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(21) International Application Number: PCT/US95/01381 (22) International Filing Date: 2 February 1995 (02.02.95) (30) Priority Data: 191,242 2 February 1994 (02.02.94) US (60) Parent Application or Grant (63) Related by Continuation US 191,242 (CON) Filed on 2 February 1994 (02.02.94) (71) Applicants (for all designated States except US): MERCK & CO., INC. [US/US]; 126 East Lincoln Avenue, Rahway, NJ 07065 (US). MERCK SHARP & DOHME (IRELAND) LTD. [IE/IE]; Ballydine Kilsheelan, Clonmel County, Tipperary (IE). (72) Inventors; and (75) Inventors/Applicants (for US only): BOYLE, Robert [IE/IE]; Ballydine Kilsheelan, Clonmel County, Tipperary (IE). VENKATARAMANI, Edamanal, S. [IN/US]; 126 East Lincoln Avenue, Rahway, NJ 07065 (US).		(74) Common Representative: MERCK & CO., INC.; Patent Dept., 126 East Lincoln Avenue, Rahway, NJ 07065 (US). (81) Designated States: AM, AU, BB, BG, BR, BY, CA, CN, CZ, EE, FI, GE, HU, JP, KG, KR, KZ, LK, LR, LT, LV, MD, MG, MN, MX, NO, NZ, PL, RO, RU, SI, SK, TJ, TT, UA, US, UZ, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG), ARIPO patent (KE, MW, SD, SZ). Published <i>With international search report.</i>
(54) Title: BIODEGRADATION OF METHANESULFONIC ACID		
(57) Abstract		
A process is described for the acclimation and enrichment of an activated sludge culture for the degradation of high concentrations of methanesulfonic acid, so as to render it non-toxic to the aquatic environment.		

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TITLE OF THE INVENTION

BIODEGRADATION OF METHANESULFONIC ACID

BACKGROUND OF THE INVENTION

Microbial degradation of methanesulfonic acid (MSA) is a missing link in the biogeochemical sulfur cycle. Atmospheric dimethyl sulfide, arising from marine algae, cyanobacteria and salt marsh plants is the principal sulfur compound entering the atmosphere from aquatic and terrestrial environments. MSA has been identified as a major product of the photochemical oxidation of dimethyl sulfide in the atmosphere. Dimethyl sulfide and MSA are predominantly biogenic in origin and are the main gaseous links in the biogeochemical sulfur cycle. MSA is a stable compound and does not undergo photochemical decomposition. Removal of MSA from the atmosphere is by wet and dry deposition. MSA partitions into aerosol, in nucleating droplet formation and is deposited in rain and snow. Analysis of Antarctic ice cores gives evidence of its global deposition over many thousands of years.

The search for methylotrophs and sulfur bacteria, able to derive energy from the degradation of MSA, has recently been revealed. Organisms that are involved in the microbial degradation of MSA are identified as facultatively heterotrophic methylotrophs and include *Escherichia coli* K-12 and *Chlorella fusca*.

However, information on the fate of MSA in wastewater is almost nonexistent. It has been determined, using *Daphnia magna* toxicity assay, that pure MSA has an LC₅₀ of only 2 mg/L. Therefore, MSA in wastewater poses significant environmental problems in the form of aquatic toxicity. A waste treatment system for MSA degradation to non toxic levels is highly desirable. Unfortunately, there has been no adequate secondary liquid waste treatment system for MSA degradation. Although, as noted above, reports describe microbial degradation of MSA, they are confined to low concentration inherent biodegradability of the compound in a laboratory scale, not high concentration secondary liquid waste treatment. Further,

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biodegradation of MSA in a typical activated sludge treatment system has not been taught or suggested. The present invention establishes use of a continuous, acclimated activated sludge culture that removes up to 99% of MSA in a secondary liquid waste treatment system at concentrations as high as 1000 mg/L MSA. The acclimated system of the present invention has also been found to utilize MSA as the sole source of carbon for growth and energy, at concentrations as high as 1000 mg/L.

SUMMARY OF THE INVENTION

By this invention, there is provided a process for the acclimation of activated sludge culture for the biodegradation of methanesulfonic acid (MSA). This invention is also directed to a continuous process for the treatment of wastewater containing high concentrations of MSA that comprises:

- a) Acclimating activated sludge; and
- b) Adding increasing concentrations of methanesulfonic acid in wastewater; and
- c) Adjusting and maintaining solution pH from about 6.5 to about 8.0; and
- d) Maintaining influent biological oxygen demand from about 250 to 3500 mg/L; and
- e) Maintaining a hydraulic residence time from about 40 to about 60 hours; and
- f) Maintaining a sludge density from about 4 to about 7 g/L; and
- g) Discharging methanesulfonic acid deficient effluent.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is directed to a process for the acclimation of an activated sludge culture that is capable of degrading high concentrations of methanesulfonic acid (MSA). The present invention is also directed to an aerobic biological liquid waste treatment

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process that is designed to degrade MSA in wastewater utilizing an acclimated activated sludge culture.

For the purposes of this invention "activated sludge culture" shall mean a mixed microbial population of activated sludge treatment plant origin.

For the purposes of this invention "acclimated activated sludge culture" shall mean an activated sludge culture that has been exposed to increasing amounts of a chemical to serve as a carbon source and/or an energy source over a fixed period of time while feeding the sewage sludge microbial community with raw or synthetic sewage.

For the purposes of this invention "biodegradation" shall mean the microbial mediated process of breakdown of a chemical which serves as a carbon or energy source.

For the purposes of this invention "Centrum vitamin solution" shall mean a liquid comprising 166.7 I.U. vitamin A, 2.0 I.U. vitamin E, 4.0 mg vitamin C, 0.1 mg vitamin B₁, 0.1 mg vitamin B₂, 0.4 mcg vitamin B₁₂, 26.6 I.U. vitamin D, 20 mcg biotin, 0.7 mg pantothenic acid, 10 mcg iodine, 0.6 mg iron, 0.02 mg zinc, 0.17 mg manganese, 1.6 mcg chromium, 1.6 mcg molybdenum per ml.

For the purposes of this invention "hydraulic residence time (HRT)" shall mean the time that a given liquid spends in a vessel.

Preferably, this invention comprises acclimating activated sludge; adding methanesulfonic acid; maintaining solution pH from about 6.5 to 8.0; maintaining biological oxygen demand from about 250 to 3500 mg/L; maintaining hydraulic residence time from about 40 to 60 hours; maintaining a sludge density from about 4 to about 6 g/L; and discharging methanesulfonic acid deficient effluent.

The acclimation of the activated sludge culture involves a stepwise addition of increasing concentrations of a carbon source over time and establishing the extent of biodegradation of the carbon source.

More specifically, the acclimation of the activated sludge culture of the present invention involves a stepwise addition of increasing concentrations of MSA in the presence of an additional

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carbon source over time and establishing the extent of biodegradation of MSA and the additional carbon source.

Preferably, the present invention involves the stepwise addition of MSA beginning with about 25 mg/L and ultimately maintaining steady state conditions to effect quantitative biodegradation of MSA at each stepwise increase in MSA concentration. This is normally achieved in about three to about ten days.

The acclimation of the activated sludge culture is initiated by securing inocula of activated sludge from domestic and industrial wastewater treatment facilities. The activated sludge is then grown in nutrient media that lacks sulfur containing compounds, such as magnesium sulfate. However, in order to maintain the ionic balance of the medium, the chloride salt of a metal compound may be used as a replacement for the magnesium sulfate. This nutrient media is supplemented with Centrum vitamin solution that provides essential organic micronutrients and minerals to the microorganisms for growth. In the present case, ethanol and methanol served as the additional, easily metabolizable carbon source.

Acclimation of the activated sludge culture requires using from about 5 to about 50 mg/L MSA, preferably 40 mg/L MSA in this nutrient medium. Total sludge density in the reactor is maintained in the range of about 4.6 to about 7.8 g/L, preferably at about 6 g/L by appropriate wasting of mixed liquor suspended solids (MLSS). The hydraulic residence time for the acclimated activated microbial population in the continuous culture reactor is maintained from about 40 to 60 hours, preferably about 60 hours. The pH is maintained between 6.5 and 8.0, preferably about 7.2.

MSA concentration in the reactor is increased when biodegradation in the reactor for the current MSA concentration is generally >99% for at least three consecutive days. The amount of the increase ranges from 25 to 100% MSA with the maximum concentration at 2000 mg/L MSA. Percent biodegradation of MSA is monitored using direct ion chromatography. In order to confirm MSA biodegradation, effluent sulfate generation is also monitored via direct

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ion chromatography. Theoretically, the sulfate to MSA mole balance is 1:1.

Total organic carbon (TOC) and total oxygen demand (TOD) parameters are used as indirect measurements of the acclimated activated microbial growth and degradation performance during acclimation and degradation of MSA in steady state. TOC removal is generally from about 72 to 97% and TOD removal is generally from about 77 to 99%. Percent TOC and TOD removal efficiency increases as the system is well acclimated before challenging with increasing concentrations of MSA.

EXAMPLE 1

Acclimation of Activated Sludge Culture using MSA and Continuous Biodegradation of High Concentrations of MSA in Liquid Waste

About 1.0 L of activated sludge culture from internal and POTW sources was added to a 2.95 L bioreactor. The activated sludge culture was grown in a nutrient media that comprised 6.0 mg/L KN_3 , initially 750.0 mg/L NaHCO_3 , 25.0 mg/L NaH_2PO_4 , 4.0 mg/L KCl , 1600.0 mg/L $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$, 40.0 mg/L $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$, 2.0 mg/L CaCl_2 , 2.0 mg/L ZnCl_2 , 20.0 mg/L $\text{MnCl}_2 \cdot 4\text{H}_2\text{O}$, 2.4 mg/L $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$, 0.080 mg/L $\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$, 0.040 mg/L H_3BO_3 , 0.028 mg/L $\text{Na}_2\text{MoO}_4 \cdot 2\text{H}_2\text{O}$, 160.0 mg/L Bacto® beef extract, 110.000 mg/L Bacto® peptone, 90.000 mg/L urea, 15.000 mg/L Bacto® yeast extract, 473.400 mg/L ethanol, 477.600 mg/L methanol, 1000.000 mg/L Centrum liquid vitamins, 40.000 mg/L MSA. However, NaHCO_3 was used as a buffer and its concentration was adjusted from about 750.0 to 1500 mg/L to maintain a reactor pH from about 6.5 to 8.0, preferably 7.2. Aeration of the continuous culture was accomplished by forced air pumped into the bioreactor from the bottom. The HRT of the activated sludge culture was maintained at about 60 hours using a peristaltic pump. The ratio of aeration to solid settling volume was about 7.0. The solids in the reactor were maintained at about 6.0 g/L by appropriate wasting of MLSS through the stopcock port located at the bottom of the reactor.

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The components of the media in the bioreactor were constantly monitored by taking about 10.0 mL samples and subjecting these samples to direction chromatography. Specifically, MSA degradation, sulfate generation, TOC, TOD and TS were monitored. Once MSA biodegradation reached $\geq 98\%$ for at least three consecutive days, the amount of MSA in the media was increased to the next level. Specifically, the stepwise additions of MSA for the acclimation of the activated cultures comprised 75, 100, 150, 200, 250, 500, and 1000 mg/L MSA. TOC and TOD removal rates were from 72-99%, respectively. Steady state operation of the acclimated activated sludge culture was attained after about three to five residence times. Indicia of steady state were the amount of biodegradation of MSA, sulfate generation, TOC, TOD and TS within the aforementioned parameters. Once steady state was attained, the culture could be maintained indefinitely provided TOC, TOD, sludge density, pH, MSA concentration and MLSS parameters were strictly maintained. The effluent from the reactor during steady state operation contained $\leq 2\%$ of the influent MSA concentration.

EXAMPLE 2

Use of MSA as the Sole Carbon Source for Growth and Energy

The processes described in Example 1 can be used without the addition of ethanol and methanol to the media. However, the nutrient addition is balanced for the reduced carbon source. The activated sludge culture was grown in a nutrient media that comprised 6.0 mg/L KN_3 , initially 750.0 mg/L NaHCO_3 , 25.0 mg/L NaH_2PO_4 , 4.0 mg/L KCl , 1600.0 mg/L $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$, 40.0 mg/L $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$, 2.0 mg/L CaCl_2 , 2.0 mg/L ZnCl_2 , 20.0 mg/L $\text{MnCl}_2 \cdot 4\text{H}_2\text{O}$, 2.4 mg/L $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$, 0.080 mg/L $\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$, 0.040 mg/L H_3BO_3 , 0.028 mg/L $\text{Na}_2\text{MoO}_4 \cdot 2\text{H}_2\text{O}$, 160.0 mg/L Bacto® beef extract, 110.0 mg/L Bacto® peptone, 90.0 mg/L urea, 15.0 mg/L Bacto® yeast extract, 473.4 mg/L ethanol, 477.6 mg/L methanol, 1000.0 mg/L Centrum liquid vitamins, 40.0 mg/L MSA. However, NaHCO_3 was used as a buffer and its concentration was adjusted from about 750.0 to about 1500 mg/L to

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maintain a reactor pH from about 6.5 to 8.0, preferably 7.2. The stepwise addition of MSA for acclimation comprised 100, 200, 250, 500, 1000, and 2000 mg/L MSA.

EXAMPLE 3

Large Scale Wastewater Treatment of MSA

In the large scale, 3 completely mixed aeration basins, operating in parallel, were acclimated to MSA. The operating parameters utilized were: Aeration volume = 4.5×10^6 L, MLSS = 5.8-6.2 g/L, Dissolved Oxygen (DO) = 4-6.5 mg/L, T = 13-15°C, HRT = 2.4 days (60 hours), pH = 6.9-7.2. The BOD of the influent was maintained at 1500 mg/L using Methanol, Ethanol and plant waste components. The Nitrogen and Phosphorous were maintained at 30-40 and 4-8 mg/L, respectively.

Large scale wastewater acclimation to MSA was prepared utilizing 20 mg/L MSA as the initial concentration. Influent concentration of MSA was increased when the MSA level in the effluent was <1 mg/L. MSA levels were monitored using Ion Exchange Chromatography. The MSA concentration in the influent was eventually increased to about 250 mg/L (about 450 kg/day) in about 2-3 weeks. During this period of slow acclimation, MSA degradation was >98% for each and every concentration. The well acclimated activated sludge could degrade >98% of MSA at about 250 mg/L for several weeks.

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WHAT IS CLAIMED IS:

1. A continuous process for biodegradation of methanesulfonic acid in wastewater comprising use of an acclimated activated sludge culture.
2. The process of Claim 1 wherein the concentration of methanesulfonic acid in a feed to the acclimated activated sludge culture is about 5 to about 2000 mg/L.
3. The process of Claim 2 wherein the concentration of methanesulfonic acid is about 1000 mg/L.
4. The process of Claim 3 wherein the acclimated activated sludge culture has a pH from about 6.0 to about 8.0.
5. The process of Claim 4 wherein the pH of the acclimated activated sludge culture is about 7.2.
6. The process of Claim 5 wherein the methanesulfonic acid containing wastewater has a hydraulic residence time from about 24 to about 70 hours.
7. The process of Claim 6 wherein the hydraulic residence time of the methanesulfonic acid containing wastewater is from about 40 to about 60 hours.
8. The process of Claim 7 wherein the hydraulic residence time is about 60 hours.
9. The process of Claim 8 wherein the feed to the acclimated activated sludge culture has a biological oxygen demand from about 250 to about 3500 mg/L.

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10. The process of Claim 9 wherein the biological oxygen demand is from about 250 to about 1500 mg/L.

11. A process for acclimating an activated sludge culture wherein methanesulfonic acid is added in a stepwise manner.

12. The process of Claim 11 wherein about 5 to about 50 mg/L of methanesulfonic acid is initially added to the activated sludge culture.

13. The process of Claim 12 wherein about 25 mg/L of methanesulfonic acid is initially added to the activated sludge culture.

14. The process of Claim 13 wherein the concentration of methanesulfonic acid is increased every three to twenty days.

15. The process of Claim 14 wherein the methanesulfonic acid is increased after 10 days.

16. The process of Claim 15 wherein the methanesulfonic acid addition is increased 100%.

17. The process of Claim 16 comprising a final total concentration of less than 2000 mg/L methanesulfonic acid.

18. A continuous process for the biodegradation of methanesulfonic acid comprising:

- a) Acclimating activated sludge; and
- b) Adding increasing concentrations of methanesulfonic acid in wastewater; and
- c) Adjusting and maintaining solution pH from about 6.5 to about 8.0; and

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- d) Maintaining influent biological oxygen demand from about 250 to 3500 mg/L; and
- e) Maintaining a hydraulic residence time from about 40 to about 60 hours; and
- f) Maintaining a sludge density from about 4 to about 6 g/L; and
- g) Discharging methanesulfonic acid deficient effluent.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/01381

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :C02F 3/34

US CL :210/610

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 210/610, 611, 624, 631, 928; 435/262.5, 245, 287, 821

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONEElectronic data base consulted during the international search (name of data base and, where practicable, search terms used)
NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	NATURE, Volume 350, issued 18 April 1991, Baker et al, "Microbial Degradation of Methanesulfonic Acid", pages 627-628.	1-18

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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