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(71) Applicant: BATTELLE MEMORIAL INSTITUTE [US/US]; Pacific Northwest Division, Intellectual Property Services, P.O. Box 999, Richland, WA 99352 (US).

(72) Inventors: SURMA, Jeffrey, E.; 806 Brian Lane, Kennewick, WA 99337 (US). BRYAN, Garry, H.; 508 S. Filmore, Kennewick, WA 99336 (US). GEETING, John, G., H.; 4021 Westlake Drive, West Richland, WA 99353 (US). BUTNER, R., Scott; 7058 Bayview Drive S.E., Port Orchard, WA 98366 (US).

(74) Agent: ZIMMERMAN, Paul, W.; Battelle Memorial Institute, Pacific Northwest Division, Intellectual Property Services, P.O. Box 999, Richland, WA 99352 (US).

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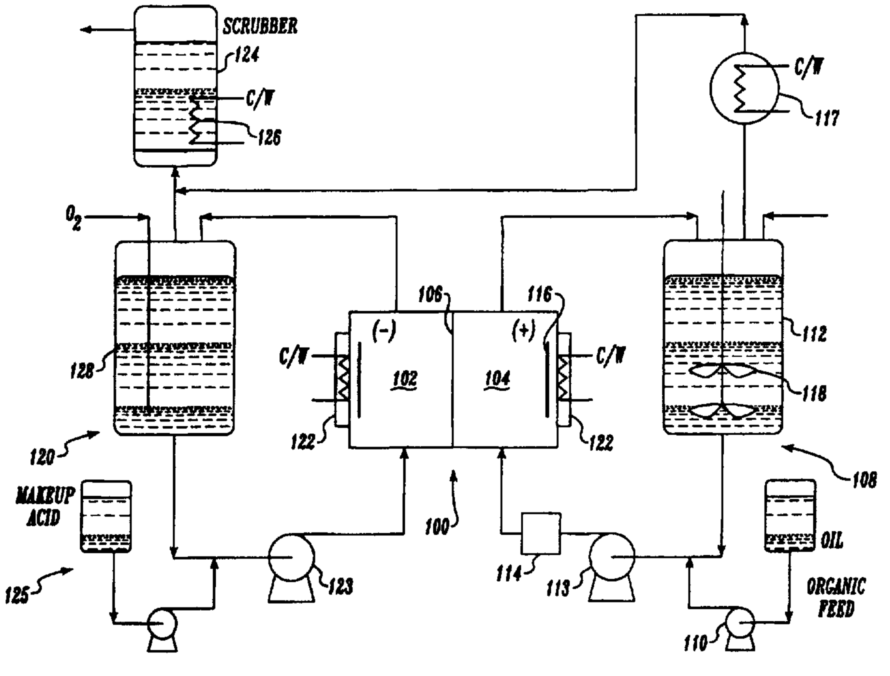

(57) Abstract

The invention is a method and apparatus using high cerium concentration in the anolyte of an electrochemical cell to oxidize organic materials. The method and apparatus further use an ultrasonic mixer to enhance the oxidation rate of the organic material in the electrochemical cell.

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APPARATUS AND METHOD FOR OXIDIZING ORGANIC MATERIALS

FIELD OF THE INVENTION

The present invention relates generally to an apparatus and method for oxidizing organic materials. More specifically, the invention relates to an apparatus and method using catalyzed electrochemical oxidation wherein the catalyst is a regenerative oxidant.

BACKGROUND OF THE INVENTION

Many organic materials are stored and ultimately require disposal. Disposal, however, is becoming more difficult with increasing environmental regulations. In addition, conventional disposal methods, for example incineration, may create additional waste, and may create a hazard especially when the organic materials are exoenergetic materials.

Use of cerium in an electrochemical cell is taught by Silva et al. in U.S. patent 5,420,088 issued 5/30/95. The Silva et al. process is for the purpose of recovering catalyst material from latent catalyst material solids. Oil or organic material is preferably extracted or removed from latent catalyst material solids before the latent catalyst material solids are placed into the electrochemical cell. However, organic material may be reacted in the electrochemical cell together with the latent catalyst material solids, but with a reduced efficiency of recovering catalyst material.

The destruction of cutting oils using catalyzed electrochemical oxidation technology has been studied (Surma et al. 1991) using silver (II) as the catalyst in the HNO_3 anolyte solution. That work indicated that near complete (>99.9%) destruction of the oil could be achieved. Optimization of the oil destruction rate by selecting operating parameters of temperature, silver concentration, and electrode current density resulted in destruction efficiencies greater than 99.9%. Operating temperatures up to about 70°C were preferred.

Studies by Bray et al. 1989 have shown that organic compounds may be destroyed using electrochemical methods coupled with a catalytic oxidant, such as silver or cerium. However, the work indicated that cerium may not be kinetically fast enough for an industrial organic oxidation process.

Accordingly, there is a need for a method of disposal of organic materials that is safe for both the environment and the personnel handling the organic materials.

SUMMARY OF THE INVENTION

The invention is based upon the unexpected discovery that cerium electrooxidation of an organic/water/acid emulsion is specific to the organic phase of the emulsion and therefore exhibits a greater organic reaction rate than silver. Thus, the present invention is a method and apparatus using high cerium concentration in the anolyte of an electrochemical cell to oxidize organic materials. Organic materials specifically include organic liquids, for example oils, and solid combustible materials, for example paper products, plastics, rubber, cloth, tape, and wood. The invention includes the discovery that under certain conditions cerium can be at least as effective as silver in the destruction of organic materials, particularly cutting the oils. Specifically, conditions for cerium(IV) oxidation of combustible materials are at elevated temperature (i.e., >85°C) and at increased electrocatalyst concentrations.

The use of cerium as an electrocatalyst has shown that the catalytic electrochemical oxidation process can operate continuously with only minimal electrocatalyst depletion in the anode. The only loss of cerium is due to the slow migration across the membrane into the cathode compartment. When silver is used as an electrocatalyst for Trimsol destruction, a portion of the catalyst is lost in the precipitation reaction with chloride. Also it was observed that the migration of the cerium across the membrane separating the anode for the cathode was much lower than was observed for silver.

The use of cerium as an electrocatalyst has many advantages over silver. Specifically the cerium is not subject to losses due to precipitation as a halide as is silver. Cerium is not a hazardous or listed substance which aids in the disposition of the spent anolyte. Operation of the cell using cerium also has the advantage that higher current densities can be used resulting in higher efficiency than when silver is the electrocatalyst. Other advantages with respect to the operation of the pilot-plant were also observed that make cerium the electro-catalyst of choice. Further advantages are realized because cerium is neither a listed or a hazardous compound, making a cerium based electrochemical oxidation process a more attractive alternative than incineration.

The method and apparatus further use an agitating emulsifier to reduce the size and increase the surface area of the organic phase and enhance the oxidation rate of the organic material in the electrochemical cell.

It is an object of the present invention to provide a method for oxidizing organic materials.

The subject matter of the present invention is particularly pointed out and distinctly claimed in the concluding portion of this specification. However, both the organization and method of operation, together with further advantages and objects thereof, may best be understood by reference to the following description taken in connection with accompanying drawings wherein like reference characters refer to like elements.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of the apparatus of the present invention.

FIG. 2 is a graph of amount of oil destroyed and CO_2 concentration in the apparatus as a function of time.

FIG. 3 is a graph of amount of oil destroyed versus time for various operating temperatures.

FIG. 4 is a graph of coulombic efficiency versus time for various operating temperatures.

FIG. 5 is a graph of power factor as a function of temperature.

FIG. 6 is a graph of amount of oil destroyed, CO_2 concentration and coulobic efficiency as a function of time for Example 5.

DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

According to a preferred method of the present invention, organic materials are destroyed by (a) providing an electrochemical cell having a cathode compartment and an anode compartment separated by a porous membrane; (b) providing an oxidant in an anolyte within said anode compartment, the oxidant that is not reactive with the aqueous solution but reactive with the organic phase; (c) heating the mixture together with the cerium; (d) emulsifying the heated mixture and increasing the surface area of the organic phase; and (e) flowing electrical current through said electrochemical cell and oxidizing said organic molecules in said anode compartment.

The organic materials may be any organic materials, but the process of the present invention is especially useful for immiscible organic liquids, most especially exoenergetic materials including but not limited to chemical warfare agents, for example sarin ($C_4H_{10}FO_2P$), and high explosives, for example HMX ($C_4H_8N_8O_8$, RDX, nitrocellulose, trinitrotoluene, and nitroglycerin. Of course any combustible organic material is exoenergetic.

The oxidant is preferably cerium. For cerium, the electrochemical cell may be operated at any temperature compatible with the anolyte solution and is preferably from about 30°C to about 100°C and most preferably from about 80°C to about 100°C. The concentration of cerium is at least about 0.5M. Preferably, the cerium concentration is from about 1.0M to about 1.7M, and most preferably from about 1.5M to about 1.7M. The higher concentrations permit operation of the electrochemical cell at higher current densities and higher current efficiencies. The electrical power consumption ranges from about 4 kWh/lb to about 9 kWh/lb of the organic materials. Most organic materials can be processed at near 100% columbic efficiency, i.e., the amount of electrical power used is very near the theoretical electrical power needed to completely oxidize the organic materials to CO_2 and H_2O and possible inorganic acids in the anolyte.

Further efficiency is gained when the organic material is mixed in water and the mixture passed through an agitating emulsifier. The agitating emulsifier provides a more thorough mixing and more even distribution of the organic material in the water. In solution, the agitating emulsifier serves to completely homogenize the organic material water mixture. In a 2-phase mixture, the agitating emulsifier breaks the organic material phase into smaller "bubbles" thereby emulsifying the mixture and increasing its surface area. Whether in solution or multi-phase mixture, the agitating emulsifier improves the physical properties of the mixture for better contact to the electrodes. The agitating emulsifier may be any agitating emulsifier including but not limited to ultrasonic vibrator, and high speed propeller.

In addition, further efficiency may be realized by vibrating the electrodes and increasing the mass/charge transfer coefficient between the liquid and the electrodes.

An apparatus of the present inventions is shown in **FIG. 1.** The electrochemical cell **100** has a cathode compartment **102** and an anode compartment **104** separated by a porous membrane **106.** The electrochemical cell **100** is filled with a solution of cerium in a concentration of at least about $1\underline{M}$ in an anolyte. Because the cerium is generally present as a cerous ion, Ce(III), it is oxidized to ceric ion, Ce(IV) in the anode compartment. The ceric ion reacts with the organic material to destroy it. Electrical current flowing through said electrochemical cell provides the energy to re-oxidize cerous ions in the anode compartment **104** and continue to oxidize the organic molecules in the cathode compartment **102.** The feed may consist of a liquid organic fed into the anolyte loop **108** with a metering pump **110.** Alternatively, solids such as paper pulp and wood chips could be introduced into the anolyte loop via a screened cage (not shown) in the anolyte tank **112.**

The anolyte solution is pumped (pump **113**) through the anolyte loop **108** having of an agitating emulsifier **114.** The agitating emulsifier **114** serves to increase the organic surface area for faster oxidation rates and may provide 100 to 5000 watts or more of energy to the anolyte/organic solution. After emulsification, the solution enters the electrochemical cell anode compartment **104**, where the metal catalyst is oxidized (e.g., Ce^{3+} to Ce^{4+}). Cerium(IV) is a kinetically rapid, powerful oxidizing agent, which is reduced by reacting with and oxidizing organic molecules. After the cerium(IV) is reduced, it again is oxidized in the electrochemical cell **100**. In this cyclic manner, cerium acts as an oxidation catalyst, carrying electrons from the material being oxidized to the anode **116**. After the electrochemical cell **100**, the anolyte solution enters the anolyte tank **112**, which not only serves as a gas/liquid separator and surge tank, but also provides the capability for the oxidation of solids. Gases exiting the anolyte tank **112** pass through a condenser **117**. The anolyte tank **112** is provided with an agitator **118** to promote mass transfer if oxidation of solids is evaluated. Temperature, pressure, density, and flowrate of the anolyte and catholyte loops **108**, **120** are measured.

The cell temperature of the anode and cathode can be independently maintained through heat exchange to fluid jackets **122** on the outside of the electrochemical cell **100**. Operating temperatures of the anolyte may range from about 20°C to about 100°C, but are preferably between about 30°C and about 100°C, and most preferably from about 80°C to about 100°C. Operating pressure is preferably ambient pressure of about 1 atmosphere. Heating may be done separately, or as a result of passing electrical current through the electrochemical cell. Although the catholyte may be about the same temperature as the anolyte, it is preferred to maintain the catholyte at a lower temperature than the anolyte to reduce generation of gaseous nitrous oxide(s) (No_x). The catholyte may be cooled to just above a freezing temperature of the catholyte. Preferably, catholyte temperature is maintained at about 25°C to about 70°C which is approximately 30°C cooler than the anolyte.

The catholyte loop **120** is separated from the anolyte loop **108** with a porous barrier **106** chosen to minimize mixing while maintaining electrical conductivity. The catholyte pump **123** moves catholyte through the catholyte loop **120**. The main chemical reaction in the catholyte loop **120** is the reduction of nitric acid to HNO_2, which is reoxidized in part by bubbling O_2 through the solution from the catholyte tank. Make up acid (acid addition unit **125**) is added to the catholyte loop **120** to maintain the acid concentration. The acid is an inorganic acid in which cerium is soluble. Preferably, the acid is nitric acid which has a high solubility for cerium. Other acids include sulfuric acid and hydrochloric acid.

The evolved gases from the anolyte and catholyte tanks **112**, **128** are evacuated to the atmosphere after NO_x removal. A gas proportioner (not shown) optionally allows controlled mixing of NO_x from the catholyte off-gas and O_2 from the anolyte off-gas. Optionally, the evolved gases may be passed through a reaction vessel (not shown), where the gas phase catalytic oxidation of NO to NO_2 takes place. Because NO_2 is absorbed faster by water than NO, this reaction greatly enhances the efficiency of the NO_x scrubber **124**. After exiting the NO_x scrubber **124**, the gas is exhausted to the atmosphere. Scrubber temperature is maintained by a cooling coil **126** running through the scrubber **124**.

DATA ACQUISITION FOR EXAMPLES

A 386 computer was used with AIMAX-PLUS data acquisition and control software to control the process with minimal operator oversight. Measured parameters were automatically recorded, and the computer had direct control over four final control elements. The anolyte and catholyte temperatures were controlled by motor-operated valves which opened or closed to maintain the anolyte and catholyte temperature set points. A third motor-operated valve minimized the differential pressure between the anolyte and catholyte loops. (In the past, a build-up of pressure in one of the loops had caused the membrane to rupture.) The fourth, and final, control element was the speed of the makeup HNO_3 metering pump. Additions of HNO_3 maintained acid concentrations at set point and prevented H_2 generation. All of the final control elements were controlled via a 4 to 20 amp signal generated from the computer.

During normal operation, the computer displays a process diagram by which the operator monitors control parameters. All measured parameters can be displayed on the process diagram and provide the operator with real time measurements. In addition to monitoring parameters, the control system provides the operator with manual control of the anolyte and catholyte pumps, the power supply voltage and amperage, and the capability to override all final control elements from the computer.

Example 1

An experiment was conducted to compare organic phase destruction in an electrochemical cell with cerium or silver, and with or without emulsification. In this experiment, the agitating emulsifier was an ultrasonic mixer Model 800D, Heat Systems-Ultrasonics, Farmingdale, NY. Because the oxidation potential for silver (II) is about 1.98 volts that for cerium (IV) is about 1.64 volts, it was expected that silver would outperform cerium. The organic material was Trimsol cutting oil.

For tests without emulsification, the organic phase was not effectively destroyed. It was observed that little or no detectable oxidation of an immiscible organic liquid occurred without the use of the ultrasonic mixing. It was also observed that when the operation of the ultrasonic emulsification system was inadvertently interrupted, the oxidation rate of the organic would drop quickly.

For tests with emulsification, the results are shown in Table 1.1.

Table 1.1 Organic Destruction Rate

Oxidant	Temperature (C)	Amount of Organic Phase	Organic Destruction Rate (g/hr)
Silver (II)	70	20 ml batch	24
Cerium (IV)	95	10 ml batch	24
Cerium (IV)	85	10 ml batch	6.24
Cerium (IV)	80	10 ml batch	0.4
Silver (II)	70	118 ml continuous	51
Cerium (IV)	95	116 ml continuous	60

The cerium organic destruction rate is strongly affected by temperature. The silver is shown only for 70°C because above 70°C, the silver causes water separation and release of oxygen. Tests above 70°C were attempted and only reached as high as about 85°C beyond which the oxygen generation from the aqueous solution overwhelmed the test. The organic destruction rate is also a function of the amount or concentration of organic phase present and is less for decreasing amounts of organic phase. Thus, the fact that cerium has a destruction rate for 10 ml of organic phase equal to the destruction rate for silver starting with 20 ml of organic phase illustrates the improved destruction rate of cerium over silver. In the continuous operation tests, the cerium shows a higher destruction rate than silver both operated at optimal operating temperatures. Although cerium does not appreciably react with the aqueous solution at elevated temperatures, it is preferable to avoid boiling the aqueous solution.

Example 2

An experiment was performed to demonstrate destruction of sarin ($C_4H_{10}FO_2P$). For sarin in water, destruction to phosphoric acid, hydrogen fluoride and carbon dioxide requires 26 faradays of charge per mole of sarin or about 5 kWh/lb of sarin. The electrochemical cell **100** was operated between 40°C and 60°C at ambient pressure. Silver concentration was about 0.5M.

By analyzing the off-gas, it was calculated that the destruction efficiency was better than 99.9999%. Hence, for sarin, it does not appear that using cerium would offer any improvement in destruction efficiency compared to silver.

Example 3

An experiment was conducted to demonstrate the destruction of OTTO Fuel II according to the present invention. The elemental analysis for OTTO Fuel II was

32.50 wt%	Carbon
5.22 wt%	Hydrogen
12.87 wt%	Nitrogen
49.41 wt%	Oxygen.

Two tests were conducted: 1) a baseline or control, without electrochemical oxidation, and 2) with electrochemical oxidation. The operating conditions were identical for both tests, except for the baseline test wherein no current was passed. Both tests were conducted using silver and cerium as the oxidant to compare destruction performance between silver and cerium.

Operating conditions for silver were:

Electro-catalyst Temperature 50°C
4 M HNO_3/0.5 M silver
initial conc OTTO Fuel ≈ 1000 ppm

The destruction rate of OTTO Fuel by silver in terms of total organic carbon (TOC) was ~ 0.004 - 0.020 ppm TOC per coulomb charge passed through cell.

Operating conditions for cerium were:

Electro-Catalyst Temperature 75°C
4 M HNO_3/1.5 M cerium
initial conc OTTO Fuel ≈ 2600 ppm

The destruction rate of OTTO Fuel by cerium in terms of total organic carbon (TOC) was ~ 0.025 ppm TOC per coulomb charge passed through cell. This represents an unexpected increase in destruction rate using cerium compared to silver of at least 25% and as much as a factor of 6.

The electrochemical cell was operated with and without ultrasonic vibration and no difference in destruction performance was observed. This was expected because the concentration of OTTO Fuel in 4<u>M</u> nitric acid was near its solubility limit and therefore the OTTO Fuel was in solution. The electrochemical cell with cerium was operated for about 2 hours which resulted in 28% of the total organic carbon destroyed. Had the experiment been operated to completion, it is estimated that complete destruction would have occurred in about 7 hours under these conditions.

Example 4

Experiments were conducted to demonstrate the destruction of a cutting oil, specifically Trimsol cutting oil.

Experiments were conducted in a catalyzed electrochemical oxidation system as described above and shown in FIG. 1.

The first seven experiments were conducted to determine optimum operating conditions for the oxidation of Trimosol cutting oil. Table 4.1 lists the conditions for these seven tests.

Table 4.1. Operating Conditions for Parametric Study Using Cerium (IV) as the Electrocatalyst at a concentration of 1.5M/L

Run Identification	**Current Density Amperes/m2**	**Temperature (°C)**
Run 1	3750	80
Run 2	2500	80
Run 3	5000	90
Run 4	5000	80
Run 5	2500	97
Run 6	2500	85
Run 7	3750	95

All seven tests involved the oxidation of 10 ml of Trimsol oil. The Trimsol oil was fed continuously for 10 minutes at a feed rate of 1 ml/min. After feeding was terminated, the system operated until the evolution of CO_2 from the anode compartment approached the baseline prior to the injection of the oil. **FIG. 2** presents the data from run 5 showing nearly complete destruction of the Trimsol oil in about an hour. **FIG. 3** shows the effect of temperature on destruction rate and **FIG. 4** shows the effect of temperature on columbic efficiency. This presentation of data for this run is typical of all subsequent runs in that CO_2 concentration data is present with a calculated value of oil destroyed, and data on the overall efficiency of destruction and columbic efficiency are presented. The sharp increase in CO_2 concentration in **FIG. 4** at about 10 minutes corresponds to the initial oxidation rate of Trimsol oil which is relatively high. The oxidation rate decreases as the concentration of oil decreases in the anolyte solution. The data show a strong correlation of oxidation rate to the temperature of the anolyte solution. This is evident in the columbic efficiencies presented for each of the runs. In general it is seen that higher columbic efficiencies are obtained when the cell is operated at elevated temperatures (i.e., above 90°C). There is an exception to this trend in runs 3 and 4 because the cell operated at higher current densities, resulting in inefficiencies caused by side reactions at the anode surface (i.e., the oxidation of water, $H_2O \rightarrow e^- + H^+ + O_2$).

A summary of power factor versus temperature is presented in **FIG.5**. It is shown that operation of the CEO process above 90°C is required to obtain reasonable and cost effective performance with respect to the oxidation of Trimsol cutting oil.

Under these conditions power requirements for the oxidation of Trimsol cutting oil was observed to the 205 Kwh per gallon of cutting oil destroyed. This corresponds to a cost in the range of $6.00 to $10.00 per gallon processed.

Example 5

Three additional tests were performed to evaluate the performance of the pilot plant under continuous operations. More specifically, the tests were to determine the steady state destruction rate achievable under differing operating conditions. The primary operating parameter of interest was the concentration of cutting oil in the anolyte compartment. A summary of the runs is presented in Table 4.1.

The data from run 8 is shown in **FIG.6.** It was observed that as the concentration of oil in the anolyte increased a steady state oxidation rate of 60 ml/hour was achieved during run 8. The columbic efficiency is much higher than in runs 1 through 7 because of the much higher concentration of oil in the anolyte in run 8 relative to the prior runs.

In run 9 data shows that a steady state oil destruction rate was also achieved, evidenced by the flatting of the CO_2 concentration curve, and the destruction rate was very close to that of run 8.

Table 4.1. Operating Conditions for Continuous Operation of Pilot Plant

	Run 8	**Run 9**	**Run 10**
Current Density (ampere/m^2)	3750	2500	2500
Temperature (°C)	95	95	95
Oil Feed Rate (ml/min)	1.8	4.0	1.0 - 4.0
Cerium Concentration (moles/liter)	1.5	1.0	1.5
Duration of Test (hours)	3	5	8
Total Oil Fed (ml)	115.42	507	500

Throughout the duration of run 9, the feed rate of the oil into the anolyte compartment was altered. However, the average rate was very near that of run 8; therefore, steady state conditions were anticipated to be nearly the same for the two runs. During periods when the feed rate was increased to 4 ml/minute, steady state oil destruction rates of 80 ml/hour were observed. It is anticipated that higher rates are achievable by further increasing the organic (oil) concentration in the anolyte.

Closure

While a preferred embodiment of the present invention has been shown and described, it will be apparent to those skilled in the art that many changes and modifications may be made without departing from the invention in its broader aspects. The appended claims are therefore intended to cover all such changes and modifications as fall within the true spirit and scope of the invention.

We Claim:

1. A method of destroying a mixture of an organic phase in an aqueous solution, comprising the steps of:

(a) providing an electrochemical cell having a cathode compartment and an anode compartment separated by a porous membrane;

(b) providing an oxidant that is substantially non-reactive with the aqueous solution at an operating temperature above about 70° C in an anolyte within said anode compartment;

(c) emulsifying the mixture and increasing the surface area of the organic phase; and

(d) flowing electrical current through said electrochemical cell and oxidizing said organic molecules in said anode compartment.

2. The method as recited in claim 1, wherein said organic materials are exoenergetic materials.

3. The method as recited in claim 2, wherein said exoenergetic materials are selected from the group consisting of chemical warfare agents and high explosives.

4. The method as recited in claim 1, wherein said operating temperature is from about 80°C to about 100°C.

5. The method as recited in claim 4, wherein the operating temperature is maintained by a fluid jacket on the outside of the electrochemical cell.

6. The method as recited in claim 1, wherein the oxidant is cerium.

7. The method as recited in claim 6, wherein the concentration of cerium is from about 1.0M to about 1.7M.

8. The method as recited in claim 1, wherein the electrical current is at least about 4 kWh/lb of the organic materials.

9. The method as recited in claim 1, the step of agitating comprises:

passing the organic materials through an ultrasonic mixer.

10. The method as recited in claim 1, further comprising the step of maintaining a temperature of a catholyte below the temperature of the anolyte.

11. The method as recited in claim 10, wherein the temperature of the catholyte is above a freezing temperature of the catholyte.

12. The method as recited in claim 11, wherein the temperature of the catholyte is from about 25°C to about 70°C.

13. An apparatus for destroying an organic phase within an aqueous solution, comprising:

(a) an electrochemical cell having a cathode compartment and an anode compartment separated by a porous membrane; and

(b) cerium in an anolyte within said anode compartment; and

(c) an agitating emulsifier that increases the surface area of the organic phase.

14. The apparatus as recited in claim 13, further comprising:

a heater for raising a temperature of the electrochemical cell, wherein flowing electrical current through said electrochemical cell oxidizes said organic molecules in said anode compartment.

15. The apparatus as recited in claim 13, wherein said organic materials are exoenergetic materials.

16. The apparatus as recited in claim 15, wherein said exoenergetic materials are selected from the group consisting of chemical warfare agents and high explosives.

17. The apparatus as recited in claim 14, wherein an operating temperature is from about 30°C to about 80°C.

18. The apparatus as recited in claim 14, wherein the concentration of cerium is from about 1.5$\underline{M}$ to about 1.7$\underline{M}$.

19. The apparatus as recited in claim 14, wherein said agitating emulsifier is an ultrasonic mixer which mixes the organic materials in advance of the electrochemical cell.

20. The apparatus as recited in claim 14, wherein the heater is a fluid jacket on the outside of the electrochemical cell.

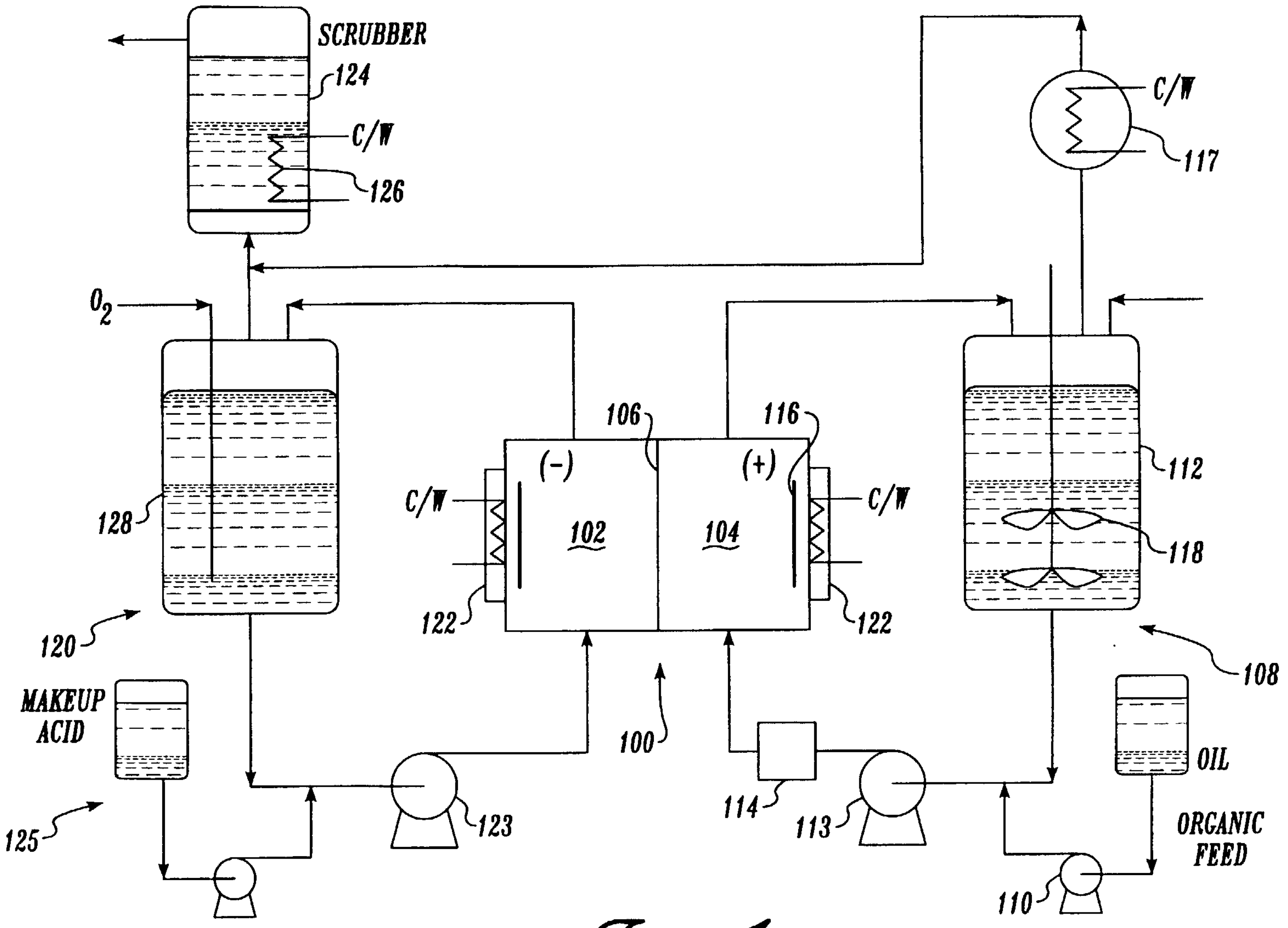
21. The apparatus as recited in claim 20, further comprising a second fluid jacket for cooling a catholyte.

22. An apparatus for destroying organic materials, comprising:

(a) an electrochemical cell having a cathode compartment and an anode compartment separated by a porous membrane; and

(b) an ultrasonic mixer for mixing the organic materials into the cathode compartment; wherein

(c) flowing electrical current through said electrochemical cell oxidizes said organic molecules in said anode compartment.


SCRUBBER
124
C/W
126
C/W
117
O2
128
120
106
116
(-)
(+)
C/W
102
104
C/W
122
122
112
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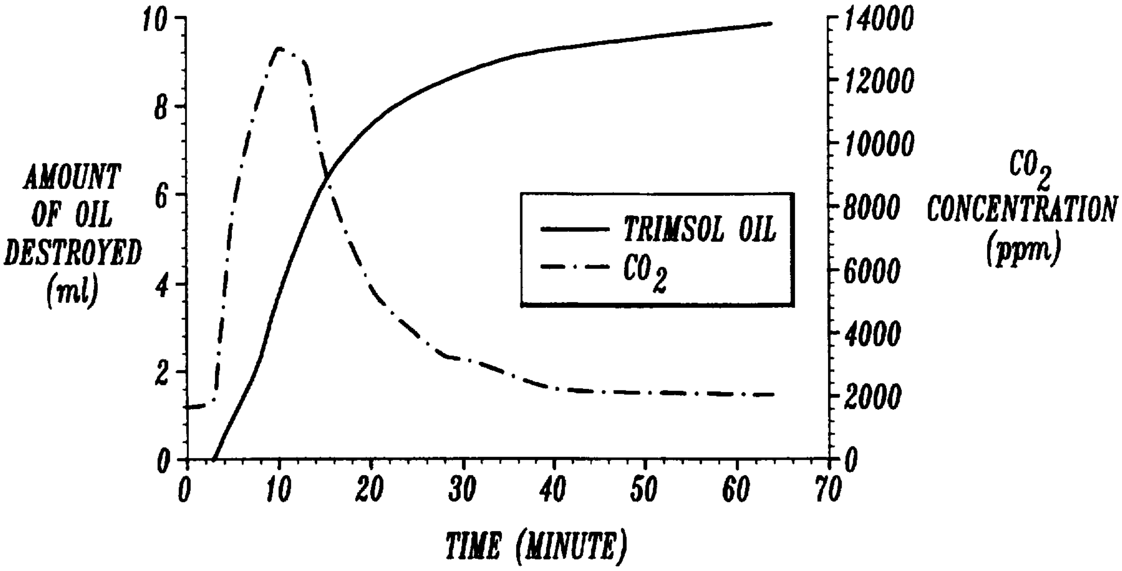
108
100
MAKEUP
ACID
125
123
114
113
OIL
ORGANIC
FEED
110

Fig. 1


10
8
6
4
2
0
AMOUNT OF OIL DESTROYED (ml)
0
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20
30
40
50
60
70
TIME (MINUTE)
14000
12000
10000
8000
6000
4000
2000
0
CO2 CONCENTRATION (ppm)
TRIMSOL OIL
CO2

Fig. 2

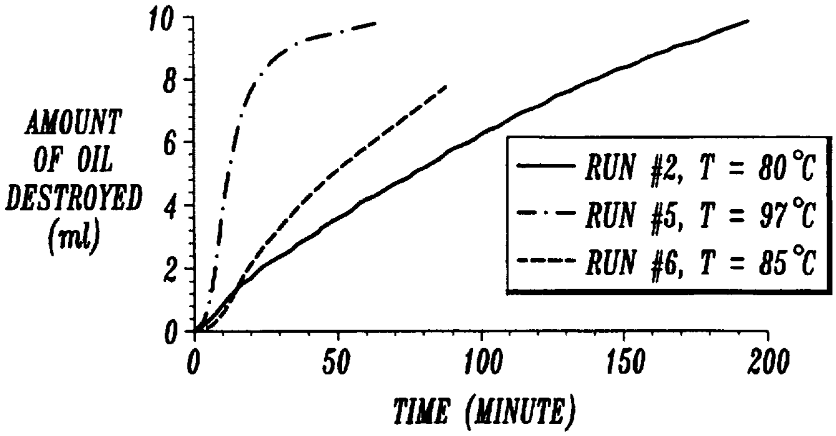
AMOUNT OF OIL DESTROYED (ml)
10
8
6
4
2
0
0
50
100
150
200
TIME (MINUTE)
RUN #2, T = 80°C
RUN #5, T = 97°C
RUN #6, T = 85°C

Fig. 3

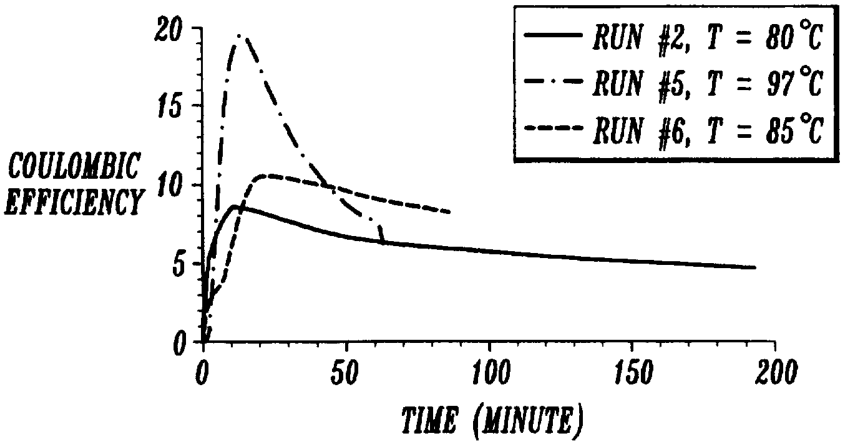
COULOMBIC EFFICIENCY
20
15
10
5
0
0
50
100
150
200
TIME (MINUTE)
RUN #2, T = 80°C
RUN #5, T = 97°C
RUN #6, T = 85°C

Fig. 4

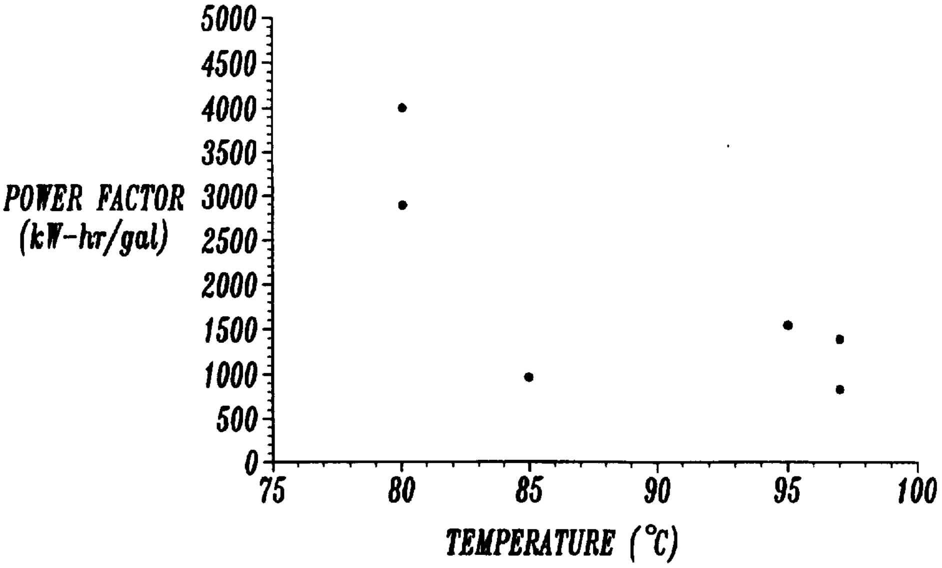
POWER FACTOR
(kW-hr/gal)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
75
80
85
90
95
100
TEMPERATURE (°C)

Fig. 5

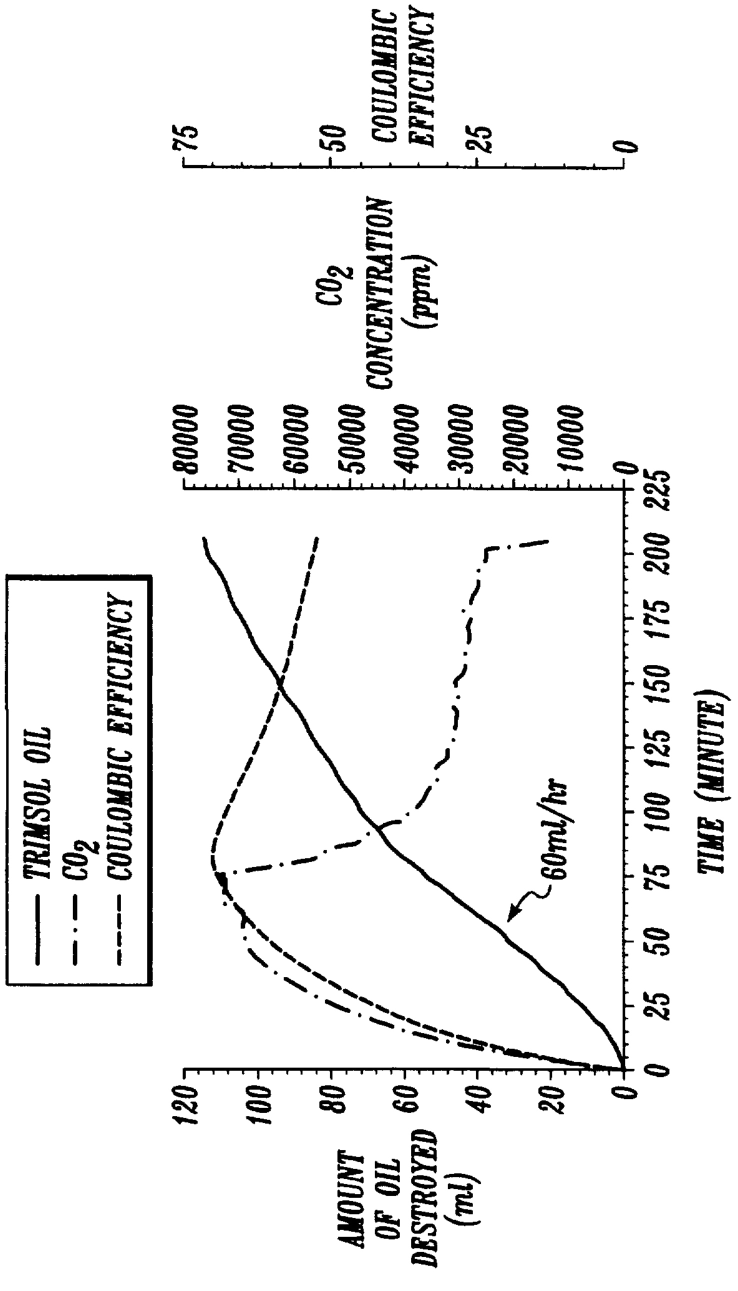
TRIMSOL OIL
CO_2
COULOMBIC EFFICIENCY
AMOUNT OF OIL DESTROYED (ml)
120
100
80
60
40
20
0
TIME (MINUTE)
0
25
50
75
100
125
150
175
200
225
60ml/hr
CO_2 CONCENTRATION (ppm)
80000
70000
60000
50000
40000
30000
20000
10000
0
COULOMBIC EFFICIENCY
75
50
25
0

Fig. 6