

PATENT SPECIFICATION

(11) 1325 321

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DRAWINGS ATTACHED

- (21) Application No. 31855/70 (22) Filed 1 July 1970
 (31) Convention Application No. 838 498 (32) Filed 2 July 1969 in
 (33) United States of America (US)
 (44) Complete Specification published 1 Aug. 1973
 (51) International Classification C02C 1/06
 (52) Index at acceptance C1C 431 432 43Y



(54) METHOD OF TREATING OXIDIZABLE WASTE MATERIAL

(71) We, UNION CARBIDE CORPORATION, a corporation organised and existing under the laws of the state of New York, United States of America, residing at 270, Park Avenue, New York, State of New York, 10017, United States of America, (assignee of ERNEST KENT ROBINSON and JOHN RUBEN McWHIRTER), 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 to a method for biochemically treating waste water containing biochemically oxidizable material such as municipal sewage, by oxygenation.

With few exceptions, biochemical oxidation methods have employed air as the oxygen source. The large quantity of air required to supply oxygen is primarily due to the 4:1 dilution with nitrogen, and the mass transfer efficiency of the method is low. However, air is "free" and the large amount of energy which was supplied to the air to satisfy oxygen dissolution requirements was normally sufficient to mix and suspend the solids containing active bacteria hereinafter termed "biomass" in the liquid.

In one biochemical oxidation method which is known as the activated sludge method as applied to municipal sewage treatment, the sewage is mixed with oxygen-containing gas and activated sludge. The latter consists essentially of aerobic organisms which have the ability in the presence of sufficient dissolved oxygen to absorb and assimilate the biochemically oxidizable organic material which provides the Biochemical Oxygen Demand (BOD) of the municipal sewage, thereby converting the organic material to forms which can be separated readily from the purified water. Under normal conditions the bacteria multiply rapidly in the aeration tanks during this treatment step. When the requisite period of BOD conversion is complete, the mixed liquor is settled, the purified effluent decanted to re-

ceiving waters and sludge is withdrawn from the bottom of a clarifier.

A portion of the sludge must be recirculated to the inlet of the treatment tank to inoculate the incoming BOD-containing waste water. In the usual practice the recycled sludge cannot constitute 100% of the sludge withdrawn from the clarifier or the sludge inventory in the system will gradually build to intolerable levels and will overload the clarifier system. Perhaps only about 90% of the sludge may be recycled leaving at least 10% to be discarded. Accordingly there is a substantial net production of sludge from the conventional activated sludge method.

Unfortunately this excess sludge must be further treated to render it non-putrescible before disposition. One commonly employed method is anaerobic (without oxygen) digestion, by long-term storage, e.g. 30 days, sufficient for reasonably complete decay of the organic material. Large covered reservoirs are employed to provide the long residence time and to avoid escape of obnoxious gases; nevertheless the residual solids after anaerobic digestion may still comprise 40—50% of the original volume of excess sludge. Sludge treatment and disposal is expensive and typically represents 35—40% of the total cost of a secondary municipal water treatment.

Prior art activated sludge methods normally operate with 1500—3500 ppm. total suspended solids mixed liquor in aeration (MLSS) and with dissolved oxygen concentrations of from near zero to perhaps 2 ppm. The recycle sludge after concentration in the clarifier usually contains about 10,000 ppm. total suspended solids (SS) or less, and returns at a recycle/feed volume flow ratio of between 0.25 and .50. Settling time in the clarifier is typically 2 to 3 hours and the retention time of the waste water in aeration is between 4 to 6 hours. The effluent, while substantially free of dissolved BOD, is often turbid and contains a high content of disperse bacteria which escape separation in the clarifier. Typically, a municipal sewage plant treating 220 ppm.

BOD feed water with 2500 ppm. MLSS is provided with about 250,000-gallons (696,000 liters) aeration tank capacity per million gallons (liters) daily influent.

5 An activated sludge system is essentially a closed community of bacteria. If allowed to operate without deliberate alteration of the bacterial content, the system would eventually equilibrate at some maximum level of biologically active solids concentration which the food and oxygen supplies can sustain. At equilibrium, the grain in active solids by cell synthesis will equal the loss in active solids by lysis, oxidation of cell residue and by overflow.

10 In usual practice, the system is not permitted to come to equilibrium because the biologically active solids concentration in aeration corresponding to equilibrium is higher than that value which for various reasons is considered most favorable. Therefore, the solids inventory is suppressed by the procedure of wasting sludge to the thickener, continuously or periodically, and at such average rate as to maintain the suspended solids level in the mixed liquor within a predetermined range, e.g., 1500—3500 ppm.

The primary reasons why the prior art has suppressed the solids concentration in the activated sludge are as follows: First, high solids concentrations have resulted in zones of essentially zero dissolved oxygen-(DO) in the mixed liquor, particularly at or near the point of introduction of the waste liquid. When the DO-level drops to zero, there is a shift in the cell synthesis from aerobic strains desirable in the activated sludge method toward anaerobic and facultatively aerobic organisms which are less desirable.

40 Second, efforts to increase oxygen dissolution rates and to eliminate zero-DO conditions in aeration have resulted in uneconomically high aeration gas compression rates. Moreover, if heavy mechanical agitation is used to increase dissolution of oxygen, the flocculent agglomerates of bacteria are comminuted and dispersed so that the effluent becomes more turbid and contains a higher content of BOD.

50 Third, it has been reported that increasing the solids concentration in the mixed liquor reduces the settling rate in the clarifier — hence, a larger clarifier is needed to extend the hold-up time and to permit the sludge to become reasonably compact before withdrawal.

55 Fourth, the maximum sludge density attained in the clarifier has been low. The density bears an inverse relationship to the Mohlman sludge volume index (SVI), and values of this index are typically 100 or above corresponding to a total solids level of 10,000 ppm. or less for the recycle sludge.

60 Fifth, the inherently low settleability and low compactability of the sludge requires excessive recycle rates to achieve high solids in the mixed liquor. Recycle rates as high as 65 100% of the waste liquid feed rate have been

attempted and this greatly increases the hydraulic load on both aeration basins and clarifier. Thus, the plant size becomes prohibitively large.

Sixth, experience has shown that the overflow of unsettled solids in the effluent increases with an increase in solids concentration in aeration. This may be due either to overloading the clarifier and/or to the highly disperse character of the facultative bacteria resident in the system.

70 Seventh, prior art efforts to increase the density of the recycle sludge by longer settling times in the clarifier have resulted in the problem of "rising sludge." The phenomenon is attributed to de-nitrification in the clarifier as a result of extended sludge storage under anaerobic conditions. When "rising sludge" occurs, gas evolved in the clarifier forces the sludge blanket upward through the supernatant liquid and over the effluent discharge weir. Bulking in the clarifier is also attributed to the micro-organism *Sphaerotilus* whose rapid growth is promoted by low dissolved oxygen levels in the cell synthesis zone of the method. This not only depletes the solids needed by the method but also heavily contaminates the receiving waters.

95 Even in plants where sludge wasting is reduced or eliminated (e.g., in extended aeration plants), the mixed liquor volatile solids concentration (MLVSS) in aeration remains relatively low, e.g., in the range of 3000 to 4000 ppm. Such plants repetitively experience "rising sludge" and the gross loss of solids by this phenomenon is responsible at least in part for the apparent limit on solids concentration.

100 According to the invention there is provided a method for treating waste water having a Biochemical Oxygen Demand (BOD) by aeration in contact with a bacterially active sludge having a volatile suspended solids to total suspended solids mass ratio of at least 0.55 which includes concentrating solids from the aeration and recycling concentrated solid to the aeration zone as said sludge, comprising introducing into an oxygenation zone waste water having a BOD, bacterially active sludge having 12,000 to 50,000 ppm. Total suspended solids content (SS) and feed gas comprising at least 50% oxygen (by volume) in sufficient relative quantities to provide mixed liquor of 4,000 to 12,000 ppm. total suspended solids content (MLSS) and gas above said mixed liquor having an oxygen partial pressure of at least 300 mm. Hg. in said oxygenation zone, and mixing said components in said zone for 20 to 180 minutes solids residence time to from oxygenated liquor having a dissolved oxygen content (DO) of at least 3 ppm., with the day average food/biomass weight ratio (BODS/volatile Suspended Solids) for said liquor during the oxygen gas mixing being maintained at least at 0.15, separating said 130

oxygenated liquor into said sludge and clarified effluent; and recycling at least part of said sludge to said oxygenation zone at flow rate relative to that of said waste water having a BOD such that the recycling sludge/waste water having a BOD volume ratio is 0.1 to 0.5.

The BOD of the waste water is produced in the main by a content of biochemically oxidizable material in the waste water.

The invention will be described further by way of example, with reference to the accompanying drawings, in which:

Fig. 1 is a graph showing the relation between the recycle sludge suspended solids concentration and the mixed liquor solids concentration, for various volume ratios of recycling sludge/water having a BOD.

Fig. 2 is a schematic view taken in cross-sectional elevation of apparatus including a single submerged agitator and sparger assembly within an oxygenation chamber, and a clarifier arranged to practice one embodiment of the invention.

Fig. 3 is a schematic view taken in cross-sectional elevation of apparatus comprising a multiplicity of submerged agitators and spargers all positioned within the same oxygenation chamber to practice another embodiment.

Fig. 4 is a schematic view taken in cross-sectional elevation of apparatus comprising a multiplicity of oxygenation chambers each having a surface-type mixer and oxygen feed gas introduction means, and arranged for staged flow of oxygenated liquor.

Fig. 5 is a schematic view taken in cross-sectional elevation of apparatus similar to Fig. 4 but with means for staged flow of oxygen-depleted gas cocurrent to the oxygenated liquor staging, and

Fig. 6 is a schematic view taken in cross-sectional elevation of apparatus similar to Fig. 5 but with means for concentrating BOD-depleted solids between oxygenation stages.

As previously indicated, the sludge mixed with the oxygen gas and BOD-containing waste water in the oxygenation zone has between 12,000 and 50,000 ppm. total suspended solids (SS). Concentrations above 50,000 ppm. require excessively long residence time in the clarifier — time in addition to that needed to merely separate the effluent so that the settled sludge will become highly compact. Such high recycle sludge concentration also tends to permit anaerobic conditions for a prohibitively long period thereby reducing the overall efficiency of the treatment method. On the other hand, concentrations below 12,000 ppm. do not provide sufficient solids in the mixed liquor for volume ratio of sludge water having a BOD below about 0.5, as demonstrated by Fig. 1. For example, a recycle sludge solids concentration (SS) of 12,000 ppm. and a recycle sludge/feed volume ratio (R/F) of 0.5 corresponds to a mixed liquor suspended solids concentration (MLSS) of

4,000 ppm., the lower limit for mixed liquor concentration required to realize the advantages of this invention. With a recycle sludge solids concentration (SS) of 10,000 ppm., the R/F ratio must be about 0.7 to achieve the 4,000 ppm. mixed liquor suspended solids concentration (MLSS). Recycle sludge/feed volume ratios above 0.5 impose lower treatment efficiency and higher aeration power costs for a given size system, or larger components, i.e. oxygenation chambers, fluid transfer piping, and clarifier.

The mixed liquor in the oxygenation zone has 4,000 to 12,000 ppm. total suspended solids (MLSS). At least 4,000 ppm. total suspended solids is necessary to achieve high rates of BOD absorption and assimilation by the sludge, necessary to realize shorter liquor treatment times and smaller equipment as compared to the prior art air aeration method.

As previously indicated, mixed liquor total suspended solids concentrations (MLSS) above about 12,000 ppm. require prohibitively high solids concentrations in the recycling sludge, i.e. above 50,000 ppm (SS). Another reason for this 12,000 ppm. upper limit on the mixed liquor suspended solids concentration is to avoid inhibiting settling rate, which in turn results in prohibitively long solids settling time. Whereas solids tend to settle more rapidly in relatively dilute mixtures, as the solids concentration increases to a high level, the solids themselves tend to limit the solids settling rate. For a particular size oxygenation chamber, mixed liquor composition and desired level of BOD assimilation and biochemical oxidation, increased settling time requires very large, expensive clarifiers. Moreover, the long retention time of the solids in the clarifier without aeration may result in anaerobic conditions which in turn may cause loss of biological activity, denitrification, and the well-known phenomenon of "rising sludge."

Still another reason for limiting the mixed liquor total suspended solids content (MLSS) to 12,000 ppm. is to avoid reducing the day average food/biomass weight ratio (BODS/MLVSS) to a level at which the sludge biological activity and settling rates are limited. Stated otherwise, for a fixed ratio of volatile suspended solids to total suspended solids in the liquor (MLVSS/MLSS), the food/biomass ratio diminishes as the total solids level increases in the oxygenation zone, and there is insufficient food (from the BOD-containing water) to feed the increasing quantity of active biomass.

Biological oxidation systems which benefit from this invention are characterized by a biologically active sludge in the system having MLVSS/MLSS ratios of at least 0.55. The MLVSS/MLSS ratio for the mixed liquor is very similar to that of the recycle sludge (VSS/SS) as the waste water adds a relatively small quantity of solids to the system.

High total solids content in aeration are advantageous only insofar as they reflect high content of biologically active material. If the ratio is below 0.55, the active solids level will be low or modest even though total solids are very high. Ratios below 0.55 mean that a large amount of inert non-biodegradable solids have accumulated in the system and are being recirculated repeatedly through aeration and sedimentation. In order to obtain the high biological activity solids levels in aeration needed for high-rate treatment, the recycle rate of total solids must necessarily be very high. Excessive amounts of inert solids can therefore over-burden the system and prevent operation within the required limitations of the invention.

The value of the MLVSS/MLSS and VSS/SS ratios are not always controllable and is determined largely by the type of pollutants contained in the waste water. Such pollutants may be soluble or insoluble, organic or inorganic, biochemically oxidizable or non-biodegradable. Any solids such as sand, grit, polyethylene fragments or wood fiber which are not converted to CO_2 , water or cell tissue, and are deposited in the settled sludge, will augment the inerts in the system and reduce the ratio. One method of controlling the accumulation of inert solids is to suppress the auto-oxidation of bacteria and to discard larger quantities of excess sludge from the system. Another positive control available to the operator is to occasionally remove the system from service, dispose of the solids and start afresh with a new culture.

The concentration of biologically oxidizable organic material in municipal waste is sufficiently high so that volatile to total suspended solids ratio of at least 0.55 can be readily maintained in the sludge. For example MLVSS/MLSS ratios of 0.70 to 0.75 have been measured in the treatment of wastes from two different municipalities. The concentration of biologically oxidizable organic material in dairy and petrochemical waste is also high enough to provide this ratio.

The feed gas to be mixed with waste water having a BOD and recycled sludge in the oxygenation zone must comprise at least 50% by volume oxygen. Lower oxygen concentrations do not permit the establishment and maintenance of an appreciable DO content in the oxygenation zone because of dilution by the other feed gas constituent(s), e.g. nitrogen and carbon dioxide. It is also necessary to provide this feed gas in sufficient quantity to maintain gas above the mixed liquor having oxygen partial pressure of at least 300 mm. Hg. in the oxygenation zone. This high partial pressure driving force (at least twice that available with air), provides the necessary rate of oxygen dissolution into the mixed liquor without expending prohibitive power for agitation and without performing excessive mechanical attrition

on the biomass floc, reducing its agglomerate size and thus impairing its settling properties.

It has also been discovered that aeration gas affording oxygen partial pressure of at least 300 mm. Hg. is necessary to produce a heavy, settleable active biomass, aside from the associated influences of appreciable DO level and low mixing energy. In comparative bio-oxidation tests using 21% and 99.5% oxygen at about 1 atmosphere (160 mm. and 755 mm. Hg. respectively), but otherwise with equal energy input, with equal food/biomass ratio, and with high DO levels of at least 7 ppm., it was found that 99.5% oxygen produced the desirable dense biomass floc. The 21% oxygen produced a light, diffuse suspension which settled poorly leaving a turbid supernatant liquid. Moreover, this influence of an oxygen-enriched aeration gas on the floc density remained strong at oxygen partial pressure of 380 mm. Hg. (dense biomass), diminished at 300 mm. Hg. (moderately dense biomass) and essentially vanished at about 250 mm. Hg. (light, diffuse biomass). To achieve consistently high settling rates and dense sludge with relatively short liquor retention time, it is preferred to employ feed gas comprising at least 90% oxygen and in sufficient quantity to provide an oxygenation gas above the mixed liquor with oxygen partial pressure of at least 380 mm. Hg.

The oxygen gas-sludge-water having a BOD mixing step is continued for 20 to 180 minutes. If the object of the particular system employing this method is to simply remove municipal waste water's BOD content by absorption and assimilation in the sludge and provide a clean effluent, the mixing time may be relatively short, e.g. 20 minutes. If the object is to not only absorb and assimilate the BOD but also to auto-oxidize the sludge to the extent that the net production of sludge is substantially reduced, the mixing time will be considerably longer, i.e. up to 180 minutes. Based on either performance criteria, this invention permits a substantial reduction in mixing time as compared with the conventional air aeration. For example, to achieve substantial auto-oxidation in municipal waste treatment, the prior art has extended the aeration time from the 4-6 hours of common practice to at least 18-24 hours. It will be apparent that longer mixing times proportionately increase the costs of supplying aeration basin capacity, gas and agitation. Relatively longer mixing times may be required for waste water such as the petrochemical type, having higher BOD level than municipal waste water.

As discussed hereinafter in detail, the mixing is performed in a single zone which may be divided into a plurality of sub-zones wherein the oxygenated liquor flows from sub-zone to sub-zone. The aforementioned mixing duration of 20 to 180 minutes refers to the total period in which a particular quantity of solids

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are mixed with oxygen gas. By way of example, if the aeration with oxygen gas occurs in four separate sub-zones, the mixing time is the sum total gas-liquor contact times for all zones. Moreover, if the concentrated solid is aerated (stabilized) after separation from the effluent, the mixing time includes the aeration time for both mixed liquor and concentrated solids.

When the oxygenation zone is divided into sub-zones, the supernatant liquor may be separated from the liquor discharged from an oxygen mixing sub-zone and only the remaining solid passed on to the next oxygen mixing sub-zone.

Another important aspect of this method is continuing the oxygen gas-liquor mixing step to form oxygenated liquor having a dissolved oxygen content (DO) of at least 3 ppm. Where the oxygen mixing zone is divided into sub-zones, the liquor discharged from the mixing sub-zone immediately preceding the clarification zone has a DO of at least 3 ppm. As discussed hereinafter in detail, this mixing zone may be the final oxygenation sub-zone as exemplified by Fig. 5 or an intermediate oxygenation sub-zone as for example illustrated in Fig. 6. Such dissolved oxygen levels are highly desirable to insure aerobic conditions and adequate driving force for biochemical oxidation, but have normally been unattainable in prior art air aeration systems with mixed liquors containing 4,000—12,000 ppm. total suspended solids, i.e. the high concentrations characteristic of this invention. The prior art limitation was due to the rapid assimilation of BOD and the concurrent uptake of dissolved oxygen by the sludge; oxygen could not be dissolved at sufficient rate to sustain the DO level. A DO level of at least 3 ppm. in the oxygenated liquor entering the clarifier is not only necessary to avoid a chronic DO-depleted condition in the mixed liquor but additionally to accommodate momentary peaks in the BOD level fed to a plant. Moreover, the large, relatively dense floc particles which characterize the sludge produced by the

method of this invention present a diffusional resistance to the penetration of dissolved oxygen from the surface to the center of the floc particle. An adequate rate of diffusion requires a high DO level in the liquor, and is assured by a concentration of at least 3 ppm. O_2 is oxygenated liquor discharged from the mixing step. Another important reason for maintaining the DO of the oxygenated liquor at least at 3 ppm. is to insure that the effluent from the clarification zone may be introduced to a larger water body, e.g. a river, without depleting its oxygen concentration. Moreover, this method offers the opportunity of introducing an effluent with appreciably higher DO level than the larger water body, an advantage which is often economically impossible with conventional air treatment of waste water.

To obtain biologically active sludge characterized by high settleability, this invention requires control of the mixing step parameters so as to maintain the food to biomass day average weight ratio ($BOD_5/MLVSS$) at least at 0.15. This was demonstrated by a series of tests in which 99.5% oxygen gas was continuously mixed with municipal waste and recycled sludge to form mixed liquor. The latter was oxygenated in a zone comprising four consecutive mixed liquor stages by concurrently staged oxygen-containing gas. The waste feed rate and BOD content (hence the food to biomass ratio) fluctuated greatly between day and night. This fluctuation resulted in very substantial cyclic changes in the sludge initial settling rate and Sludge Volume Index, as demonstrated by Table I. The process conditions prevailing during the night periods are not within the scope of the present invention and are included for comparative purposes only. All measurements during these tests were conducted in accordance with the standard practices of the waste treatment industry as for example outlined in "Standard Methods for the Examination of Water and Wastewater Including Bottom Sediments and Sludges," published by the American Public Health Association, Inc., 11th Ed. (1962).

TABLE I

	Period A		Period B		Period C	
	Day	Night	Day	Day	Day	Night
Waste Water Feed Rate (GPM)(liters/min.)e	8.4(31.8)	4.8(18.2)	9.8(37.1)	5.3(20.0)	11.3(42.8)	5.0(18.9)
Recycle Sludge (GPM) (liters/min.)	1.6(6.1)	1.6(6.1)	1.5(5.7)	1.5(5.7)	1.6 (6.1)	2.3(8.7)
Recycle Sludge/Feed (Vol/Vol)	0.19	0.33	0.15	0.28	0.14	0.46
Feed Waste Water BOD (PPM)	187	99	250	156	227	103
Mixed Liquor: Total Suspended Solids MLSS (PPM)						
Stage 1	5743	8390	4826	7319	4701	9269
Stage 4	5623	8047	5176	7149	4873	8784
:Volatile Suspended Solids MLVSS (PPM)						
Stage 1	4406	—	—	—	—	6757
Stage 4	3879	—	—	—	—	6631
MLVSS/MLSS (Stage 1)	0.77	—	—	—	—	0.73
SVI						
Stage 1	52	66	56	74	58	99
Stage 4	49	70	57	94	59	99

TABLE I (Continued)

	Period A		Period B		Period C	
	Day	Night	Day	Night	Day	Night
Recycle Sludge						
SS (PPM)	41,379	39,723	38,629	31,013	41,512	31,543
VSS (PPM)	31,334	—	—	—	—	24,002
VSS/MLSS	0.76	—	—	—	—	0.76
Initial Settling Rate (ft/hr.) (M/HR)						
Stage 1	5.8(1.8)	1.3(0.4)	5.8(1.8)	1.7(0.5)	6.4(2.0)	0.3(0.1)
Stage 4	5.8(1.8)	1.3(0.4)	5.8(1.8)	0.9(0.3)	6.4(2.0)	0.3(0.1)
Day Average Food/Biomass Weight Ratio (BOD ₅ /MLVSS)	0.31	0.064	0.55	0.13	0.63	0.07

A possible explanation for relatively high settling rates and dense active biomass at food/biomass ratios above 0.15 is that the biomass possesses an abundance of substance(s) produced by the bacteria which promote agglomeration and flocculation of the particles. Under low food/biomass conditions below a ratio of 0.15, this substance is consumed to sustain the organisms so that the floc particles become structurally weak and are dispersed. Another possible explanation is that cell destruction (lysis) accelerates under food-depleted conditions and results in weakening the structure of the floc particles.

It should be noted that as used herein, the average food/biomass ratio of at least 0.15(lb.(kg)BOD₅)/(day × lb.(kg)MLVSS) is based upon the sum of volatile suspended

solids in all oxygenation sub-zones where when the oxygenation zone is divided into sub-zones as described above. In embodiments wherein the liquor is staged through several sub-zones the ratio will vary widely from the average value, being much higher in the initial treatment sub-zone and far lower in the final treatment sub-zone. By way of illustration, if four liquor treatment sub-zones are employed as in Fig. 4 with equal liquor flow rate and MLVSS but different liquor retention times T_1 , T_2 , T_3 and T_4 , and corresponding food/biomass ratios of 0.4, 0.3, 0.2 and 0.1, the average ratio is $(0.4 T_1 + 0.3 T_2 + 0.2 T_3 + 0.1 T_4) / (T_1 + T_2 + T_3 + T_4)$.

In the Fig. 2-6 embodiments, corresponding components have been identified by the same reference numbers for simplicity.

Referring now to Fig. 2, water having a BOD, as for example municipal sewage, enters chamber 10 through conduit 11. A source (not shown) of oxygen comprising at least 50% oxygen is provided and the oxygen gas is flowed therefrom through conduit 12 having control valve 13 therein to chamber 10. The latter is provided with gas-tight cover 14 to maintain an oxygen-enriched environment over the liquor. Recycling sludge having 12,000—50,000 p.p.m. total suspended solids is also introduced to chamber 10 through conduit 15, although the said feed water and sludge may be mixed prior to introduction in the chamber if desired.

The aforementioned streams are intimately mixed in chamber 10 as the mixing zone by mechanical agitation means 16 driven by motor 17 having a shaft passing through seal 18 in the cover 14. Although the agitation means may comprise one or more impellers located near the liquor surface, it is illustrated as positioned below the surface. In this particular embodiment, oxygenating gas disengaged from the liquor into the overhead gas space is withdrawn through conduit 19 by blower 20 for compression and return through conduit 21 to submerged sparger or diffuser 22 preferably positioned beneath agitator 16. Blower 20 is driven by a motor (not illustrated) and is preferably provided with controls to permit adjustment of its speed of rotation. Oxygen-depleted or spent oxygenation gas is discharged from chamber 10 through restricted flow conduit 23 which may also be provided with flow control valve 24.

To practice the method of this invention, the BOD-containing water, oxygen-rich feed gas and sludge are mixed to form the mixed liquor of 4,000—12,000 ppm. total suspended solids content with an active sludge characterized by a MLVSS/MLSS ratio of at least 0.55, and the oxygenating gas is continuously recirculated into the liquor for dissolution. Inert gases such as nitrogen entering with the BOD-containing water and with the oxygen-rich feed gas, and gases such as CO₂ produced in the biochemical reaction are evolved and collected with unconsumed oxygen in the space above the liquor. This gas has an oxygen partial pressure of at least 300 mm. Hg. and preferably at least 380 mm. Hg. The oxygen-rich gas may be continuously introduced to chamber 10 through conduit 12 during the mixing step, or the gas flow may be terminated when mixing is started. Similarly, the oxygen-depleted gas may be continuously discharged from the overhead space through conduit 23, or only discharged on completion of the mixing step. As a further alternative the mixing step may be performed cyclically, whereby the BOD-containing water, recycle sludge and a first quantity of oxygen-rich feed gas are mixed in a first cycle to produce partially oxygenated liquor and unconsumed oxygen-con-

taining gas of lower purity than the feed gas. This spent gas is discharged through conduit 23 and a second quantity of oxygen-rich feed gas is introduced through conduit 12 for mixing in a second cycle preferably with liquor comprised at least in part of the partially oxygenated liquor from the first cycle. This method is described more completely and claimed in our copending patent application No. 31861/70 (Serial No. 1325325) (L—7781).

The liquor level in enclosure 10 is controlled by weir 25 which discharges into overflow trough 26 and thence through discharge conduit 27. The dissolved oxygen level in the oxygenated liquor formed in the mixing step is maintained at least at 3 ppm. Adjustments in DO level may be accomplished by varying the rate of oxygen-rich feed gas flow using valve 13 in conduit 12 thereby increasing or decreasing the oxygen partial pressure in the enclosure 10 gas space. The DO level may also be adjusted by varying the power input and speed of rotation of blower 20, thereby increasing or decreasing the rate of diffusion of oxygenating gas into the liquor. The DO level may also be controlled by varying the retention time of the liquor in chamber 10. All other parameters being constant, a longer liquor retention time tends to provide a higher DO level.

At the end of the mixing step of 20 to 180 minutes duration, oxygenated liquor is discharged through conduit 27 to within a central concentric baffle 28 of clarifier 29. Baffle 28 preferably extends from above the liquid level to a point intermediate this level and the clarifier's conical bottom. Motor 30 drives a slowly rotating rake 31 across the clarifier bottom to prevent "coning" of the dense settled sludge. The purified supernatant liquid overflows weir 32 into trough 33 and is discharged through conduit 34. The sludge is withdrawn from the clarifier bottom through conduit 35 and at least a portion thereof is pressurized by pump 36 for recycling in conduit 15 to enclosure 10 for inoculation of the incoming BOD-containing water. Any sludge not needed for recirculation is discharged through bottom conduit 37 having control valve 38 therein. As previously discussed, the volume ratio of recycling active sludge/water having a BOD is maintained in the range of 0.1 to 0.5. This ratio may be maintained by varying the speed of pump 36.

Fig. 3 illustrates another embodiment employing a multiplicity of submerged agitators 16a—e and recirculation oxygen enriched gas spargers 22a—e spaced longitudinally from end-to-end of oxygenation enclosure 10. After premixing, the water having a BOD and recycling sludge are introduced through conduit 11 at one end of enclosure 10. The resulting liquor is mixed with oxygen-rich gas introduced through

conduit 12 and the oxygenated liquor discharged from the opposite end of enclosure 10 through conduit 27 to a clarifier (not shown). Oxygen depleted gas is also discharged from the space above the liquor level and at this opposite end through conduit 23, 5 Oxygenating gas is withdrawn through longitudinally spaced conduits 19a—e for pressure recirculation through blowers 20a—e and 10 spargers 22a—e in a manner analogous to the Fig. 2 embodiment.

Enclosure 10 may be designed so that its length is very large relative to its width and depth. For a given enclosure volume such 15 geometry increases the velocity of liquor flow from feed end to discharge end, and suppresses backmixing of liquor from downstream zones into upstream zones. Such suppressed backmixing or plug flow is beneficial when multiple 20 mixing means are employed in the instant method. When backmixing is prevented, the food/biomass ratio is high at the feed end of the enclosure where the water having a BOD enters, and is low at the discharge end where 25 the oxygenated liquor overflows to the clarifier. Both of the local conditions are beneficial to complete and high rate bio-oxidation, and are representative of a preferred embodiment wherein a multiplicity of staged liquid oxygenation sub-zones constituting the oxygenation 30 zone are employed. If back-mixing is permitted, e.g. by other oxygenation enclosure geometry, the food content at the feed end would be diluted with partly oxygenated liquor from downstream sub-zones while a portion 35 of the liquor discharged to the clarifier would have by-passed complete treatment and still contain unassimilated BOD.

Prior art multiple air aerator systems have 40 not had the capacity to supply sufficient oxygen to avoid anaerobic conditions in a sub-zone of high solids and high food/biomass ratio. Accordingly, it has usually been preferable to operate a substantial portion of the air 45 aeration systems at the feed end under completely mixed conditions with no appreciable BOD gradient. In this manner the high BOD feed water was diluted and the BOD content deliberately dispersed into the downstream 50 aerations sub-zones.

It will be apparent from the foregoing description of Fig. 3 that the liquor is oxygenated in a series of stages from the feed to the discharge end of container 10 even though the 55 stages are not physically partitioned from each other. If container 10 is designed with small lateral cross-sectional area in the gas space beneath cover 14, a similar staged or plug flow effect can be realized in the oxygenation gas 60 flow from feed to discharge end. This also promotes virtually complete BOD removal at high flow rate, because a substantially higher partial pressure of oxygen can be maintained over the liquor at the feed gas end. Another 65 advantage of staged gas flow is that the inert

gaseous impurities can be discharged from the opposite end in a smaller volume of vent gas. As the oxygenation gas flows from end-to-end of the enclosure 10 the rate of oxygen dissolution into the liquor is substantially greater 70 than the rate of inert gas evolution from the liquor. Accordingly, the volume of the oxygenating gas stream progressively diminishes and its fractional content of inerts increases 75 from the gas feed to discharge end. It is desirable to create the high food/biomass zone (where water having a BOD is introduced) with the gas of highest oxygen content available because the oxygen demand is greatest in this zone. Conversely, the oxygen demand is 80 lowest at the oxygenated liquor discharge region and it is preferable to employ the available aeration gas of lowest oxygen content in this region. Accordingly, in embodiments of 85 this invention wherein liquor is flowed through a plurality of sub-zones for staged mixing with oxygen-containing gas, it is also preferred to flow the aeration gas cocurrently with the liquor from stage-to-stage with the gas of 90 highest oxygen content mixing with the water of highest BOD.

The Fig. 4 apparatus illustrates a mixing chamber 10 which defines an oxygenation zone, which chamber is divided into four 95 separate compartments or stages 30a, 30b, 30c and 30d, each of which defines an oxygen mixing sub-zone. Partition 31a—b extends from bottom to top of chamber 10 to separate first and second compartments 30a and 30b. 100 Similarly, partition 31b—c separates second and third compartments 30b and 30c, and partition 31c—d separates third and fourth compartments 30c and 30d. Restricted opening 32a—b provides flow of partially oxygenated liquor from first compartment 30a to 105 second compartment 30b, restricted opening 32b—c provides flow of further oxygenated liquor from second compartment 30b to third compartment 30c, and restricted opening 32c—d provides flow of still further oxygenated liquor from third compartment 30c to 110 fourth compartment 30d.

Oxygen-rich gas is introduced through manifold 12 and control valves 13a, 13b, 13c 115 and 13d in branch conduits to each of the four compartments for simultaneous mixing therein with BOD-containing liquor. These valves may for example, be responsive to a suitable measured variable such as DO level in the liquor or gas composition within the compartment. Surface type aerators 22a, 22b, 22c 120 and 22d are used to mix the oxygen-containing aeration gas in each compartment with liquor. Because the chamber walls and partitions confine the fluids within each compartment, surface mixers may be used in this embodiment without backmixing of the liquor 125 thrown upward and outward of the impeller. The oxygen-depleted gas disengaged from the liquor is discharged from each compartment 130

through restricted flow conduits 23a, 23b, 23c, and 23d. These conduits may be provided with flow control valves if desired.

An advantage of the Fig. 4 apparatus is the close approach to true plug flow of liquor. The liquor velocity through restricted openings 32a—b, 32b—c and 32c—d is sufficient to prevent backmixing. The liquor in each compartment or stage is substantially uniform in composition and the BOD content progressively declines from the liquor feed stage 30a to the liquor discharge stage 30d.

The Fig. 5 apparatus differs from Fig. 4 in the provision of flow restricting openings in the upper portions of partitions 31a—b, 31b—c and 31c—d above the liquor in the compartments. Oxygen-depleted gas from first compartment 30a flows through opening 40a—b into second compartment 30b as the feed gas therefor, and with sufficient pressure differential to prevent backmixing. In the second compartment 30b additional oxygen of the aeration gas is consumed by dissolution and biooxidation in the partially oxygenated liquor, and additional inert gases evolve into the aeration gas from the liquor. Further oxygen-depleted gas flows through restrictive opening 40b—c into third compartment 30c for mixing therein with further oxygenated liquor having entered through flow restricted liquor opening 32b—c. The third stage 30c operates in the same manner as second stage 30b, and still further oxygen-depleted gas passes therefrom through flow restricted opening 32c—d. Aeration gas of lowest oxygen content and highest inerts content is vented from fourth chamber 30d through conduit 23 at restricted rate, and oxygenated liquor of lowest BOD content is discharged through conduit 27 for passage to a clarifier (not shown).

Summarizing the method embodiment as practiced in the Fig. 4 and 5 apparatus, liquor is transferred through a plurality of sub-zones, which together comprise the oxygenation zone, for staged mixing with oxygen containing gas in each sub-zone such that the food content (BOD) of the liquor in a particular sub-zone is higher than the liquor in the next sub-zone to which the first mentioned liquor is passed. Moreover, the liquor discharged from the last sub-zone zone is the liquor which is separated into sludge and clarified effluent. In Fig. 5, unconsumed oxygen containing gas is transferred through the plurality of sub-zones for staged mixing with liquor in each sub-zone such that the oxygen content (volume % oxygen) of the gas above the liquor in a particular sub-zone is higher than the corresponding gas in the next sub-zone to which the first mentioned gas is passed, the gas flowing concurrently with the liquor from sub-zone-to-sub-zone. Whereas the feed gas introduced to the first sub-zone, i.e. into the oxygenation zone, for mixing with BOD-containing water com-

prises at least 50% oxygen (by volume) the aeration gas introduced to any or all of the succeeding sub-zones may be lower oxygen purity. For example, if the feed gas to a four-stage system is 50% oxygen the gas introduced to the second stage may contain of the order of 40% oxygen. Oxygen gas staging is described more completely and claimed in our copending patent application No. 31858/70 (Serial No. 1325324) (L-7779).

The Fig. 6 apparatus differs from the previously described multi-stage systems in that clarifier 29 is positioned intermediate second oxygenation sub-zone defined by compartment 30b and third oxygenation sub-zone defined by compartment 30c with respect to liquor flow. Further oxygenated liquor is discharged from compartment 30b through conduit 27 and flowed to clarifier 29 for separation into supernatant liquid and more concentrated solid. The former is discharged through conduit 34 and the latter is withdrawn from the clarifier bottom through conduit 50 for flow to third oxygenation sub-zone defined by compartment 30c by pump 51.

Further oxygen-depleted aeration gas is discharged from second oxygenation chamber 30b in flow restricting conduit 52 and introduced to third oxygenation chamber 30c as the aeration gas for mixing with the concentrated solid introduced through conduit 50. Control valve 53 may be provided in gas transfer conduit 52 if required. The still further oxygenated solid discharged from third compartment 30c in conduit 37 is at least partly recycled through conduits 35 and 15 to first compartment 30a as the sludge.

The advantages of this invention were demonstrated in a series of tests using a system similar to Fig. 5 and municipal sewage as the wastewater having a BOD. Four 457-gallon (1,730 liter) oxygenation chambers were provided in a rectangular covered tank, 14 ft. (4.26 meters) long x 5 ft. (1.53 meters) wide x 4 ft. (1.22 meters) deep, fitted with interstage vertical baffles extending from top to bottom. The clarifier was a cylindrical wall-conical bottom unit of 8 ft. (2.44 meters) diameter and 4-1/2 ft. (1.37 meters) center depth. A bottom rake was rotated at 4 rph. by a motor and speed reducer assembly. The liquor from the fourth oxygenation chamber was introduced at a center concentric baffle in the clarifier upper end, and the concentrated sludge withdrawn at the center of the conical bottom.

The mixing system for each chamber consisted of a 1/2-HP (5.34 kg. Cal/min) motor-driven submerged variable speed axial flow 6-inch (15.25 cm.) diameter impeller which dispersed gas from a stationary sparger located directly beneath the agitation impeller. The spargers were constructed of 1/2-inch (1.27 cm.) diameter pipe with sixteen spaced 1/16-inch (1.59 mm.) diameter orifices. A variable speed sliding vane rotary compressor was used

to recirculate the oxygenating gas from the overhead gas space of each chamber back to the submerged sparger.

- 5 Oxygen gas at 99.5% purity was supplied from pressure-regulated liquid storage cylinders. The feed oxygen was saturated with water and then introduced into the gas space above the mixture of BOD-containing water and recycled sludge in the first chamber. The
- 10 unconsumed oxygen gas (plus disengaged inert diluent and reaction product gas) was conducted to each succeeding stage by a 24—30 inch (61—76 cm.) length of two-inch (5.1 cm.) diameter tubing joining openings through the

cover over adjacent chambers. These interconnections were of such size as to provide restricted sequential gas flow from the first to the fourth oxygenation chamber under a stage-to-stage pressure differential of about 0.12-inch (0.30 cm.) H₂O. The liquor flowed in the general pattern illustrated by arrows in Fig. 5.

Table II is a summary of values for four selected days operation. All measurements summarized in Table II were performed in accordance with the procedures outlined in the previously referenced "Standard Methods for the Examination of Water and Wastewater Including Bottom Sediments and Sludges."

TABLE II

	Day A	Day B	Day C	Day D
BOD—containing Water Feed:				
Rate GPM (liters/min.)	9.7(36.7)	9.5(36.0)	10.1(38.1)	8.4(31.8)
BOD PPM	253	200	168	171
SS ¹ PPM	118	147	—	249
Oxygen Feed:				
Rate, CFH (liters/hr.)	16.8(476)	20.6(584)	29.5(836)	27.2(770)
Purity, Vol. %	99.5	99.5	99.5	99.5
Mixed Liquor:				
MLSS ¹ PPM	5880	5515	7730	5610
MLVSS ² PPM	3065	—	—	4170
MLVSS/MLSS	0.52	—	—	0.74
SVI ³ to Clarifier	—	47.5	54.2	48.9
Settling Rate⁴ to Clarifier, ft/hr (m./hr.)	5.8(1.77)	5.8(1.77)	3.2(0.98)	5.8(1.77)
DO in Stage 1 PPM	3.7	2.1	0.6	0.4
DO in Stage 2 PPM	5.1	4.5	4.0	7.4
DO in Stage 3 PPM	6.7	6.6	7.0	11.3
DO in Stage 4 PPM	3.6	11.4	9.4	13.6
Recycle Sludge:				
Rate GPM (liters/min.)	1.6(6.05)	1.0(3.79)	1.3(4.92)	1.6(6.05)
SS PPM	—	42,949	46,766	41,379
Effluent:				
BOD PPM	28.8	35.8	—	10.2
SS PPM	9	33	—	16
Day Average Food/Biomass Weight Ratio (BOD₅/MLVSS)	0.65	0.38	0.27	0.28
Solids Residence Time, Min.	160	160	156	180
Removal Efficiency, % BOD	88.6	82.0	—	94.0
Recycle Sludge/Feed, Vol/Vol	0.17	0.11	0.13	0.19

¹Total Suspended Solids.

²Volatile Suspended Solids

³Sludge Volume Index.

⁴Unstirred samples, Slowly stirred (raked) samples settle at substantially higher rates.

Table II demonstrates that the instant method may be used to achieve high BOD removal efficiency from municipal waste (82.0—94.0%) with relatively low mixing times 15 156—180 minutes), high sludge initial settling rates 3.2—5.8 ft/hr), (.98—1.77 m/hr.) and low sludge recycle rate (recycle/feed volume ratio of 0.11—0.19) at high MLSS levels (5500—7700 ppm.).

Table I and II also demonstrate a preferred embodiment wherein the oxygenated liquor has an unstirred initial settling rate of at least 5 feet (1.52 m/hr.) per hour and Mohlman sludge volume index (SVI) of no more than 15 60. These conditions have been found advantageous in providing a dense sludge.

Tables I and II also demonstrate a preferred embodiment for treating municipal sewage which is particularly suitable in offering 20 the aforescribed advantages, e.g. high solids concentration in the aeration zone and shorter solids residence time. In this embodiment the recycled sludge has 30,000 to 50,000 total suspended solids content (SS), the feed 25 gas comprises at least 90% oxygen (by volume) and the gas above the mixed liquor has oxygen partial pressure of at least 380 mm. Hg. in the oxygenation zone. The oxygenated liquor has DO of at least 5 ppm. 30 with the day average food/sludge weight ratio (BODS/volatile suspended solids) for the liquor during the oxygen gas mixing being maintained at least at 0.25. The oxygenated liquor has the initial settling rate and Mohlman sludge volume index characteristics specified 35 in the previous paragraph and the recycling sludge/municipal sewage volume ratio is 0.1 to 0.3.

Application No. 31856/70 (Serial No. 40 1325322) which teaches a method for treating water having a BOD by oxygenation in contact with bacterially active biomass, said method comprising mixing water having a BOD biomass and feed gas comprising at least 45 60% oxygen by volume in an aeration zone to form a liquor body, as necessary venting gas from said aeration zone, and continuing said mixing while simultaneously:

a) continuously recirculating one of said 50 aeration gas above the liquor and the liquor fluids in intimate contact with the other of said fluids in said aeration zone, the energy used in said mixing and said contacting being defined as the mixing plus gas liquor contact 55 energy, and maintaining

b) the oxygen feed gas to mixing plus-liquor contact ratio at 0.02—0.24 Kg. moles oxygen per kilowatt hour of energy supplied,

c) the aeration gas above said liquor at an 60 oxygen partial pressure of at least 300 mm. Hg. but below 80% by volume of oxygen while consuming at least 50% by volume of the feed gas oxygen in said liquor,

d) the dissolved oxygen concentration of 65 said liquor at below 70% of saturation with

respect to the oxygen in said aeration gas above the liquor but above about 2 ppm; and thereafter withdrawing oxygenated liquor containing dissolved liquor from said aeration zone.

Application No. 31857/70 (Serial No. 1325323) which teaches a method for treating water containing bio-chemically oxidizable material which provides a BOD comprising 70 introducing into a contact aeration zone as hereinbefore defined, said water having a BOD sufficient recycling bacterially active sludge from a subsequent sludge stabilization and/or auto-oxidation zone or zones as hereinbefore 75 defined to provide volatile suspended solids content of at least 3000 ppm; and a first gas comprising at least 50% oxygen (by volume) and mixing same as the aeration gas with the water having a BOD and recycled sludge in the aeration zone for a liquid-solid contact 80 time of at least 5 minutes in sufficient quantity and rate to maintain the dissolved oxygen content (DO) of the mixture at least 0.5 ppm and form suspended activated sludge; discharging said suspended activated sludge from the aeration zone into a separate sludge stabilization zone or zones; introducing a second 85 gas comprising at least 35% oxygen (by volume) and mixing same with said suspended activated sludge in said stabilization zone or zones in sufficient quantity and rate to form BOD-depleted activated sludge having a lower BOD than said suspended activated sludge, the liquid-solid total contact time in said aeration 90 plus said sludge stabilization zones being 20—90 minutes; discharging said BOD-depleted activated sludge from the sludge stabilization zone or zones into a separate auto-oxidation zone or zones; introducing a third gas comprising at least 35% oxygen (by volume) 105 and mixing same with said BOD-depleted activated sludge in said auto-oxidation zone or zones in sufficient quantity and rate to maintain the DO of such mixture at least 5 ppm with liquid-solid contact time of 30—110 120 minutes to form auto-oxidized sludge; and withdrawing and returning at least part of sludge derived from said sludge stabilization and/or auto-oxidation zones to aeration zone containing water having a BOD as said recycling 115 sludge.

Application No. 31858/70 (Serial No. 1325324) which teaches in one aspect a method for treating water having a BOD oxygenation in contact with a bacterially active biomass, 120 comprising mixing water having a BOD biomass and feed gas comprising at least 50% oxygen (by volume) and simultaneously continuously recirculating one of such fluids against the other fluids in a first gaseous oxygenation stage to form first oxygenated liquid-solid and first unconsumed oxygen-containing gas comprising at least 35% oxygen, discharging said first unconsumed oxygen-containing gas from the first stage and mixing the 125 130

discharged gas with liquid-solid and simultaneously continuously recirculating one of such fluids against the other fluids in at least one further gaseous oxygenation stage to form at least a second oxygenated liquid-solid and second unconsumed oxygen-containing gas of lower oxygen purity and content than the first gas, and discharging the second gas from the second stage; and regulating the flow of oxygen-containing gas and/or liquid-solid contact energy input to the first and all succeeding gaseous oxygen stages such that:

a) at least 60% (by volume) of the oxygen in said feed gas is consumed in the liquid-solid of all stages,

b) between 0.04 and 0.24 kg.—moles per hour of oxygen are introduced to the first stage per one kilowatt of mixing and gas-liquid contact energy used in all stages, and

c) the gas discharged from the final gaseous oxygenation stage wherein unconsumed oxygen gas from the preceding stage has been contacted with aqueous liquid-solid, comprises more than 21% and less than 80% oxygen; and, in another aspect, apparatus for oxygenation of water having a BOD provided by biochemically oxidizable material comprising a storage enclosure for BOD-containing water, an oxygen gas source at least two separate oxygenation chambers within said storage enclosure each having walls extending substantially to the floor of said storage enclosure and a roof over the upper ends of said walls, means for introducing feed water having a BOD to one oxygenation chamber, passageway means between said oxygen source and said one oxygenation chamber, means for mixing oxygen gas with said feed water within the one oxygenation chamber to form a first oxygenated liquid-solid, restricted passageway means for flow of unconsumed aeration gas from the upper portion of said one oxygenation chamber to at least one further oxygenation chamber, restricted flow means for transferring the first oxygenated liquid-solid to said second oxygenation chamber, and means for mixing said unconsumed oxygen gas with first oxygenated liquid-solid within said second oxygenation chamber to form a second oxygenated liquid-solid, and separate means for continuously recirculating a fluid in each of said oxygenation chambers in contact with other fluids in such chamber.

Application No. 31861/70 which teaches in one aspect a method for treating water having a biochemical oxygen demand (BOD) provided by biochemically oxidizable material by cyclic oxygenation in contact with bacterially active biomass, said method comprising a first oxygenation cycle of mixing said water having a BOD and biomass as liquor and a first feed gas comprising at least 50% oxygen (by volume) and having an oxygen partial pressure of at least 37.8 cm Hg. while simultaneously and continuously recirculating one of such

fluids against the other fluids in a chamber for at least 10 minutes and with sufficient mixing and gas-liquor contact energy input to consume at least 60% (by volume) of the oxygen in said first feed gas to form a first oxygenated liquid-solid and a first unconsumed oxygen-containing gas over said first oxygenated liquid-solid comprising 10—70% oxygen but of lower oxygen purity than said first feed gas and having an oxygen partial pressure of at least 7.6 cm. Hg.; discharging said first unconsumed oxygen-containing gas from said chamber; a second oxygenation cycle of mixing in said chamber a second feed gas quantity comprising at least 50% oxygen (by volume) and having an oxygen partial pressure of at least 37.8 cm. Hg. and second water having a BOD and second biomass composed at least in part of said first oxygenated liquid-solid while simultaneously continuously recirculating one of such fluids against the other fluids for at least 10 minutes and with sufficient mixing and gas-liquid contact energy to consume at least 60% (by volume) of the oxygen in said second feed gas to form a second oxygenated liquid-solid and a second unconsumed oxygen-containing gas over said second oxygenated liquid-solid comprising 10—70% oxygen but of lower oxygen purity than said second feed gas and having oxygen partial pressure of at least 7.6 cm. Hg.; and discharging said second unconsumed oxygen-containing gas from said chamber, and in another aspect apparatus for cyclic oxygenation of liquor containing biochemically oxidizable material said apparatus including a liquid storage enclosure for containing liquor to be treated, an oxygenation chamber adapted to be at least partially immersed in liquor contained in the enclosure and having an opening in its normally submerged portion to allow free flow of liquor between the vessel and the chamber, oxygen supply conduit means between an oxygen gas source and said oxygenation chamber, means for mixing said oxygen gas and said liquor in said oxygenation chamber, conduit means for discharging unconsumed oxygen-containing gas from the upper portion of said oxygenation chamber and having a vent valve therein, and gas flow control means comprising a gas inlet flow control valve in said oxygen supply conduit arranged to maintain a predetermined gas pressure in said oxygenation chamber, a shut-off valve in said oxygen supply conduit; and cycle control means for simultaneously closing said shut-off valve and opening the gas vent valve, and thereafter simultaneously closing said gas vent valve and opening said shut-off valve.

WHAT WE CLAIM IS:—

1. A method for treating waste water having a Biochemical Oxygen Demand (BOD) by aeration in contact with a bacterially active sludge having a volatile suspended solids to



discharged gas with liquid-solid and simultaneously continuously recirculating one of such fluids against the other fluids in at least one further gaseous oxygenation stage to form at least a second oxygenated liquid-solid and second unconsumed oxygen-containing gas of lower oxygen purity and content than the first gas, and discharging the second gas from the second stage; and regulating the flow of oxygen-containing gas and/or liquid-solid contact energy input to the first and all succeeding gaseous oxygen stages such that:

a) at least 60% (by volume) of the oxygen in said feed gas is consumed in the liquid-solid of all stages,

b) between 0.04 and 0.24 kg.—moles per hour of oxygen are introduced to the first stage per one kilowatt of mixing and gas-liquid contact energy used in all stages, and

c) the gas discharged from the final gaseous oxygenation stage wherein unconsumed oxygen gas from the preceding stage has been contacted with aqueous liquid-solid, comprises more than 21% and less than 80% oxygen; and, in another aspect, apparatus for oxygenation of water having a BOD provided by biochemically oxidizable material comprising a storage enclosure for BOD-containing water, an oxygen gas source at least two separate oxygenation chambers within said storage enclosure each having walls extending substantially to the floor of said storage enclosure and a roof over the upper ends of said walls, means for introducing feed water having a BOD to one oxygenation chamber, passageway means between said oxygen source and said one oxygenation chamber, means for mixing oxygen gas with said feed water within the one oxygenation chamber to form a first oxygenated liquid-solid, restricted passageway means for flow of unconsumed aeration gas from the upper portion of said one oxygenation chamber to at least one further oxygenation chamber, restricted flow means for transferring the first oxygenated liquid-solid to said second oxygenation chamber, and means for mixing said unconsumed oxygen gas with first oxygenated liquid-solid within said second oxygenation chamber to form a second oxygenated liquid-solid, and separate means for continuously recirculating a fluid in each of said oxygenation chambers in contact with other fluids in such chamber.

Application No. 31861/70 which teaches in one aspect a method for treating water having a biochemical oxygen demand (BOD) provided by biochemically oxidizable material by cyclic oxygenation in contact with bacterially active biomass, said method comprising a first oxygenation cycle of mixing said water having a BOD and biomass as liquor and a first feed gas comprising at least 50% oxygen (by volume) and having an oxygen partial pressure of at least 37.8 cm Hg. while simultaneously and continuously recirculating one of such

fluids against the other fluids in a chamber for at least 10 minutes and with sufficient mixing and gas-liquor contact energy input to consume at least 60% (by volume) of the oxygen in said first feed gas to form a first oxygenated liquid-solid and a first unconsumed oxygen-containing gas over said first oxygenated liquid-solid comprising 10—70% oxygen but of lower oxygen purity than said first feed gas and having an oxygen partial pressure of at least 7.6 cm. Hg.; discharging said first unconsumed oxygen-containing gas from said chamber; a second oxygenation cycle of mixing in said chamber a second feed gas quantity comprising at least 50% oxygen (by volume) and having an oxygen partial pressure of at least 37.8 cm. Hg. and second water having a BOD and second biomass composed at least in part of said first oxygenated liquid-solid while simultaneously continuously recirculating one of such fluids against the other fluids for at least 10 minutes and with sufficient mixing and gas-liquid contact energy to consume at least 60% (by volume) of the oxygen in said second feed gas to form a second oxygenated liquid-solid and a second unconsumed oxygen-containing gas over said second oxygenated liquid-solid comprising 10—70% oxygen but of lower oxygen purity than said second feed gas and having oxygen partial pressure of at least 7.6 cm. Hg.; and discharging said second unconsumed oxygen-containing gas from said chamber, and in another aspect apparatus for cyclic oxygenation of liquor containing biochemically oxidizable material said apparatus including a liquid storage enclosure for containing liquor to be treated, an oxygenation chamber adapted to be at least partially immersed in liquor contained in the enclosure and having an opening in its normally submerged portion to allow free flow of liquor between the vessel and the chamber, oxygen supply conduit means between an oxygen gas source and said oxygenation chamber, means for mixing said oxygen gas and said liquor in said oxygenation chamber, conduit means for discharging unconsumed oxygen-containing gas from the upper portion of said oxygenation chamber and having a vent valve therein, and gas flow control means comprising a gas inlet flow control valve in said oxygen supply conduit arranged to maintain a predetermined gas pressure in said oxygenation chamber, a shut-off valve in said oxygen supply conduit; and cycle control means for simultaneously closing said shut-off valve and opening the gas vent valve, and thereafter simultaneously closing said gas vent valve and opening said shut-off valve.

WHAT WE CLAIM IS:—

1. A method for treating waste water having a Biochemical Oxygen Demand (BOD) by aeration in contact with a bacterially active sludge having a volatile suspended solids to



* C L M S *

- total suspended solids mass ratio of at least 0.55 which includes concentrating solids from the aeration and recycling concentrated solid to the aeration zone as said sludge, comprising
- 5 introducing into an oxygenation zone waste water having a BOD, biologically active sludge having 12,000 to 50,000 ppm. total suspended solids content and feed gas comprising at least 50% oxygen (by volume) in sufficient relative
- 10 quantities to provide mixed liquor of 4,000 to 12,000 ppm. total suspended solids content and gas above said mixed liquor having an oxygen partial pressure of at least 300 mm. Hg. in said oxygenation zone, and mixing said
- 15 components in said zone for 20 to 180 minutes to form oxygenated liquor having a dissolved oxygen content (DO) of at least 3 ppm., with the day average food/biomass weight ratio (BOD₅/Volatile Suspended
- 20 Solids) for said liquor during the oxygen gas mixing being maintained at least at 0.15; separating said oxygenated liquor into said sludge and clarified effluent; and recycling at least part of said sludge to said oxygenation
- 25 zone at flow rate relative to that of said waste water having a BOD such that the recycling sludge/waste water having a BOD volume ratio is 0.1 to 0.5.
- 30 2. A method as claimed in claim 1 in which said oxygenated liquor has an unstirred initial settling rate of at least 5 feet (1.52 meters) per hour and Mohlman sludge volume index (SVI) of no more than 60.
- 35 3. A method as claimed in claim 1 or 2 in which said feed gas comprises at least 90% oxygen and the oxygenation gas above said mixed liquor has an oxygen partial pressure of at least 380 mm. Hg.
- 40 4. A method as claimed in claim 1, 2 or 3, in which liquor is transferred through a plurality of sub-zones which together comprise said oxygenation zone for staged mixing with oxygen-containing gas in each sub-zone such that the food content (BOD) of the liquor in a particular sub-zone is higher than the liquor 45 in the next oxygen mixing sub-zone to which the first mentioned liquor is transferred.
5. A method as claimed in claim 4 in which the liquor discharged from the last sub-zone is said liquor separated into said sludge and 50 clarified effluent.
6. A method as claimed in claim 4 in which supernatant liquid is separated from the liquor discharged from an oxygen mixing sub-zone and only the remaining solid is passed to the 55 next oxygen mixing sub-zone.
7. A method as claimed in claim 4 in which unconsumed oxygen-containing gas is transferred through said multiplicity of sub-zones for staged mixing with liquor in each sub-zone 60 such that the oxygen content (volume % oxygen) of the gas above the liquor in a particular sub-zone is higher than the corresponding gas in the next sub-zone to which the first mentioned gas is transferred and the gas flows co- 65 currently with liquor from sub-zone-to-sub-zone.
8. A method as claimed in any of the preceding claims in which the biologically active sludge has 30,000 to 50,000 ppm. total suspended solids content, the dissolved oxygen content (DO) of said oxygenated liquor is at least 5 ppm., the day average food/biomass weight ratio (BOD₅/volatile suspended solids) for said oxygenated liquor during the oxygen 70 gas mixing is maintained at least and at 0.25, and the recycling sludge/waste water having a BOD volume ratio is 0.1 to 0.3.
9. A method for biochemically treating waste water containing biochemically oxidiz- 80 able material according to claim 1, substantially as hereinbefore particularly described with reference to and as illustrated in the accompanying drawings.
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