

REDUCTION OF CARBON MONOXIDE EMISSIONS WITH REGENERATIVE THERMAL OXIDIZERS

Scott M. Firmin
Sheldon Lipke, P.E.
Passaic Valley Sewerage Commissioners

Allen Baturay, P.E.
Carlson Associates

Abstract

Regenerative thermal oxidizers (RTOs) have been extensively used for the control of volatile organic compound (VOC) emissions from various sources. However, very little information is available on the ability of RTOs to control carbon monoxide (CO) emissions. This paper presents the results of extensive tests conducted on two RTOs to determine their VOC and CO control efficiencies.

The inlet gas stream to the RTOs includes VOC and CO concentrations as high as 2,000 ppm and 3,600 ppm, respectively. The testing demonstrated that both RTOs were capable of controlling greater than 98% of both inlet VOCs and CO. While the destruction efficiencies within the combustion chambers exceeded 99.9%, direct leakage past valves accounted for the lower control efficiencies.

The tests indicated that the overall VOC and CO control efficiencies of the RTOs may be limited by valve leakage. The design and permitting of a RTO should include conservative control estimates which account for possible valve leakage.

Introduction

The Passaic Valley Sewerage Commissioners (PVSC) own and operate a 330 million gallon per day secondary wastewater treatment facility located in Newark, NJ. The area serviced by PVSC is highly industrial, with a population of approximately 1.5 million people. The wastewater treatment process includes primary treatment and a pure oxygen activated sludge process followed by secondary clarification. Sludge generated in the treatment of the wastewater is thickened in gravity thickeners prior to treatment through the Zimpro Wet Air Oxidation Process. The Zimpro treated sludge is then thickened in decant tanks and dewatered in recessed plate filter presses. The current sludge production is close to 250 wet tons per day.

The Zimpro process utilizes high temperature (420°F) and pressure (650 psi) with the addition of air to oxidize approximately 65 percent of the volatile matter in the liquid sludge. Bound water within the sludge is released through the Zimpro process, which results in the improved coagulation of the solids. The vapors released during the decanting of the

treated sludge are odorous and contain high concentrations of VOCs, CO₂, and CO. The original odor control system included a carbon adsorption system which did not effectively control the Zimpro odors.

In 1991 PVSC purchased and installed two identical RTOs to control odors and VOC emissions from the Zimpro process and the filter press building. One RTO operates at all times with the second unit acting as a stand-by.

Each RTO consists of three canisters containing ceramic media which captures thermal energy from the exhaust stream during an outlet cycle and transfers this energy to the inlet gas stream during an inlet cycle. The flow is controlled by butterfly valves which are opened and closed by linkage arms connected to a drive shaft which completely rotates once every 3-4 minutes. A common combustion chamber is located above the canisters. Two natural gas fired burners, located at opposite ends of the combustion chamber, maintain a temperature of 1,500°F. Prior to an outlet valve opening (an outlet cycle) a purge valve is opened to evacuate any foul gas within the canister and valve area to prevent excessive levels of contaminants from being discharged. A simplified diagram of the system and the valve positions during each cycle are shown in Figures (1) and (2).

The inlet gas stream consists of approximately 30,000 cfm of highly odorous off-gas from the Zimpro process with a VOC concentration as high as 2,000 ppm and an oxygen concentration between 15% and 9%. The inlet gas stream also has a high concentration of CO ranging from 1,800 ppm to 3,600 ppm. The concentration of VOCs, CO, and the percent oxygen entering the RTOs varies with the amount of sludge processed through the Zimpro facility. Both the VOC and CO concentrations increase with the amount of sludge processed by the Zimpro units, while the percent oxygen decreases as more sludge is processed by the Zimpro units.

The original permit to operate required a VOC destruction efficiency of 98%. The permit also allowed a maximum CO outlet concentration of 50 ppm or 100 ppm corrected to 7% O₂, when the oxygen concentration was below 14%. This permit condition is typical of a common combustion source such as a boiler, and indicates efficient combustion of the process off-gas and any auxiliary fuel within the combustion chamber. The

Figure (1) - Simplified RTO Diagram

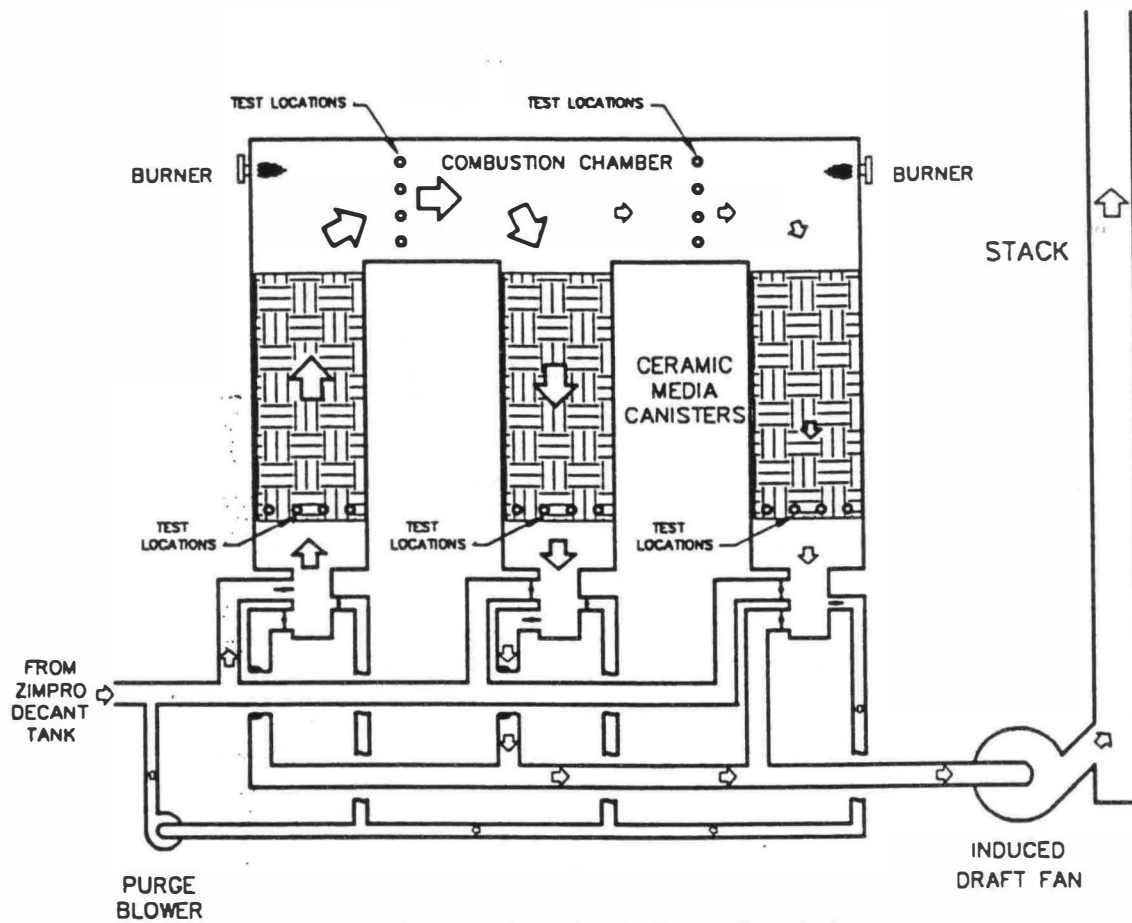
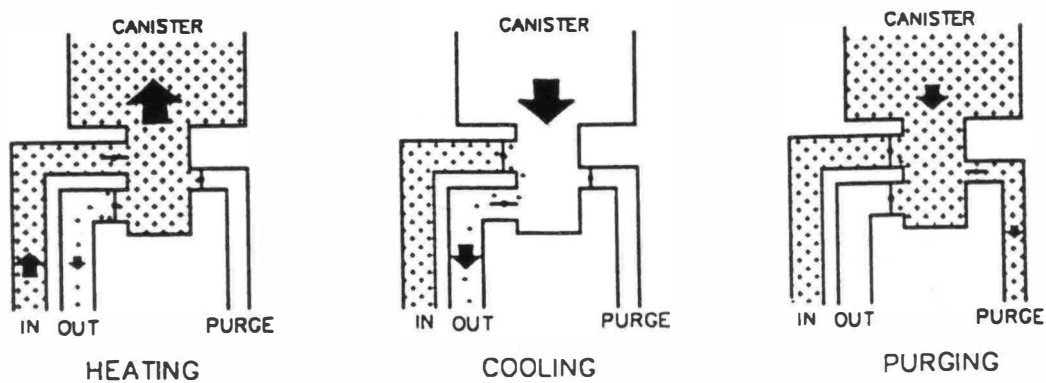


Figure (2) - Valve Position During Each Cycle



permit also included mass emission rates for these contaminants based upon these concentrations and design flow rates. This permit condition did not recognize the RTOs as a control device for inlet CO.

Both units effectively controlled odors from the Zimpro process since start-up, and stack tests in 1992 indicated a VOC control efficiency in excess of 98%. However, neither RTO was able to consistently comply with the permit conditions for CO emissions. Both RTOs emitted higher levels than the permitted mass emission rate for CO during the original stack tests.

With the inlet concentration of CO as high as 3,600 ppm and the inability of either RTO to regularly comply with the permit to operate, the problem of CO control was addressed. PVSC first attempted to modify the permit to reflect the high inlet concentration and a control efficiency for CO similar to the 98% control efficiency for VOCs. The New Jersey Department of Environmental Protection (NJDEP) requested that PVSC continue to investigate alternate methods of compliance with the existing permit conditions. Suggested areas of study included baffles to increase mixing, increased temperatures in the combustion chamber, and valve sequencing.

Early investigations revealed that the outlet CO concentration followed a cyclic pattern which repeated with each valve cycle of approximately 3-4 minutes, as shown in Figures (3) and (4). The amplitude of the "peaks" varied proportionally with the inlet CO concentration. At this point, PVSC contracted with Carlson Associates to investigate the performance of the RTOs and possible methods of compliance with the existing permit.¹

Testing Procedures

Until the testing procedures were devised, PVSC had studied the RTOs as an entire system, sampling only the inlet and outlet streams. The testing procedures implemented were designed to monitor CO concentrations entering each canister, within the combustion chamber, and exiting each canister. The locations of the test ports utilized in the testing are shown in Figure (1). The testing procedures included the following:

1. The total destruction efficiency for both CO and VOCs was evaluated by sampling the inlet and the outlet streams with continuous analyzers.
2. Temperature and CO profiles in the combustion chamber, between each of the canisters, were monitored. This portion of the testing program was designed to determine whether short-circuiting within the combustion chamber or the location of the burners were factors contributing to the high outlet CO concentrations.
3. The effect of temperature on CO destruction efficiency was monitored. The temperature in the combustion chamber was increased from 1,520°F to 1,720°F, in increments of 50°F.

4. Sampling below all three media canisters determined the concentration of CO during both the inlet and outlet cycles. During the inlet cycle, the concentration of CO entering the canister was monitored. During the outlet cycle, the outlet concentration of CO from the canister was monitored prior to flowing past the closed inlet valve. By monitoring the CO concentration over a series of inlet and outlet cycles the destruction efficiency within the combustion chamber was determined.

5. CO levels in the purge ductwork were monitored to determine the success of the purge cycle prior to the opening of the outlet valve. The purge cycle time was increased to determine if the purge time was adequate. If the purge cycle is not complete, "peaks" of CO would result as the slug of bad gas was released into the outlet stream.

6. Sampling between the inlet and outlet valves was performed to determine if leakage past the valves contributed to the elevated CO emissions.

This testing was performed on RTO #1 which consistently exhibited higher outlet CO concentrations than RTO #2. The testing program lasted several days.

Initial Testing Results

The initial testing of RTO # 1 indicated that the system control efficiency for both CO and VOCs was approximately 95%, as shown in Table (1). However, sampling within the combustion chamber and below the media beds indicated that the CO and VOC destruction efficiency within the combustion chamber exceeded 99.9%. No significant stratification of temperature or CO concentration was seen within the combustion chamber. The concentration of CO in the outlet stream did not decrease as the temperature was increased.²

Testing within the purge ductwork showed that the concentration of CO prior to the outlet cycle was reduced to levels below 600 ppm, and did not improve as the purge cycle time was increased. Due to the small volume of gas contained in this area, the purge cycle did not seem to contribute a significant amount of CO to the outlet stream.

The concentration of CO exiting the combustion chamber and canisters, as measured below the media bed and in the combustion chamber, ranged between 0 and 10 ppm. Testing just beyond the inlet valve during an outlet cycle (inlet valve closed) revealed CO concentrations as high as 200 ppm.² The low concentrations of CO below the media bed and significantly higher concentrations beyond the inlet valve during an outlet cycle were observed repeatedly in each of the three canisters.

The results of this testing showed that the RTO achieved nearly 99.9% combustion of both CO and VOCs within the combustion chamber, with an average residence time of close to 1 second. The testing suggested that almost no short circuiting

Figure (3) - Outlet CO (ppm) Prior to Valve Replacement

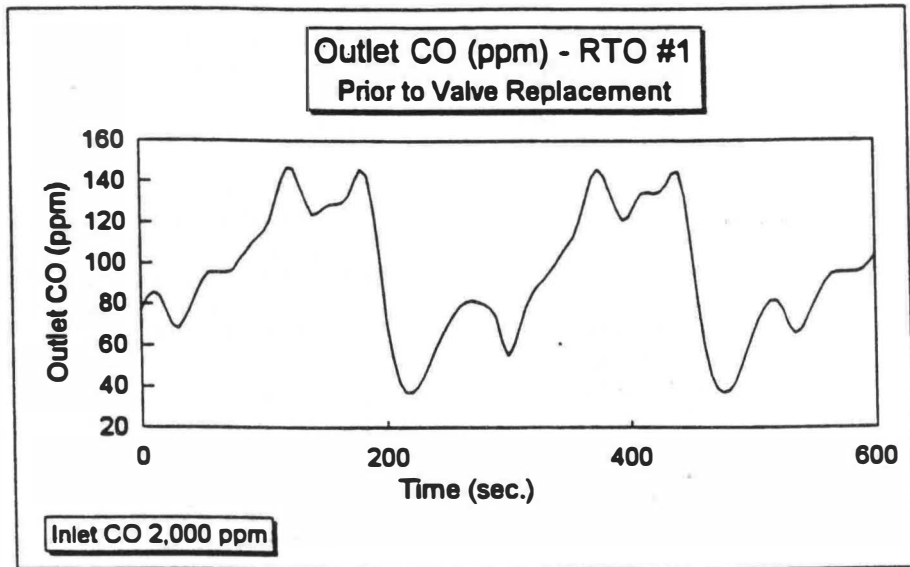
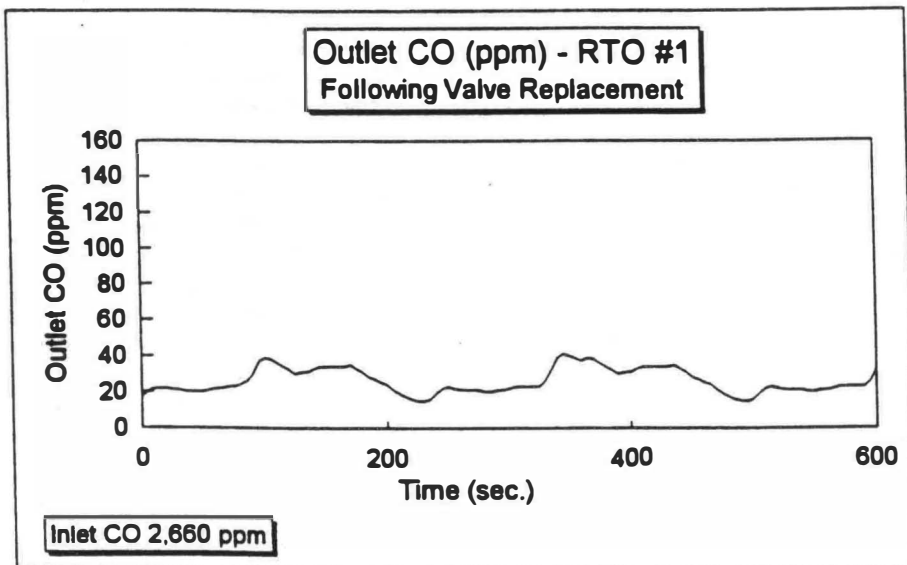


Figure (4) - Outlet CO (ppm) Following Valve Replacement



was occurring between each canister within the combustion chamber, the operating temperature of 1,520°F was sufficient, and the location of the burners was satisfactory. The purge cycle seemed to be adequately evacuating high concentrations of CO prior to the outlet cycles and was not a great contributor to the excessive levels of CO in the exhaust stream.

In summary, there are three sources of CO (and any other contaminant in the inlet stream) in the outlet gas stream:

1. Residual from the combustion chamber
2. Any residual from the purge cycle prior to an outlet cycle
3. Leakage directly past closed valves

The residual portion from combustion was less than 0.1% of the inlet, and given adequate purge times and flows, the residual from the purge cycle was small. The results indicate that the valve leakage is responsible for the majority of any contaminant in the outlet stream. Closed inlet valves were allowing between 5% and 10% of the inlet gas to leak past the valve directly into the outlet stream. This leakage allowed the inlet gas to bypass the combustion chamber and exit the RTO through the outlet stack. Depending on the amount of sludge processed by the Zimpro units (varying the inlet CO concentration), the average outlet CO concentration ranged between 50 and 200 ppm.

Rather than using the term destruction efficiency to describe afterburner performance, the term control efficiency would be more appropriate since the destruction efficiency is responsible for only a small amount of the outlet concentrations. The most startling result of the testing was that the RTO was not achieving the required 98% control efficiency of VOCs. If CO emissions had not been a constant problem with the RTOs, due to the high inlet concentration of CO, PVSC would have assumed proper VOC control based on the 1992 stack test. The reduced control efficiency would have been undetected until the next stack test was performed 5 years after the original test. Without CO in the inlet stream, monitoring the outlet CO concentration will not give an indication of the leakage past valves which accounted for the majority of both VOCs and CO in the outlet.

Valve Replacement

After recognizing the reduced control efficiency, PVSC proposed the replacement of the inlet, outlet, and purge valves to the NJDEP. The new valves were state of the art, designed to seal more effectively than the existing valves. The valve bodies were also designed to resist corrosion, which may have accounted for the increased leakage and the decreased control efficiency of the RTOs in the past.

In order to determine the leakage rates of each valve, additional test ports were installed directly above each outlet valve. The CO concentration exiting the combustion chamber could be determined from the test port below each canister. During an

outlet cycle, any increase could be attributed to leakage past the inlet valve as shown in Table (2).

A second series of tests were conducted following the valve replacement. The testing demonstrated that the RTOs were achieving the required 98% control efficiency of VOCs and the proposed control efficiency of 98% for CO, as shown in Tables (3) and (4). The permit to operate was modified to allow for a mass emission rate for CO based upon a 98% control efficiency of the inlet CO, uncorrected.

This testing indicated that the VOC and CO control efficiencies were similar, since the majority of losses were due to leakage past the valves. The testing was also used to determine leakage past each individual valve. Since leakage accounts for the majority of the outlet concentration of contaminants, this is the area that allows for the most improvement of control efficiency.

Findings

The most important finding was that both units were capable of combusting 99.9% of both VOCs and CO within the combustion chamber. The possible combustion of VOCs in the lower portion of the media beds (600 - 800°F) and CO in the upper portion of the media beds (1,200 - 1,550°F) may contribute to the observed destruction efficiencies. A pressure drop of 8 inches of water column across each media bed seems to provide adequate mixing of the gas stream resulting in little stratification or short circuiting in the combustion chamber.

Despite the destruction efficiency observed within the combustion chamber, leakage past inlet and outlet valves may limit the ultimate performance of a RTO system. Due to the regenerative nature of the system and the number of valves, the overall system efficiency is limited by the valve design. Consideration should be given to the required control efficiency and alternate methods of valve arrangement, such as in series or with a positive air seal. The use of a system with only single valves similar to those installed at PVSC may limit a system to a 98% control efficiency for permitting purposes. Consideration must also be given to possible valve performance decline over their lifetime, with comfort built into the permit.

In order to monitor any future deterioration in the performance of the new valves, PVSC will continue to monitor the control efficiency of each RTO. It is anticipated that the RTOs will be tested by PVSC personnel on a quarterly basis. The leakage rates past each individual inlet and outlet valve will be monitored using procedures similar those employed during these tests. Any decreased performance will hopefully be detected early, and possible solutions explored before the diminished efficiency results in any permit violations.

With regards to leakage past valves, test results suggest that the installation of the valves is critical for effective performance. Butterfly valves similar to those installed at PVSC must rest on a true and level surface. Any irregularity in the supporting surface may result in distortion of the valve body and seat,

Table (1) - RTO #1 Control Efficiency Test Results²
Prior to Valve Replacement

Inlet VOC (ppm)	Outlet VOC (ppm)	VOC Control Eff. (%)	Inlet CO (ppm)	Outlet CO (ppm)	CO Control Eff. (%)
1511.28	76.69	94.9	2864	139.3	95.1

Table (2) - Inlet Valve Leakage Testing Results³
Following Valve Replacement

RTO #2

Canister	Inlet CO Concentration (ppm)	CO Concentration Below Canister (ppm)	CO Concentration At Outlet Valve (ppm)	Average CO Conc. At Exhaust Stack (ppm)
1	2000	~ 0	70	70
2	2000	~ 0	30	40
3	2000	~ 0	25	20

Table (3) - RTO #1 Control Efficiency Test Results³
Following Valve Replacement

Test	Inlet VOC (ppm)	Outlet VOC (ppm)	VOC Control Eff. (%)	Inlet CO (ppm)	Outlet CO (ppm)	CO Control Eff. (%)
1	1440.8	21.1	98.5	1870.3	34.9	98.1
2	1432.7	22.8	98.4	1831.2	34.1	98.1
3	1291.8	20.8	98.4	1956.3	36	98.2

Table (4) - RTO #2 Control Efficiency Test Results³
Following Valve Replacement

Test	Inlet VOC (ppm)	Outlet VOC (ppm)	VOC Control Eff. (%)	Inlet CO (ppm)	Outlet CO (ppm)	CO Control Eff. (%)
1	1511.2	17.3	98.9	2496	31.2	98.8
2	1561.3	17.5	98.9	2533.7	31.3	98.8
3	1833.5	21.5	98.8	3018.4	28	99.1

affecting the ability of the valve to seat properly. It has also been observed that stresses associated with the support of additional weight, such as any manifolds above the valves, should be translated directly to the support of the valve and not to the valve itself. Additional time and care during the installation of the valves may be rewarded by an improved control efficiency of inlet contaminants by minimizing direct leakage past the valves.

Without CO present in the inlet stream, monitoring the outlet CO concentration as an surrogate for VOC destruction may not indicate the actual performance of a RTO. The destruction efficiency of any contaminant within the combustion chamber may be within acceptable levels. However, VOCs bypassing the combustion chamber by leaking past valves will not be detected without an on-line total hydrocarbon analyzer. More frequent monitoring or testing of an RTO may be required to assure continued compliance with any permit conditions.

A continuous CO monitor may be effectively used as an indication of both VOC and CO control if CO is present in the inlet stream. If the permit is based upon a control efficiency for both VOCs and CO, and mass emission rates based upon historical influent concentrations and flows, compliance with the permit can be monitored using a continuous CO analyzer on the outlet stream.

Finally, the tests undertaken by PVSC indicate that an inlet oxygen concentration as low as 9% may be sufficient for adequate combustion of both CO and VOCs. Originally, the average oxygen concentration of 12% to 13% was considered a possible factor in the inability of the RTOs to effectively control CO. No increase or decrease in control efficiency has been detected as the oxygen concentration has varied between 15% and 9%.

Conclusion

When controlling CO or VOC emissions, consideration must be given to the overall control efficiency of the system. While an oxidizer with indirect heat exchangers may be capable of constantly exceeding 99% control efficiency, a regenerative system is limited by valve performance. Depending on the desired control efficiency of the system, appropriate valves or valve configuration must be included in the design.

The use of a continuous CO analyzer to monitor the VOC control efficiency of a RTO system without CO in the inlet stream may not give an accurate representation of the actual performance of the RTO. While monitoring CO may assure that the destruction of VOCs in the combustion chamber is within acceptable limits, it will not detect an inadequate purge cycle or leakage past valves.

The permitting of any source should include conservative estimates of control efficiency which allow for possible leakage past valves. The possible reduction in control efficiency over

time due to deterioration in valve performance should also be considered. After installing any system, continued monitoring and testing by the owner will play a valuable role in proper source control and continued compliance with the permit to operate.

Acknowledgments

The authors wish to acknowledge Mr. Richard Sharp and Mr. Courtnie Logan of Smith Engineering for their work in testing and data interpretation. Thank you to Mr. Victor Fonseca and Mr. Donald Stacy of PVSC, among others, for their invaluable assistance.

References

1. Baturay, A., 1994, "Performance Evaluation for Regenerative Thermal Oxidizers (RTO)", Carlson Assoc., Catharpin, VA.
2. Sharp, R. C., 1994, "Engineering Study" Smith Project No. E-4493, Smith Engineering Co., Broomall, PA.
3. Sharp, R.C., 1995, "Engineering Study for Carlson Associates" Smith Project No. E-4507, Smith Engineering Co., Broomall, PA.