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**FY 1992
Annual Report**

**Incineration Alternatives for Combustible Waste
Ultraviolet/Hydrogen Peroxide Process**

Final Report to Rocky Flats Plant
FY92 Tasks under TTP SF 221207

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Contents

Executive Summary	1
1.0 Introduction.....	1
2.0 Treatability of liquid compounds	2
2.1 Apparatus	2
2.2 Experiments	2
2.2.1 Experiments on Ethylene Glycol (EG), a Model Compound for Water-Soluble Nonhalogenated Organics	2
2.2.2 Experiments on Trimsol, a Model Compound for Water-Dispersible Organic Mixtures	3
2.3 Trimsol Destruction Studies Conducted by Purus, Inc.	8
3.0 Treatability of solid compounds	9
3.1 Apparatus	9
3.2 Experiments	9
3.2.1 Experiments on Sodium Salts of Carboxymethylcellulose (Na-CMC), a Model Compound for Water-Soluble Cellulosics	9
3.2.2 Experiments on Powdered Fibrous Cellulose, a Model Compound for Water-Insoluble Cellulosics	9
Appendix A.....	13

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Tables

1.	Carbon Balance for Two Destruction Runs on Trimsol	8
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Figures

1.	UV/H ₂ O ₂ reactor chamber (LLNL).....	2
2.	TOC vs. time for ethylene glycol (EG) destruction with various H ₂ O ₂ concentrations.	3
3.	TOC vs. time for Trimsol destruction with various H ₂ O ₂ concentrations.....	5
4.	Steady-state destruction of Trimsol at ~200 ppm carbon with a Trimsol feeding rate of 2.0 mL/h.....	5
5.	Doubling the Trimsol addition rate from 2.0 mL/h to 4.0 mL/h shows that Trimsol will be destroyed at the rate of ≤ 2.0 mL/h.	6
6.	Trimsol destruction during 15-h run reached a steady-state of ~400 ppm C.....	6
7.	Trimsol destruction during the 78-h run.	7
8.	Hg lamp spectrum (LLNL).	8
9.	Comparison of Hg lamp and Xe flash lamp spectra (Purus, Inc.).	9
10.	TOC destruction and CO ₂ formation during the photooxidation of Trimsol with a 3.7-kW Xe flash lamp.	9
11.	Destruction of a Na-CMC during a 120-h run.	10
12.	Fibrous cellulose destruction vs. pH.....	10
13.	Fibrous cellulose destruction vs. weight of Fenton reagent (g).	11
14.	Cellulose destruction rate vs. H ₂ O ₂ feed rate.	11
A-1.	Absorption spectra of H ₂ O ₂ in alkaline medium.	14
A-2.	Preliminary conceptual design of an UV/H ₂ O ₂ treatment unit.....	15

FY 1992 Annual Report

Incineration Alternatives for Combustible Waste

Ultraviolet/Hydrogen Peroxide Process

Executive Summary

We have demonstrated that the ultraviolet light/ hydrogen peroxide (UV/H₂O₂) process is capable of completely destroying liquid and solid organic wastes. Using the UV/H₂O₂ process, we destroyed two liquid wastes: ethylene glycol (water-soluble) and Trimsol (water-dispersible), and two solid wastes: sodium salts of carboxymethylcellulose (water-soluble) and powdered fibrous cellulose (water-insoluble cellulose). We have found that Fenton's reagent is needed to treat fibrous cellulose effectively and that water-soluble nonhalogenated organic compounds can be treated effectively by adding only H₂O₂ to the process. For water-dispersible and solid organic compounds, maintaining an emulsified condition and having a large reaction surface area are necessary for successful destruction of organics by the UV/H₂O₂ process. Conditions (e.g. pH, temperature, feeding rate of H₂O₂, etc.) for maximum efficiency of organic compound destruction have been identified during careful, parametric investigations.

1.0 Introduction

The UV light-catalyzed oxidation of organics by H₂O₂ (UV/H₂O₂ process) is an established technology that has been used to treat large volumes of effluent-containing dilute organic contaminants. With appropriate UV wavelengths (200–250 nm), UV/H₂O₂ undergoes photochemical decomposition to produce OH• radicals that are strong oxidants, capable of oxidizing most organic compounds stepwise to complete mineralization (i.e., all carbon atoms are oxidized to CO₂, all hydrogen atoms to H₂O and other nonmetallic elements to corresponding anions). When used for applications such as groundwater remediation, UV photolysis is successful if all the toxic organic compounds are converted to nontoxic compounds.

However, to successfully convert mixed waste containing hazardous organics to low-level radioactive waste, the UV photolysis process would need to completely destroy all the organic compounds in the mixed-waste stream. The process has not yet been demonstrated as an incineration alternative for treating this class of mixed wastes.

In this first annual report, we document our progress on demonstrating the destruction/treatment of both liquid organic compounds and cellulose. The liquids include ethylene glycol (a model compound for water-soluble nonhalogenated organics) and Trimsol oil, a commercial mixture of organic compounds, which is a water-dispersible lubricant used in metal cutting. The cellulose are sodium salts of carboxymethylcellulose (water-soluble) and cellulose (water-insoluble).

2.0 Treatability of liquid compounds

2.1 Apparatus

We obtained a functional UV/H₂O₂ system from Peroxidation System, Inc. (Phoenix, Arizona) and modified the system as follows:

- A gas-collecting system was added to allow quantitative measurement of gases evolved under constant pressure.
- A residual gas analyzer (RGA), an oxygen analyzer, and an infrared CO analyzer were installed on the gas collecting system to determine the unwanted by-products produced and to measure effluent O₂ and CO gases quantitatively. Next year, an infrared CO₂ analyzer will be installed.
- An optical probe, connected to a UV-visible spectrometer by an optical fiber, was also installed in the reactor chamber to measure the spectral distribution and the attenuation of UV light in the process stream.

The lamp is a medium high-pressure mercury lamp (25-cm long with an internal diameter of 1.6 cm) with an output power of ~2 kW. A peristaltic pump adds H₂O₂ solution to the system and continuously circulates the solution during the process. Figure 1 shows a diagram of the completed system. We believe that the LLNL bench-scale UV/H₂O₂ apparatus is the most fully instrumented example in existence. This instrumentation has given us unusual insight into the process.

2.2 Experiments

2.2.1 Experiments on Ethylene Glycol (EG), a Model Compound for Water-Soluble Nonhalogenated Organics

Mixtures of approximately 0.5% EG in water were poured into the reaction chamber. The rate of H₂O₂ solution addition was ~1.0 mL/min. The results of three runs (Figure 2) clearly show that the total organic carbon (TOC) can be reduced to near-

Figure 1. UV/H₂O₂ reactor (LLNL).

zero concentration and demonstrate that this type of organic compound can be treated/destroyed by the process.

Figure 2. TOC vs. time for ethylene glycol (EG) destruction with various H₂O₂ concentrations.

However, these results were not obtained under the most efficient process conditions. We believe that feeding the EG with a peristaltic pump will allow the process to operate at lower EG concentrations, thereby enhancing process efficiency. EG absorbs light near 200 nm and competes with H₂O₂ for available UV light. Furthermore, higher concentrations of EG tend to produce undesirably high concentrations of intermediates (methanol, ethanol, etc.). These intermediates are quite volatile and can escape from the process solution as gaseous by-products. In a circulated and sealed system, all intermediates will eventually be destroyed. During the photolysis of EG solutions with no addition of H₂O₂, the pH dropped from 7.5 to 3.4. With the addition of 30% or 10% H₂O₂ solutions, the pH dropped to 2.5. This drop in pH is probably due to the formation of intermediates, such as formic acid and acetic acid, which are found

in the mediated electrochemical oxidation of EG by Ag(II) in nitric acid solutions. A blank run was also conducted to generate baseline data. A mixture of 5 mL of 1% EG solution and 5 mL of 10% H₂O₂ was mixed together for 3 h without UV light. In this case, no reaction was observed between EG and H₂O₂.

2.2.2 Experiments on Trimsol, a Model Compound for Water-Dispersible Organic Mixtures

Composition of Trimsol

Trimsol is a mixture of organic compounds: 30–40% petroleum oil, 20–30% petroleum sulfonate, 20–30% chlorinated alkene polymer, 1–10% nonionic surfactant, aromatic alcohol, propylene glycol ether, <1% blue-green dye, silicone defoamer, and substituted indole. The remainder is water. This composition was provided by the manufacturer. The overall elemental analysis is C, 68.54%; H, 10.44%; Cl, 11.1%; O, 7.48%; S, 1.0% and N, 0.06%. The density of Trimsol is approximately 1 g/mL.

The First Experiment

The first experiment with Trimsol was carried out with an initial Trimsol to water ratio of 1:250 and a pH of 8.3. A solution of 30% H₂O₂ was added at a rate of 2 mL/min. Twenty minutes after starting the experiment, the pH of the mixture dropped to 2.2, probably due to the formation of HCl. We have found that the dispersability of Trimsol and water diminishes in acidic solutions. With the immiscible components of Trimsol separated from water, the UV/H₂O₂ treatment process produces globs of grease as a by-product. Two ways to avoid this problem are (1) controlling the pH of the solution or (2) finding other means to maintain emulsification of the water-Trimsol mixture. We decided to control the pH with a borate buffer solu-

tion made from boric acid and sodium borate (pH 9–10) because borates have very low optical absorption between 190 and 250 nm, which is the most effective region of the UV spectrum for dissociating H_2O_2 into $\text{OH}\cdot$ radicals.

Experimental Conditions for Subsequent Runs

We found that some compounds of Trimsol dissolve in water and absorb light between 200 and 250 nm. In subsequent runs, Trimsol was added to the system by a peristaltic pump to maintain a constant low concentration of unreacted Trimsol. Several experiments were carried out under the following conditions: fixed feed rate of solution (2.2 mL/min) with various concentrations of H_2O_2 ; fixed feed rate of Trimsol (2.0 mL/h); fixed temperature ($40 \pm 2^\circ\text{C}$); fixed starting process volume (2.5 L) buffered at pH~9 (established by ~0.1 M borate solution); and a fixed circulation rate (5.7 L/min). In this series of runs, the gas collection system was not used. The pH of the reaction volume never dropped below 7, and no separation of phases was observed.

Results

Effects of Photolysis on Trimsol Destruction

When Trimsol was the only species fed into the system and the lamp was switched off, the rate of TOC increase was 5.8 ppm/min in a period of ~2 h. Because the increase of TOC is linearly proportional to time, we concluded that the Trimsol was uniformly dispersed throughout the solution. The same rate of TOC increase was observed with the Hg lamp on and no H_2O_2 present. Thus, direct photolysis makes only a minor contribution to the destruction of this mixture of organic compounds.

Feeding Rate of H_2O_2

When H_2O_2 is fed, $\text{OH}\cdot$ radicals form and can attack organic compounds or they can attack H_2O_2

to produce O_2 . To minimize excess H_2O_2 parasitic consumption of $\text{OH}\cdot$ radicals, it is essential to find the optimum feed rate of H_2O_2 for a fixed feed rate of Trimsol. To maintain the same total volume in the reactor, the H_2O_2 feed rate was changed by using a constant pumping rate while feeding solutions with different concentrations of H_2O_2 .

In each run, samples were taken from the process at 20 min intervals for TOC analysis. Figure 3 is a plot of TOC against time that shows that the rate of TOC increase does not change during the first two hours, even as the concentration of fed H_2O_2 increases from 5 to 30 wt%. After turning off the Trimsol but continuing UV irradiation, a faster decrease in TOC level was observed as the concentrations of fed H_2O_2 increased from 7.5 to 30 wt%. We need to conduct experiments at the same conditions but with extended duration; we recommend durations between 15 and 30 hr. From the plots of TOC against time that show steady-state TOC levels, the most efficient H_2O_2 feed rate can be determined. For example, a lower steady-state TOC indicates a faster rate of Trimsol destruction/conversion. Based upon these important experimental data, we have decided to use 30 wt% H_2O_2 in future runs.

Achieving Steady-State Destruction of Trimsol

We have demonstrated the feasibility of destroying Trimsol by continuously feeding Trimsol to the UV/ H_2O_2 process while maintaining a constant (time-invariant) TOC concentration. A steady-state destruction rate of Trimsol can be deduced from our results. Under these conditions, the rate of destruction is identical to the feed rate. Figure 4 shows the results for a 7-h experiment in which the TOC level reached a steady of 200 ppm after 5 h of photolysis.

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Figure 3. TOC vs. time for Trimsol destruction with various H_2O_2 concentrations.

In another run, Trimsol was injected into the process at a concentration of 200 ppm. All other conditions were the same as those in Figure 4.

After 4 h, the rate of Trimsol addition was doubled from 2.0 mL/h to 4.0 mL/h and continued for an additional 3 h.

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Figure 4. Steady-state Trimsol destruction at ~200 ppm C and Trimsol feeding rate of 2.0 mL/h.

Figure 5 shows a plot of TOC against time. Note that the TOC concentration remained approximately 200 ppm for the first 4 h. During the last 2 h when the Trimsol feed rate was doubled, the TOC concentration increased at a rate of ~ 5.8 ppm/min, which is the same rate observed with that Trimsol addition rate, but without H_2O_2 and light. Therefore, we concluded that this system can destroy Trimsol at a rate of ≤ 2.0 mL/h under these conditions. Reaching a steady-state TOC concentration is a key step in demonstrating the feasibility of Trimsol destruction by the UV/ H_2O_2 process.

Figure 5. Doubling the Trimsol addition rate from 2.0 mL/h to 4.0 mL/h shows that Trimsol will be destroyed at the rate of ≤ 2.0 mL/h.

We carried out a 15-h run (Figure 6), under the same conditions as those used to generate the data shown in Figure 4. As in previous experiments, the TOC concentration reached a steady-state (fluctuation ~ 50 ppm) after 4–5 h. The TOC concentration was ~ 200 ppm in Figure 4 and ~ 400 ppm in Figure 6. We attribute the diminished rate to an increase in the rate of Trimsol addition, due to imprecision of the peristaltic pump used to feed Trimsol. After the pump warmed up and was set to a Trimsol feeding rate of 2.0 mL/h, the rate varied from 2.0 to

2.4 mL/h. The increased rate was more pronounced in experiments of longer duration.

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Figure 6. Trimsol destruction during 15-h run reached a steady-state of ~ 400 ppm C.

After the 15-h run, we conducted two experiments of longer duration. The first, lasting 60 h, was intended to study the effect of HCl formation and its interaction with the chemical buffer. Based on the results of TOC analyses and visual observations, we concluded that phase separation commences slowly only after the pH falls below 7.5. Future process designs must consider phase separation problems caused by the formation of HCl (acidification).

The second long experiment, lasting 78 h, was conducted with the same conditions as the 60-h experiment except that the pH was maintained higher than 7.5 by continually adding buffer solution. The purpose of this experiment was to see if Trimsol-water emulsions can be maintained during the destruction process, and if a steady-state TOC concentration can be maintained for periods longer than 10 h.

Figure 7 shows the results of this experiment. The TOC level seemed to reach steady-state at a

TOC concentration of 850 ppm after 15 h, and then slowly increase to 1300 ppm during the next 40 h. Figure 7 shows that it took longer (~15 h) for the TOC concentration to reach a constant level (850 ppm), which was higher than that shown in Figure 6. Subsequently, the TOC concentration increased from 850 to 1300 ppm. We believe this is a result of (1) an increase in the rate of Trimsol addition; and/or (2) the build-up of a concentration of bicarbonate ions (formed from CO_2) which absorb UV light in the region of 200 nm. Note that the bicarbonate ion has a molar extinction coefficient of ~100 at 200 nm and a pH of 9.9. The effect of bicarbonate on the steady-state TOC concentration will be examined in the future.

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Figure 7. Trimsol destruction during 78-h run.

Effects of Temperature

Preliminary studies of the effect of temperature on Trimsol destruction have been performed, but no conclusive results are yet available.

Gas-Collection System

In conducting carbon balances during Trimsol-destruction experiments, the gas-collection system for O_2 and CO_2 consisted of a manometer filled with solution of saturated sodium perchlorate (~5M) and perchloric acid (10 mL of concentrated acid). The volume was 4 L, and the pH was ~1. Carbon dioxide is not expected to dissolve in the solution. The maximum amount of gas that can be collected by the manometer is about 3.5 L at 1 atm and 25° C. The experimental plan for performing carbon balance was to use TOC and total inorganic carbon (TIC) (i.e., bicarbonate and carbonate from CO_2) analyses of solutions before and after photolysis, and samples of product gas (primarily CO_2).

Two experiments were done with 1.75 g and 1.22 g of Trimsol, respectively. Trimsol and 2.5 L of buffer solution were added to the reactor and circulated. After the circulation was stopped, the whole system was at room temperature and was opened to the atmosphere. The gas-collection system was then closed off from the atmosphere and the Trimsol destruction reaction was started. Excess H_2O_2 in solution produces only O_2 . Because the volume of the gas-collection system is limited, the addition of H_2O_2 to the reactor was controlled by turning the peristaltic pump on and off to minimize total O_2 production. We assumed that destruction was completed when the mixture became clear and the molar H_2O_2 feed rate was identical to the molar production rate of gas in the gas-collection system. We collected a liquid sample for TOC and TIC analyses and cooled the system to room temperature. After stopping circulation within the process, the pressure inside the manometer was allowed to equilibrate with the ambient environment. The total volume of product gas was recorded and

Table 1. Carbon Balance for Two Destruction Runs on Trimsol.

Trimsol (g)	TOC calculate ^a (mmol C)	TIC after run (mmol C)	TOC after run (mmol C)	CO ₂ (mmol C)	Carbon balance (%)
1.75	100	85	9	0.1	94.1
1.22	69.7	66.1	3	0.1	99.3

^a TOC calculate is the total number of millimoles of carbon added to the reactor. The C content of Trimsol is 68.54%.

gas samples were taken for mass spectrometric analyses. Table 1 summarizes the results.

2.3 Trimsol Destruction Studies Conducted by Purus, Inc.

In August 1992, Purus, Inc. started to investigate Trimsol destruction under a contract with LLNL. The unique feature of the Purus System is that the UV source is a Xe flash lamp. Figure 8 shows the emission spectrum of the Hg lamp used

in the Peroxidation System discussed in section 2.1; Figure 9 shows a comparison between the spectra of Xe and Hg lamps.

The very broad band in the UV region (240–300 nm) of the Xe lamp can excite most simple organic compounds to enhance their reactivity toward oxidants. The higher intensity of the Xe lamp in the region near 230 nm will decompose H₂O₂ into OH• radicals more effectively than the Hg lamp can.

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Figure 8. Hg lamp spectrum (LLNL).

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Figure 9. Comparison of Hg lamp and Xe flash lamp spectra. (Provided by Purus, Inc.)

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Figure 10. TOC destruction and CO₂ formation during the photooxidation of Trimsol with a 3.7-kW Xe flash lamp.

A batch Trimsol-destruction run was conducted in a 9.0-L cylindrical aluminum vessel using two 3-in., 1840-W pulsed Xe lamps. According to the results in Figure 10, total carbon is higher at the end than at the beginning. We think the excess carbon is due the solution acquiring C from CO₂ in the air, a common phenomenon in basic solutions.

3.0 Treatability of Solid Compounds

3.1 Apparatus

To treat water-soluble cellulose, the same system was used as in Figure 1. For the water-insoluble cellulose, we used a photochemical system (lamp, quartz wells, and ballast) purchased from Hanovia. The output power of the lamp is ~1.2 kW. The system was modified by replacing the quartz reactor with one made of Teflon-lined steel by Peroxidation System, Inc. and adding a circulation pump and a heat-exchanger.

3.2 Experiments

3.2.1 Experiments on Sodium Salts of Carboxymethylcellulose (Na-CMC), a Model Compound for Water-Soluble Cellulose

A solution of 5 g Na-CMC in 2.5 L of water was circulated and 30% H₂O₂ was fed at a rate of 2.0 mL/min. Figure 11 shows the results. Although the destruction reaction was not conducted under the most efficient conditions, the results clearly show that water-soluble cellulosic materials can be treated effectively with the UV/H₂O₂ process.

3.2.2 Experiments on Powdered Fibrous Cellulose, a Model Compound For Water-Insoluble Cellulose

Using powdered fibrous cellulose purchased from Sigma Chemical Company, we conducted preliminary tests in the Hanovia photochemical system. This system contains a magnetic stirring bar rather than a circulation pump. The feeding rate of 30% H₂O₂ solution was 1.7–1.8 mL/min and the

temperature was maintained at 40°C. We obtained encouraging results by adding Fenton reagents (we used ferrous ammonium sulfate) to the mixture.¹ Ideally, powdered cellulose should be continuously fed into the reactor, otherwise they will block the light. A circulating system is better than the one with a stirring bar because feeding H₂O₂ solution into the reactor for 5 h can increase the volume by 500 mL. In a circulating system, the volume of solution exposed to light is always the same as that of the reaction chamber. We modified the Hanovia system to copy the system described in section 3.1 (above). At present, we are conducting batch studies to find the most efficient conditions for the destruction of fibrous cellulose.

In conducting parametric studies of fibrous cellulose destruction, the initial conditions were 4 g of fibrous cellulose, 2.5 L water, 5 h of run time and 40°C. The variables were the pH value, the amount of Fenton reagent, and the feed rate of H₂O₂ solutions. After each run, undestroyed fibrous cellulose was collected by filtration, washed with water, and dried in a vacuum oven at ~50°C. In the future, we will investigate the effect of different iron compounds, temperature, and circulation rate on destruction of fibrous cellulose.

Using 3 g of Fenton reagent and a feeding rate of 0.75 mL/min of 30% H₂O₂, the fraction of fibrous cellulose destroyed as a function of pH is shown in Figure 12.

Maintaining the pH in the range of 2.8 ± 0.05 and a 0.75-mL/min feeding rate of H₂O₂, the fraction of fibrous cellulose destroyed as a function

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Figure 11. Destruction of Na-CMC during a 120-h run.

of the amount of Fenton reagent added is shown in Figure 13. When more than 4 g of Fenton reagent was used, an orange-colored solid was precipitated, presumably ferric oxide (i.e. rust). The solid can block the light and hence decrease the efficiency of the process.

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Figure 12. Fibrous cellulose destruction vs. pH.

¹Fenton chemistry is broadly defined as the reactions of Fe(II) or Fe(III) with H₂O₂ to generate active oxygen species with potential for oxidizing organic compounds

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Figure 13. Fibrous cellulose destruction vs. weight of Fenton reagent (g).

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Figure 14. Cellulose destruction rate vs. H₂O₂ feeding rate.

Figure 14 shows the percent of cellulose destroyed versus the H₂O₂ feed rate with the pH in the range of 2.8 ± 0.05 and 4.0 g of Fenton reagent.

Appendix A

Preliminary Conceptual Design of the UV/H₂O₂ Process

Although research and development on the UV/H₂O₂ process applied to Trimsol oil and cellulosic materials is not yet complete, this section outlines preliminary ideas on how the process might be implemented in a pilot treatment system. At its present stage of development, the UV process is neither efficient nor cost-effective for destroying dewatered Trimsol and water-insoluble cellulosic materials without pretreatment of the wastes. The following conceptual design does not include a pretreatment phase. However, at the end of this section, we describe a pretreatment stage as an enhancement to the process.

Treatment Capacity

A successful process should be able to treat ~30,000 gal of concentrated Trimsol (i.e. dewatered Trimsol waste) in a period of five years. Assuming the process is operated 300 days per year, it should be able to treat 20 gal/day of Trimsol. Two treatment units could be built, each unit treating 10 gal/day of Trimsol. More than one treatment unit is required because a large volume of 50 wt% H₂O₂ is needed and concentration higher than 50% is considered unsafe. A reasonable estimate of the amount of H₂O₂ required to destroy organic carbon is a mole ratio of ~20 of H₂O₂ to C. This estimate, based on preliminary work done by Purus Inc., predicts that approximately ~640 gal 50% H₂O₂ is needed to treat 10 gal of Trimsol (density is ~1 and 68.5% is carbon). Currently, using one 3.7-kW (in-

put power) Xe lamp, we can mineralize 4 g/h of Trimsol.

UV Source

Based on our current understanding, a more efficient UV source than Hg lamps is needed for the process. Considering the absorption spectrum of H₂O₂ (Figure A.1) and the spectra of Hg and Xe flash lamps (XFL) (Figures 9 and 10), the XFL is clearly the better choice for the process. Because XFLs are commonly used in laser technology as the pumping source, lamps of appropriate dimensions (2-cm diam × 2-m long) and powers (up to ~200 W/cm²) are readily available.

Treatment Unit Design

To treat 20 gal/day (38 L or 38 kg) of Trimsol we suggest implementing a pilot treatment plant containing two treatment units, each capable of treating 10 gal/day. Figure A.2 shows a conceptual design of one unit. Each unit requires ~700 kW of input power for 15 Xe lamps at ~47 kW. Both units share one evaporation vessel.

Each unit has three stages. Trimsol is added only to the first stage. Seven lamps are installed in stage 1, five lamps in stage 2, and three lamps in stage 3. The number of lamps decreases because the TOC concentration decreases from stage 1 to stage 3. The total volumes of stages 1, 2 and 3 are 200 gal, 200 gal, and 150 gal, respectively. For each stage, the volume ratio of reaction chamber to gas-liquid separator is 2:3 to ensure that the

Figure A-1. Absorption spectra of H_2O_2 in alkaline medium.

chamber is always filled with liquid. Trimsol is added to stage 1 at a rate of 0.5 gal/h or 10 gal/day. The rates of 50% H_2O_2 addition to stages 1, 2 and 3 are 15, 10 and 7 gal/h, respectively. While the rate at each stage may be modified, the total feed rate should be 640 gal/day. When the entire process is in progress, each stage will maintain a constant discharge rate to balance the liquid flow in and out of each stage. The rate should be 15.5 gal/h from stage 1 to 2 (determined from the in-flow of 0.5 gal Trimsol and 15 gal H_2O_2), 25.5 gal/h from stage 2 to stage 3 and 32.5 gal/h from stage 3 to the evaporation vessel. Volume contribution from concentrated NaOH solution, though small, should be

determined experimentally and added to the discharge rate.

During development of this process, a borate buffer has been used to maintain the solution at pH ~9, which is needed to keep Trimsol dispersed in water. In the plant-scale process, NaOH solution will be used to neutralize the HCl and to maintain the desired pH. Substituting NaOH for a borate buffer will eliminate the borate in the final wastes. Trimsol contains 11% Cl; 30,000 gal of Trimsol contains ~12,500 kg of Cl. If all Cl is turned into NaCl, ~20,500 kg of NaCl waste will be generated. One alternative for treating NaCl waste is to

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Figure A-2. Preliminary conceptual design of an UV/H₂O₂ treatment unit.

convert it to HCl and NaOH using bipolar electro-dialysis/salt splitting.

Pretreatment Process Enhancement

We envision that a pretreatment stage could be added before the first stage as a process enhancement. Trimsol, H₂O₂ solutions, and NaOH would be continuously added to the pretreatment chamber to maintain an appropriate mixture composition of 1% Trimsol, 10% H₂O₂, and pH ~11. The mixture would be treated with ozone but without UV light (a commercial process). After the ozone treatment, either Trimsol would become more water-soluble (i.e. some C-H and C-C bonds become C-OH bonds) or the components of Trimsol that compete

for UV light absorption with H₂O₂ would be oxidized and become transparent. After the pretreatment stage, H₂O₂ solution and UV light could be used in the follow-up stages but Trimsol would be added only in the pretreatment stage. If the pretreatment process works as expected, fewer lamps and less H₂O₂ will be needed.

Generally, real Trimsol wastes contain 2–5 wt% of Trimsol and 95–98% water. We recommend that no attempt should be made to dewater such wastes. Instead, Trimsol should be treated with a small quantity of HCl acid to drop the pH of mixture to ~3 which causes a separation of phases. Subsequently, only the aqueous phase would be treated by the UV/H₂O₂ process.

Cellulosics contain only C, H, and O. The C content is probably ~40 wt% (36 wt% for fibrous). The targeted cellulosics are water-insoluble solids, such as wipes and filter papers. Pretreatment processes are needed to facilitate mineralization of these wastes. The preferred processes are those such as hydrolysis (~100°C and dilute sulfuric acid) that are able to break up the polymer chains and turn the cellulosic into smaller molecules that might be water-soluble. Another possible pretreatment method is pulping to increase the surface area of the cellulosics. Assuming that appropriate pretreat-

ment methods are identified, destroying cellulosics would appear to be much easier and cheaper than destroying Trimsol. For this application, we recommend a UV/H₂O₂ process conducted in acidic solutions (pH~2.8) with Fenton reagents (iron compounds) as catalysts. The Fenton reagent can be recovered at the last stage by increasing the pH of the solution and precipitating the iron as hydroxide, which can be redissolved in acid and reused as a catalyst. Separation of the iron hydroxide can be done by sedimentation.

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