x^- and to contain a concentration of less
40 than 0.7 ppm dissolved oxygen; thereby effecting selective production of non-filamentous microorganisms capable of sorbing BOD;

45 (b) oxidizing BOD in the mixed liquor in a subsequent oxygenated zone to cause removal of BOD by contact with oxygen-containing gas admitted to said oxygenated zone, said oxygenated zone having maintained therein a dissolved oxygen content of at least
50 1 ppm;

55 (c) transferring the oxidized mixed liquor from said oxygenated zone to a settling zone wherein purified supernatant liquid is separated from settled sludge;

and (d) returning a portion of said settled
60 sludge to said initial contact zone to provide the activated sludge admixed therein with the wastewater influent.

4. A method according to Claim 2 or
Claim 3 wherein said initial contact zone
comprises a series of at least two hydraulically
distinct sections in concurrent liquid flow
communication.

5. A method according to Claim 4 wherein

said distinct sections are physically separated
by partitions.

6. A method according to any one of Claims
2 to 5 wherein said oxygenated zone comprises
a series of at least two hydraulically distinct
sections in concurrent liquid flow communi-
cation.

7. A method according to Claim 6 wherein
said distinct sections of said oxygenated zone
are physically separated by partitions.

8. A method according to any preceding
claim wherein said mixture contains less than
0.4 ppm of dissolved oxygen in step (a).

9. A method according to any preceding
claim wherein said wastewater influent also
contains phosphates and said mixing step
effects selective production of nonfilamentous
microorganisms capable of sorbing BOD and
capable of storing polyphosphate under oxi-
dizing conditions, and said oxidizing step
simultaneously effects storage of phosphates
within said microorganisms.

10. A method according to any preceding
claim wherein nitrogen gas is contacted with
mixed liquor in said initial contact zone to
maintain anaerobic conditions therein.

11. A method according to any preceding
claim where the biological sludge produced
contains phosphate values up to 6%, expressed
as elemental phosphorus on a dry basis, a
portion of which is recovered for industrial
use.

12. A method according to any preceding
claim wherein said wastewater influent further
contains ammonia values and wherein the
mixed liquor formed in said initial anaerobic
contact zone is further treated in an anoxic
zone under anoxic conditions before its being
sent to the oxygenated zone; said anoxic
conditions including a dissolved oxygen con-
tent not in excess of 0.7 ppm and the
admission to said zone of nitrates and/or
nitrites; said nitrates and/or nitrites being
obtained by internal transfer of mixed liquor
thereto from an oxygenated zone, said mixed
liquor having a concentration of nitrates
and/or nitrites in excess of 2 ppm, expressed
as elemental nitrogen, and said nitrates and/or
nitrites being reduced in said anoxic zone to
elemental nitrogen gas.

13. A method according to Claim 12
wherein said anoxic zone is comprised of a
series of two or more sections in liquid flow
communication.

14. A method according to Claim 12 or
Claim 13 wherein said mixed liquor trans-
ferred from said oxygenated zone to said
anoxic zone constitutes 100 to 400% by volume
of the fresh wastewater influent admitted to
said initial contact zone.

15. A method according to any one of
Claims 12 to 14 wherein the total influent
detection time in said initial anaerobic contact
zone, said anoxic zone and said aerating zone

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(19)

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does not substantially exceed three hours.

16. A method according to any preceding claim wherein the amount of sludge utilized in step (a) constitutes 10 to 50% by volume of the fresh wastewater influent admixed therewith.

17. A method according to any preceding claim wherein the total influent detention time in said initial anaerobic step (a) and said oxidizing step (b) does not substantially exceed three hours.

18. A method according to Claim 1 of treating wastewater substantially as hereinbefore described and exemplified, with par-

ticular reference to Fig. 1 or Fig. 2 of the accompanying drawings.

19. Sludge wherever produced in accordance with a method claimed in any preceding claim.

20. A fertilizer comprising sludge as claimed in claim 19.

21. The use of sludge as claimed in claim 19 as fertilizer.

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