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A NEW PROCESS AND EQUIPMENT FOR WASTE MINIMIZATION: CONVERSION OF NO_x SCRUBBER LIQUOR TO FERTILIZER

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ABSTRACT

A new emissions control system for the oxidizer scrubbers that eliminates the current oxidizer liquor waste and lowers the NO_x emissions is described. Since fueling and deservicing spacecraft constitute the primary operations in which environmental emissions occur, this will eliminate the second largest waste stream at KSC. This effort is in accord with the Executive Order No. 12856 (Federal Compliance with Right-to-Know Laws and Pollution Prevention Requirements, dated August 6, 1993) and Executive Order No. 12873 (Federal Acquisition, Recycling, and Waste Prevention, dated October 20, 1993). A recent study found that the efficiencies of the oxidizer scrubbers during normal operations range from 70 percent to 99 percent. The new scrubber liquor starts with 1% hydrogen peroxide at a pH of 7 and the process control system adds hydrogen peroxide and potassium hydroxide to the scrubber liquor to maintain those initial conditions. The result is the formation of a solution of potassium nitrate, which is sold as a fertilizer. This report describes the equipment and procedures used to monitor and control the conversion of the scrubber liquor to fertilizer, while reducing the scrubber emissions.

INTRODUCTION

Hypergolic propellants are used in spacecraft such as Space Shuttle, Titan, and others launched at Kennedy Space Center (KSC) and Cape Canaveral Air Station (CCAS). Fueling and deservicing spacecraft constitute the bulk of operations in which environmental emissions occur. Monomethylhydrazine (MMH), nitrogen tetroxide (N₂O₄ or NTO), and hydrazine (N₂H₄ or HZ) are the main propellants of concern. The scrubber liquor waste generated by the oxidizer scrubbers (approximately 250,000 lb/yr) is the second largest waste stream at KSC. Currently, the waste disposal cost for the oxidizer scrubber liquor is approximately \$0.20/lb or \$50,000 per year. In addition, a recent study⁽¹⁾ found that the efficiencies of the oxidizer scrubbers during normal operations range from 70 percent to 87 percent at the Orbiter Processing Facility (OPF), and 99 percent at Launch Pads 39A and B. An emission estimate of nitrogen tetroxide at KSC based on this study⁽¹⁾ is in excess of 200 kilograms per year. Executive Order No. 12856 (Federal Compliance with Right-to-Know Laws and Pollution Prevention Requirements, dated August 6, 1993) and Executive Order No. 12873 (Federal Acquisition, Recycling, and Waste Prevention, dated October 20, 1993) directed KSC to address the oxidizer emissions and waste disposal problems. In an effort to meet these requirements, a study was initiated to examine methods to eliminate the oxidizer scrubber liquor as a waste stream and to lower the scrubber emissions. This report covers the first phase of this study, which includes the laboratory and initial field tests.

Hydrogen peroxide (H₂O₂), with and without acids or bases, has been used to remove NO_x and other acid gases from combustion flue gases, metal pickling operations, fluidized bed gas scrubbers, spray dryers, and nuclear fuel processing operations. However, combustion flue gas scrubbing has been the primary use of hydrogen

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peroxide in scrubbers. Hydrogen peroxide alone has been added to a single column of a multiple column flue gas system^(2,3) or to the entire scrubber solution⁽⁴⁻⁶⁾ with an efficiency for NO_x that was greater than 90%. Hydrogen peroxide has been blended with nitric and/or sulfuric acids to improve the scrubber efficiency. When added to a single column of a multiple column flue gas system, hydrogen peroxide showed significant improvement in the NO_x removal^(7,8). Sodium or potassium hydroxide (KOH) with hydrogen peroxide has been used to improved scrubber efficiency for flue gases⁽⁹⁾ and for general NO_x removal from gas streams⁽¹⁰⁻¹³⁾. For example, the efficiency for NO and NO₂ removal improved from 3.8 to 46%, respectively, using 1 M KOH to 91 and 98%, respectively, when 0.12 M H₂O₂ was added to the 1 M KOH⁽¹⁰⁾. Addition of 50 ppm Cu⁺² (or Fe⁺²) improved the efficiency of a 5% NaOH/3% H₂O₂ solution from 80.6 to 93.5⁽¹¹⁾.

Currently, the KSC oxidizer scrubbers react nitrogen tetroxide and/or nitrogen dioxide with nominally 25-wt.% sodium hydroxide, which produces sodium nitrate, sodium nitrite, and nitric oxide. The spent caustic scrubber liquor could be used as a fertilizer once the pH is adjusted; however, substitution of potassium hydroxide for sodium hydroxide increases the commercial value of the scrubber liquor as a fertilizer.

The NO_x emissions from the oxidizer scrubbers have been the subject of several investigations at KSC⁽¹⁴⁻¹⁷⁾. These investigations have examined the packing materials, scrubber liquor, operating conditions, and addition of various gases in an effort to improve the performance of the oxidizer scrubbers. In one study,⁽¹⁴⁾ a falling film evaporator, used to generate a constant flow rate of NO₂ to the scrubber, produced inlet concentrations from 3,200 to over 200,000 parts per million (ppm). The flow rates of gaseous nitrogen (GN2) vented through the scrubber ranged from 0 to 700 standard cubic feet per minute (scfm). As the GN2 flow rate increased, the efficiency decreased; for example, at 150 scfm the efficiency was approximately 90 percent and at 300 scfm the efficiency fell to 60 percent. In addition, when oxygen was added to the GN2, the efficiency of removal of NO increased.

A second series of tests at KSC⁽¹⁵⁾ used "Flexiring" and "Sulzer" packing (manufactured by Koch Engineering Company) instead of ceramic saddles, and showed little change in the efficiency of the scrubbers. One interesting observation was the decrease in the efficiency as the inlet concentration decreased for the same GN2 flow rate; for example, at 50 scfm with an inlet concentration of 60,000 ppm, the efficiency was 98 percent and, with an inlet concentration of 500 ppm, the efficiency was 60 percent.

A change of the scrubber liquor from 25-weight-percent sodium hydroxide to 11.6-weight-percent sodium sulfite and 5-weight-percent sodium hydroxide in towers 3 and 4 of the scrubbers was recommended because of the increased efficiency^(16,17). For example, at 400 scfm and 8,400 ppm inlet concentration, the efficiency for 25-weight-percent sodium hydroxide was 55 percent but with 11.6-weight-percent sodium sulfite and 5-weight-percent sodium hydroxide, the efficiency was 98 percent. However, the change from 25-weight-percent sodium hydroxide to sodium sulfite blend was not made due to safety considerations.

The addition of ozone to the GN2 stream has been examined on the laboratory scale and a significant increase in the scrubber efficiency was found⁽¹⁸⁾. For example, when the inlet concentration was 25,800 ppm, the efficiency was 95.8 percent without ozone; and when the inlet concentration was 23,100 ppm, the efficiency was 99.6 percent with ozone.

As part of a project to develop an ecologically safe method for the demilitarization of MK 24 and MK 45 aircraft parachute flares, field tests were performed on sodium nitrate extracted from the process⁽¹⁹⁻²¹⁾. These tests, conducted by Purdue University, monitored the effectiveness of this waste sodium nitrate as a fertilizer. A typical MK 24 or MK 45 parachute flare contains a mixture of 10.4 lb. of magnesium, 6 lb. of sodium nitrate, and 0.6 lb. of a binder. The pilot plant process separated the magnesium from the sodium nitrate. The sodium nitrate was in the form of a water solution, which had a nominal concentration of 5-wt.%.

The fertilizer tests were performed over a period of three years on an established tall fescue sod. The sodium nitrate solution was applied seven times during the three year period. Test plots were established which received from 0 to 150 lb. nitrogen per acre in 30 lb. increments. Urea was used as a control and followed the same application rate. The soil chemical changes, plant tissue nutrient level, and differences in plant height were

monitored throughout the test program. The general conclusion drawn from this study was that after three years the sodium nitrate solution could be used effectively as a fertilizer on grass pastures or established turf at rates as high as 150 lb. nitrogen per acre. Supplemental application of 200 lb. per acre of muriate of potash (0-0-60) was used to replace potassium losses. Phosphorus application rates were 100 lb. per acre of triple super phosphate (0-46-0).

INSTRUMENTATION

Figure 1 shows a diagram of the laboratory scrubbers used to lower the concentration of the oxidizer before it was released to the laboratory fume hood, and to provide a test scrubber for the development of a new scrubber liquor. The design of the laboratory scrubbers is similar to the full-scale scrubbers used at KSC.

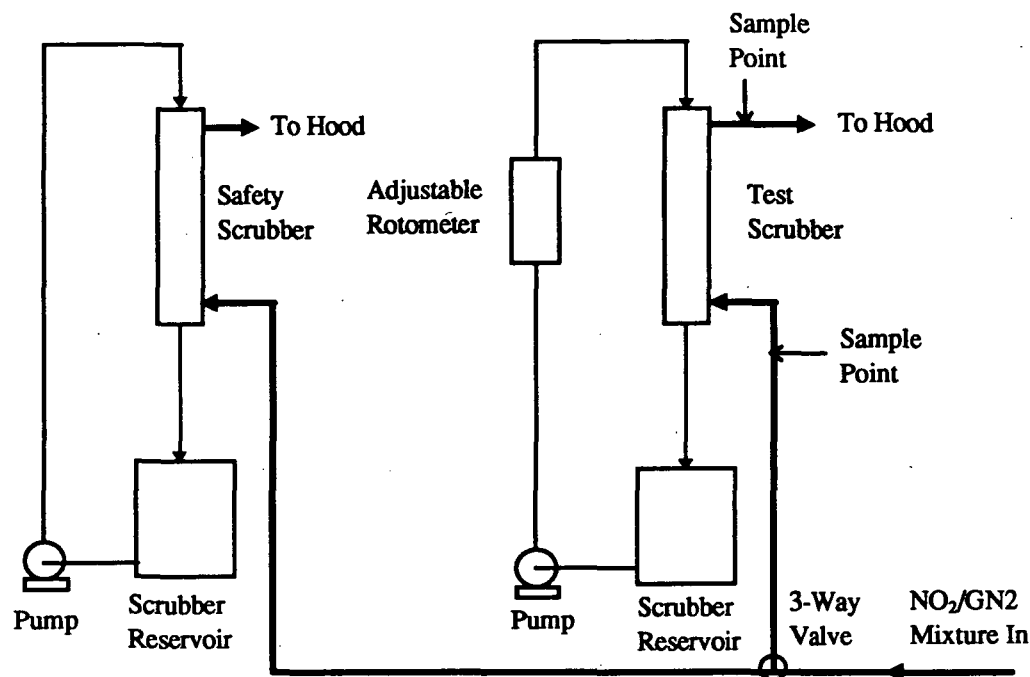


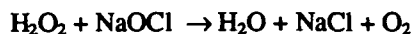
Figure 1. Laboratory Test Scrubber and Safety Scrubber

The laboratory scrubbers have glass columns 3 inches in diameter and are packed with pieces of Tri-Pac 2-inch polypropylene spheres manufactured by Tri-Mer Corporation. The safety scrubber liquor (25-percent sodium hydroxide) is pumped from a reservoir to the top of the column where it flows down to the reservoir. Gaseous nitrogen tetroxide (N_2O_4 in GN2) flows up the column and exits to the fume hood. This configuration lowers the concentration of oxidizer, which is produced by the sample systems, to levels acceptable for the fume hood.

The test scrubber was equipped with an adjustable rotometer to control the flow rate of the scrubber liquor. Two sample points, one just before the scrubber and a second just after the scrubber, were used to measure the scrubber efficiency. A 3-way valve was used to direct the N_2O_4 /GN2 flow to the safety scrubber during start-up. Once stable flow of the test gas was established the valve was rotated to the test scrubber. The test scrubber could be operated either in a scrubber liquor recirculating mode or in a single pass mode, where a second reservoir was used to collect the scrubber liquor from the scrubber. Both the safety scrubber and the test scrubber vent to the laboratory fume hood.

In order to maintain the hydrogen peroxide concentration in the scrubber liquor, a portion of the liquor is sampled offline in an automated peroxide reaction chamber²². The output of this device automatically controls the rate of addition of 35% hydrogen peroxide to the circulating scrub liquor. The hydrogen peroxide

concentration was controlled by monitoring the pressure generated when sodium hypochlorite was added to a sample of the scrubber solution, see Figure 2. The reaction of hydrogen peroxide with sodium hypochlorite is given below:



Therefore, the concentration of hydrogen peroxide in the scrubber liquor can be monitored by measuring the pressure change induced by the reaction of liquor with sodium hypochlorite (bleach) in a closed vessel.

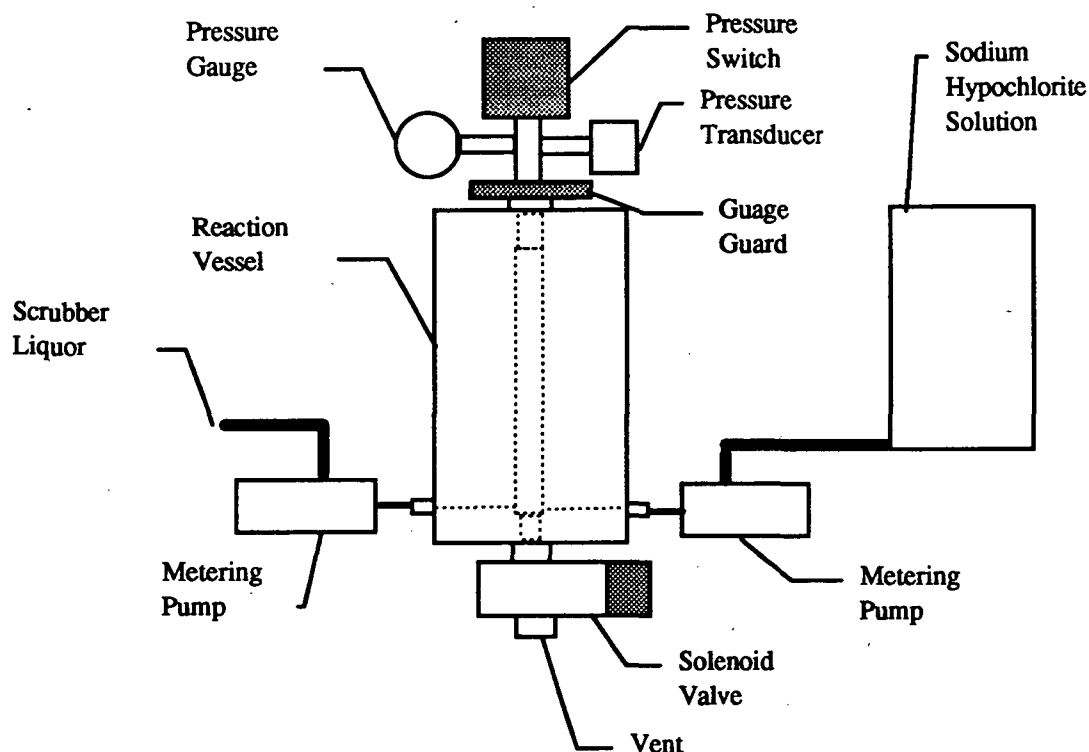


Figure 2. Hydrogen peroxide concentration control system

The reaction vessel was constructed from a 2.25-inch O.D. KYNAR rod. The volume of the reaction chamber is approximately 10 mL. The pressure switch, pressure transducer, and gauge are isolated from the reaction chamber with a gauge guard that has a Teflon diaphragm. A solenoid valve is attached to the bottom of the reaction vessel. Two metering pumps supply the scrubber liquor test solution and sodium hypochlorite solution. All wetted parts of this system are made from polymeric materials that are compatible with sodium hypochlorite and/or sodium nitrate. The electrical control system is used to maintain the concentration of hydrogen peroxide in the scrubber liquor. This system consists of a sequence timer, relay, pumps, valves and pressure switch. The sequence timer controls the addition of the reagents (scrubber liquor and sodium hypochlorite), the vent valve, and the hydrogen peroxide metering pump.

Cole-Parmer model H-56025-40 proportioning pH controller with adjustable flow rates (0 to 5.2 GPH) was selected to control the pH of the scrubber liquor for the laboratory and field tests. This controller responds to 0.1 pH unit changes and can be set to adjust the pH with acid or base feeds. The pumping rate decreases proportionally until the set point is reached. All wetted parts consist of polypropylene, PTFE, and Viton. The unit has an internal isolation transformer to protect the electronics from line voltage fluctuations. This unit is installed in the purged cart that contains the hydrogen peroxide and sampling systems.

Figure 3 is a block diagram of the sample generating system for the field validation tests, which was used in a previous project ⁽¹⁾. The storage tanks at the oxidizer farms of Pads 39A and 39B each have a GN2 purge line for a valve located at the bottom of the oxidizer storage tanks. GN2 will be introduced through this purge line at the bottom of the storage tanks and vented at the top of the tank as NTO in GN2, which flowed through a rotometer. The temperature and pressure will be measured as the NTO mixture passes from the rotometer to the liquid separator and finally to the scrubber. The quantity of oxidizer in the storage tank is large enough so there is very little decrease in the tank temperature due to the forced evaporation of NTO. Since the vapor pressure of nitrogen tetroxide is high, it is not necessary to add GN2 to the storage tank to generate a low [less than 5 cubic feet per minute (scfm)] flow rate of NTO through the scrubber. A manifold with three orifices with nominal flow rates of 100 and 200 scfm is used to generate flows through the scrubber. The flow rates of the GN2 added to the liquid separator can be varied to provide flows of 100, 200, 300, 400, and 500 scfm through the scrubber. This manifold configuration allows the field tests to cover the range of flow conditions found at KSC scrubbers.

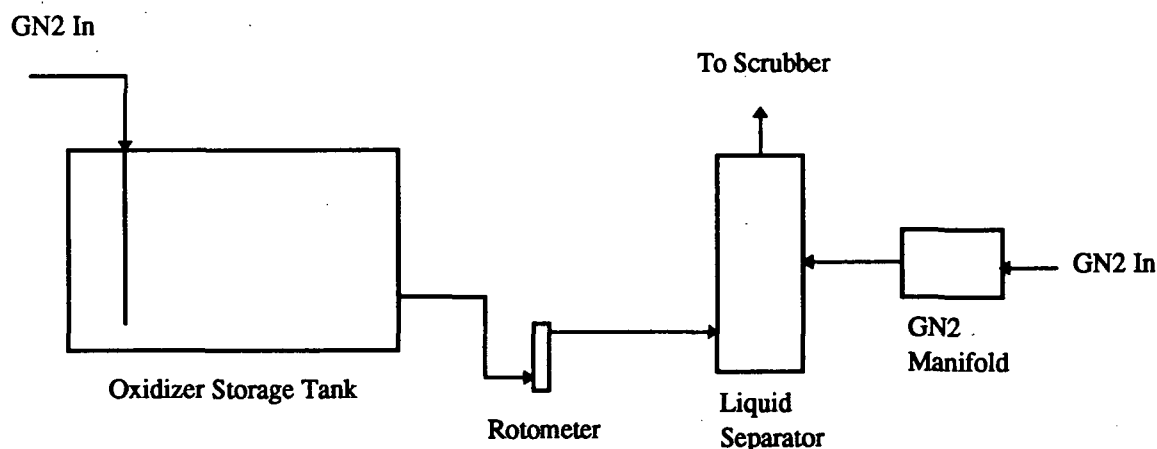


Figure 3. Diagram of the field hypergol sample generating system

The process control system (see Figure 4) used for the field validation was tested with the continuous tests in the laboratory. This system is packaged in a purged cart, which can be used in hazardous locations. The system is designed so that the scrubber liquor pump is used to circulate a small flow of sample from the pump discharge line through a line to the purged cart and back to scrubber liquor storage tank. A sample is collected from the line

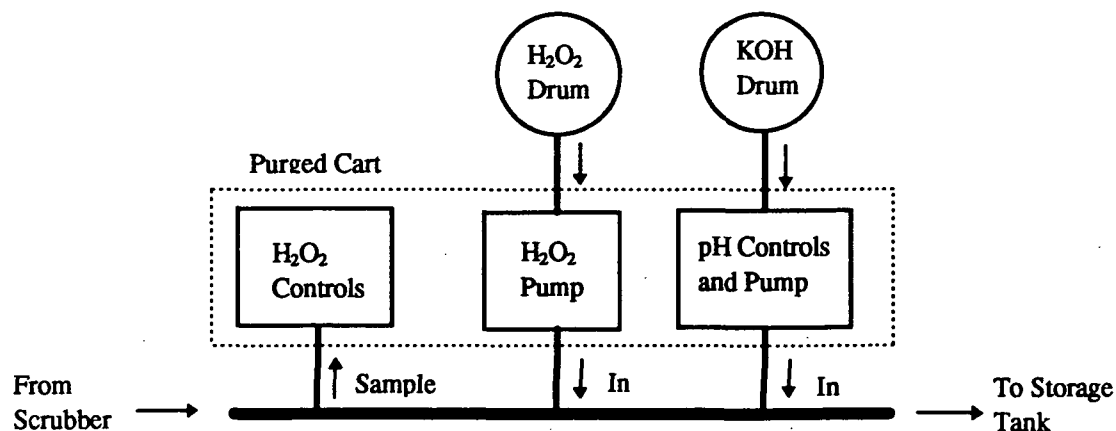


Figure 4. Block diagram of the field process control system.

at the cart for hydrogen peroxide concentration measurement and pH measurements and either/or hydrogen peroxide or potassium hydroxide are pumped into the line before it is returned to the scrubber liquor storage tank.

The sample collection system for field scrubbers was used to collect samples just before the 1st scrubber tower and just after the 4th tower. This sampling arrangement permits easy measurement of the scrubber's efficiency. The impinger solution is a 0.001 M sulfuric acid solution that contains 0.1 wt-percent hydrogen peroxide. The impinger solution is supplied from a reservoir on the sample cart by a peristaltic pump at approximately 2 mL/min.

The sample system consists of four parts: (1) an impinger solution pumping system, which circulates the impinger solution from the storage reservoir to the mixing tee at the sample point; (2) the aspirator system, that uses a PIAB vacuum pump to pull the sample from the scrubber vent through the mixing tee, where the sample is mixed with the impinger solution, and the two-phase mixture is then pulled to the liquid separator, where the liquid sample is separated from GN₂(or air), and the GN₂ is pulled through a rotometer to the PIAB pump; (3) sample collection system, which pumps the impinger solution that contains the sample from the liquid separator, through the pump head and then through a 3-way valve where a sample container may be filled or the sample solution pumped to waste; and (4) a purge system that can blow GN₂ through the two-phase sample line from the liquid separator, through the mixing tee, where impinger solution may be added, and into the scrubber vent. This last operation allows the sample inlet system to be cleaned and dried before a sample is collected. The pumps and other electrical components are contained in the purged sample cart.

PROCEDURES

This project was divided into a laboratory proof-of-concept (POC) study and a full-scale study. The laboratory POC study measured the effects of hydrogen peroxide with and without added acid or base as the scrubber liquor, and the effects of a change from sodium hydroxide to potassium hydroxide. These studies will provide data on the scrubber efficiency, quality of fertilizer, and an estimate of the costs savings. The laboratory POC study was done at approximately 1000 ppm of NO₂ in GN₂ with total gas flow rates of 3, 10, or 20 L/min and a scrubber liquor flow rate of 150 mL/min, which gave L/G ratios of 42, 12.6 or 6.3, respectively. The pH of the scrubber liquor ranged from 1.7 to 25 wt-% NaOH and the concentration of hydrogen peroxide ranged from 0.1 to 5 vol-%. The oxidizer area of KSC's hypergol storage farm for Pad 39B was used for the full-scale tests. These full-scale tests used the sampling system developed previously ⁽¹⁾ to measure the scrubber efficiencies for NO₂ concentrations of approximately 5000 ppm and flow rates from 100 to 500 SCFM. The analytical methods used for the laboratory phase of this study were used for the full-scale tests.

The analytical methods described in this section were required to analyze the used scrubber liquor, the hydrogen peroxide concentration in the test scrubber liquors before use, and the gas-phase emissions from an oxidizer scrubber for this study. Initially, the gas-phase analytical method for NO_x used ASTM method D 1608-77^(2,3), which had previously been used to develop a new procedure for monitoring the emissions from the oxidizer scrubbers at KSC ⁽¹⁾. Although this method is useful over the range from 5 to 2000 ppm, the procedure is very slow and labor intensive. Therefore, a new method, based on ion chromatography, was developed. Analysis of the scrubber liquor was complicated by the presence of two oxidizing agents, nitrate ions and hydrogen peroxide, and nitrite ions, which meant that analytical methods based on oxidation/reduction characteristics of the analyte could not be used. Analysis of the scrubber liquor was important, first, to study changes that occurred due to different scrubber liquors, and second, for the development of a process control system.

Hydrogen peroxide concentrations were measured by titrating with KMnO₄ and FTIR methods. A colorimetric method was developed for assaying hydrogen peroxide in scrubber liquors, that contained nitrite and nitrate ions, and employed anion exchange resins. Standard solutions of NO_x ions and peroxide were mixed with the resins, after which nitrite was assayed by the Saltzman method and nitrate by ASTM D 1608. Both Amberlite IRA-400 and Dowex Macroporous Resin MSA-2 worked well in absorbing NO_x ions. These results indicated that nitrate and nitrite ions were removed to the extent that there was no interference to peroxide titration's with KMnO₄. Rotometers were used to measure the flow rates of the scrubber liquor.

The IC method was based on standard anion techniques and used a HP DX 500 IC system that operated under their PeakNet Chromatography Workstation software. The DX 500 system is based on a LC20 enclosure, GP40 gradient pump, ED40 electrochemical detector, and an AS40 automated sampler. An AS4 column was used for the anion analysis. The autosampler used 5 mL filter sample tubes and injected 0.100 mL samples into the IC. A series of 4 to 6 nitrite and nitrate ion standards as NO_2^- were prepared with concentrations of 100 to 5000 ng/mL. Typically, the calibration curves covered the range from 10 to 500 ng; however, some of the initial studies covered the range 10 to 5000 ng.

RESULTS

This program was divided into three major tasks to determine the design for the control system for continuous unattended operation at the oxidizer scrubbers. First, the laboratory investigations monitored the changes in the composition of scrubber liquors during single passes down the packing countercurrent to the flow of NO_2^- . Second, the laboratory scrubber was operated in a continuous mode where the scrubber liquor circulated from a reservoir to the scrubber packing and returned to the reservoir. Finally, there will be tests of a full-size scrubber (Pad 39B) to monitor changes in the scrubber efficiency and to prepare samples of scrubber liquor to be evaluated as a fertilizer. In addition to these primary objectives, methods to control the concentration of the scrubber liquor and analytical methods to measure the concentrations were developed and tested in the laboratory and field at Pad 39B oxidizer farm.

The effect of pH on the efficiency appears to pass through a maximum around a pH of 7 and then drops on either side for the single pass laboratory tests, see Figure 5. In these tests the scrubber liquor was pumped to the scrubber and to a waste container and samples were collected and tested for nitrite, nitrate, and hydrogen peroxide concentrations and pH. Typically, there was a significant drop in the pH during the single pass runs. For example, when water was used as the scrubber liquor (initial pH 7) the pH dropped to 2 for a single pass through the scrubber when the NO_2^- concentration was 1000 ppm.

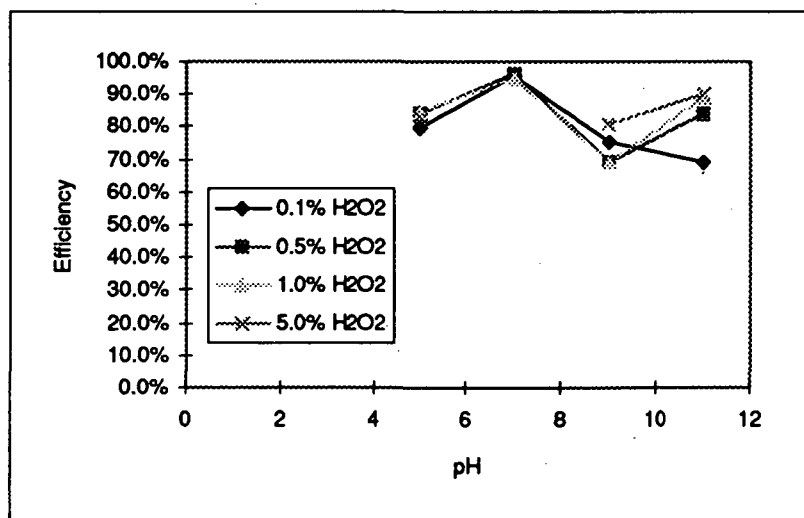


Figure 5. Efficiency vs pH at various peroxide concentrations at L/G of 12.6

The same decrease in efficiency with pH around 7 was observed in the continuous runs as well, except in this case the pH range extended beyond the range of the single pass tests and then the efficiency appeared to increase. These changes for the continuous laboratory experiments are illustrated in Figure 6. Increase in peroxide reactivity has been observed for acidic and alkaline solutions and has been attributed to the increased instability of hydrogen peroxide.

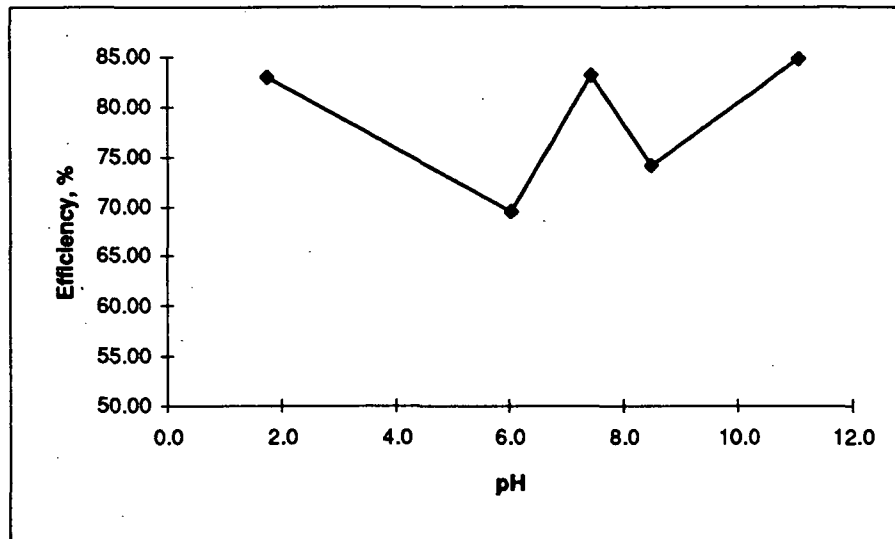


Figure 6. Efficiency vs. pH for continuous laboratory runs at 1% hydrogen peroxide and approximately 1000 ppm of NO_2

The effect of hydrogen peroxide on the efficiency is illustrated in Figures 7 and 8. These represent tests where the pH was held constant and the amount of hydrogen peroxide was varied. Figure 7 illustrates the results where the peroxide concentration is increased from 0.1 to 1.0 percent which shows efficiencies around 96% as compared to an efficiency of around 76% for 25-wt% sodium hydroxide.

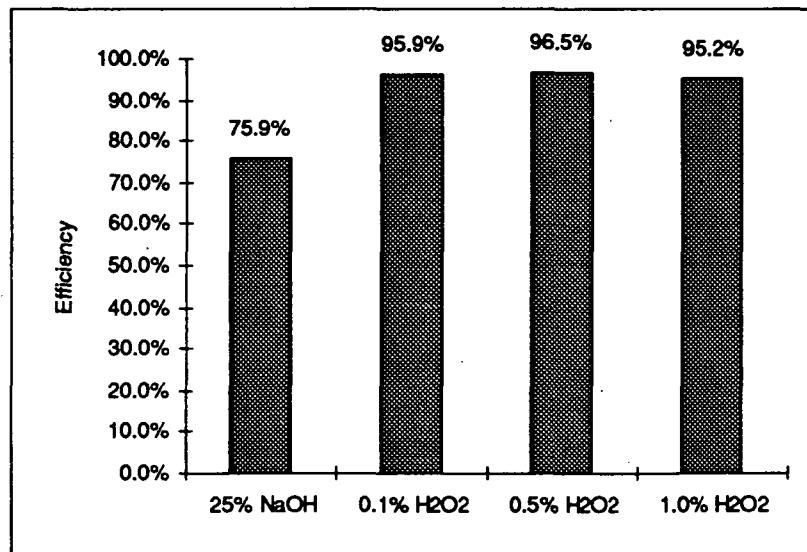


Figure 7. Efficiency for various scrubber liquors at L/G of 12.6

Figure 8 shows a similar effect for the continuous laboratory runs as compared to water. The pH for these tests was approximately 7.5 and the L/G ratio was constant. In this case there were significant increases in the scrubber efficiencies when hydrogen peroxide was added to the scrubber liquor over water.

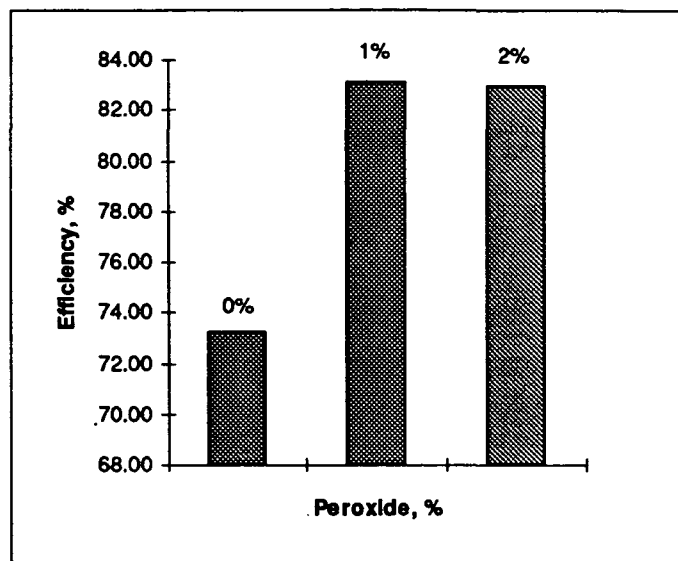


Figure 8 . Effect of hydrogen peroxide on the efficiency of the laboratory scrubber for continuous runs

Analysis of the scrubber liquors for the presence of nitrite ions indicated that the oxidation with hydrogen peroxide had oxidized all of the nitrite ions to nitrate ions, which was one of the objectives for the addition of hydrogen peroxide to the scrubber. Without the presence of hydrogen peroxide the concentration of nitrite and nitrate ions is almost equal. Since nitrite ions disproportionate to form nitric oxide and nitrate ions, oxidation of the nitrite ions is desirable to lower the emissions of NO.

CONCLUSIONS

The primary objectives of this study were achieved: to develop a new scrubber liquor that was less expensive to use than the current 25-wt% sodium hydroxide when all factors were considered including waste disposal, preparation of the scrubber liquor, and handling a hazardous waste (the spent oxidizer scrubber liquor). Improvement in the scrubber efficiencies is the second most important accomplishment of this study, and these changes are significant.

A convenient method for control of the hydrogen peroxide concentration was developed for this study. This device uses the pressure generated when hydrogen peroxide is decomposed with bleach to sense the concentration of hydrogen peroxide in the scrubber liquor.

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