White Paper

Regenerative Thermal Oxidation vs. Recuperative Thermal Oxidation: Matching the Appropriate Choice with the Appropriate Application

Thermal Oxidation of waste gases is a common control technique to destroy VOCs and/or odors in many industrial processes. Common equipment used includes Regenerative Thermal Oxidizers, Recuperative Thermal Oxidizers, Direct Fired Thermal Oxidizers, Flares, Enclosed Flares, and Catalytic Oxidizers. Each technology has strengths and weaknesses depending on the particular application and process conditions. The topic of this paper is to specifically review the performance of Regenerative Thermal Oxidization versus Recuperative Thermal Oxidization systems and assess which applications favor each technology.

In addition to the initial capital cost of the air pollution control equipment, key considerations also include ongoing operating costs including utilities and maintenance expense, equipment life, and reliability. In air pollution control equipment, reliability is typically a primary consideration as equipment downtime can lead to production downtime as well as compliance violations. Ease of maintenance and operation are additionally important as the main focus of manufacturing is production, with air pollution control equipment being a secondary and inconvenient cost of doing business.

CAPITAL COST

Generally, the initial capital cost for a Regenerative Thermal Oxidizer is similar to a Recuperative Thermal Oxidizer for the same size system. Many of the components are the same in both systems with exception that the RTO has two or more chambers of media and a valve or drive system to alternate flow, whereas the recuperative oxidizer has a Shell and Tube heat exchanger. Otherwise, they both have a combustion chamber, process blower, burner/gas train, system controls and safety interlocks, exhaust stack, and interconnecting ductwork. The pad may need to be more substantial for a RTO due to the mass of the ceramic media and the start-up may take a bit longer due to its complexity.

OPERATING COST - UTILITIES

In most cases, the largest utility operating cost associated with thermal oxidation is the thermal energy necessary to operate the system. Destruction of VOCs is accomplished by raising the incoming process stream to the required temperature, generally between 1250 - 1650 °F with the exception of catalytic systems which operate at much lower temperatures. Many processes operate at temperatures much lower than required for oxidization, so the energy consumption necessary for VOC destruction would be significant without the ability to recover some form of energy within the oxidizer.

A Regenerative Thermal Oxidizer uses ceramic media to capture and store thermal energy from the oxidizer chamber or reactor and then re-uses the energy to preheat the process gases entering the chamber. Nominal thermal efficiency is generally around 95%.

A Recuperative Thermal Oxidizer accomplishes this energy recovery by using a heat exchanger, typically shell and tube design, to transfer some of the heat exiting the reactor to preheat the process gas prior to entering the thermal oxidizer. This primary heat exchanger is generally economical at between 50 – 80% thermal efficiency. Overall energy usage will depend on the energy (BTU) contribution from the VOCs, other combustibles contained in the incoming process, and the efficiency of the energy recovered either in the ceramic media or the heat exchanger.

A simple heat balance assessment of the overall system aids in defining the thermal energy requirements. The incoming process gas, based on its mass, composition, and temperature, defines the heat energy going into the oxidizer. Other incoming sources include supplemental fuel and combustion air. Heat energy is lost from the system through the stack and radiant losses from ductwork and system walls. The supplemental thermal energy required to heat process gases is the difference between the exiting heat energy less the incoming heat energy and the contribution from combustion of the process gas. Without any contribution from the VOCs, the higher the system thermal efficiency, the less supplemental energy required to maintain appropriate chamber temperatures. As the energy contribution from the VOCs and other combustibles increase, less thermal efficiency is required to balance the system. When the energy contributed from the VOCs equals the energy required to maintain adequate chamber temperatures, this is deemed auto thermal, and supplemental energy is unnecessary. This is expressed as follows:

Energy necessary to increase process gases to oxidizer set-point, $Q1 = Mpg * Cpm * (Tsp - Tpg)$

Energy transferred from oxidizer discharge to preheat process gases, $Q2 = Mpg * Cpm * (Tsp - Tpg) * \eta th$

Energy from the combustion of products is the sum of the heat of reaction for the mass, $Q3 = \Sigma \Delta Hc$.

Supplemental thermal energy added to the oxidizer combustion chamber, Q4

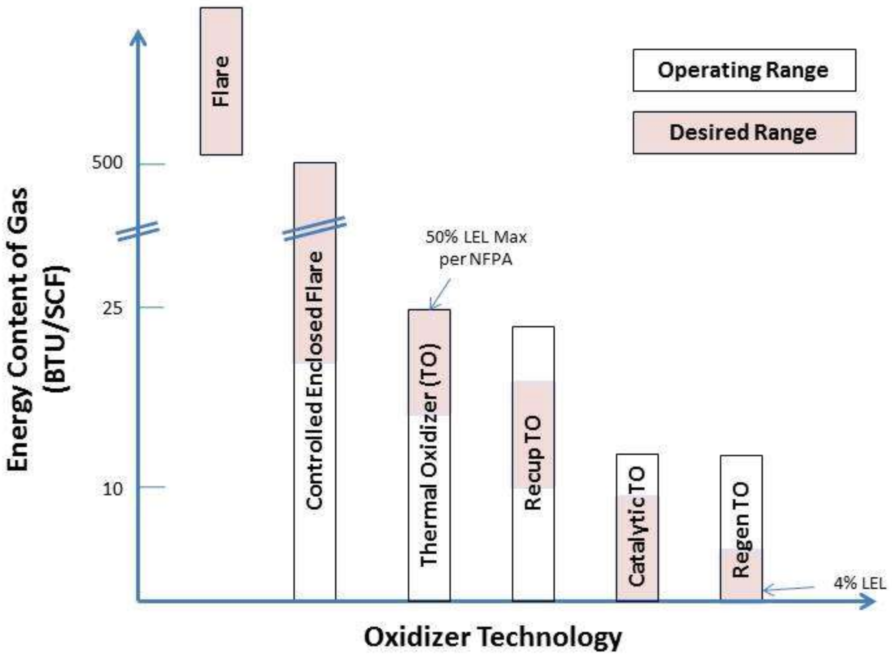
At steady state, without accounting for radiation and thermal losses:

Q1 = Q2 + Q3 + Q4

Where Tsp is oxidizer chamber setpoint temperature, Tpg is the process gas temperature, Cpm is the mean heat capacity over the temperature range and Mpg is the mass flow rate of the process gas. ηth is the thermal efficiency.

When a system is auto thermal Q1 = Q2 + Q3. By rearranging the formula, the system is in balance when Mpg * Cpm * (Tsp - Tpg) * (1 - ηth) equals the energy from the combustion products. As the energy increases above the requirements, the system efficiency needs to be reduced to stay in balance.

When energy consumption is the primary consideration and a process contains high energy due to the heat of combustion from the products contained in the process gases, these processes are ideally treated with technologies that have low thermal efficiency such as flares, enclosed flares, and direct-fired oxidizers. Processes with very low energy contribution from the combustion process are ideally treated with a regenerative thermal oxidizer or a recuperative thermal oxidizer with high heat exchanger efficiencies and potentially secondary heat recovery. Processes with low to moderate levels of energy contribution should be carefully assessed to optimize equipment efficiency versus overall energy requirements. The chart below graphically depicts this relationship:



RELIABILITY – DESTRUCTION EFFICIENCY

Destruction efficiency, through the use of Thermal Oxidizers, has been empirically demonstrated to achieve destruction efficiencies in the high 90% range. This is accomplished by maintaining the object pollutant stream at a targeted temperature above its Autoignition temperature for a specific amount of time (residence time) in the presence of adequate levels of oxygen. Recuperative thermal oxidizers are capable of maintaining continuous steady state operating conditions for nearly indefinite periods. With few moving parts and constant stable operating pressures and temperatures, a properly designed recuperative thermal oxidizer easily achieves in excess of 99% destruction efficiency. Regenerative thermal oxidizers, depending upon design and associated capital cost, experience greater difficulty in achieving the same high destruction efficiencies attained by use of the recuperative thermal oxidizers. A two chamber RTO continuously cycles valves reversing flow direction through the system using ceramic media first for heat storage and then as a heat recovery source. Continuous directional shifting allows some portion of waste gas to short circuit through the valves, thereby bypassing treatment all together, as well as preventing some portion of the gas which is stopped short of the reactor, from being treated. Additionally, the constant pressure and flow change not only impact seals and gaskets which need to be maintained (causing potential leakage), but can also be a nuisance in production processes that may be sensitive to pressure and flow fluctuations. A three chamber system aids in eliminating by-pass by use of constantly moving valves and a purging system, but are still prone to leaking seals and valve malfunctions.

RELIABILITY – ON-STREAM TIME

When designed for industrial use, both types of thermal oxidizers have good on-stream time and are capable of operating 24/7 for long periods of time. Adverse process considerations may include the presence of condensable compounds, siloxanes, and particulates all of which may foul the equipment and negatively impact performance. When these upsets occur, equipment down-time and repair may be necessary. For a recuperative thermal oxidizer, this generally means that the heat exchanger and reactor chamber may need to be opened to allow the tubes and chamber to be cleaned and remove fouling. When a regenerative thermal oxidizer is fouled, a bake-out may resolve the issue; however, severe cases require removal and disposal of the ceramic media and replacement with new media.

Additionally, an RTO is more complex than a recuperative thermal oxidizer. It has more moving parts. Both systems have fans that operate continuously but a RTO has diverter valves, which shift frequently to alter the direction of flow through the system. These valves and drives create continuous pressure and temperature fluctuation and are subject to significant wear and tear.

APPLICATIONS

The most appropriate application for Regenerative Thermal Oxidizers are processes where VOC loading is relatively low in proportion to a high exhaust flow rate that does not contain significant particulate or condensable matter. In addition, flexibility in the air quality permit for maintenance down-time to service the valves, gaskets, and ceramic media, is beneficial. As previously stated, supplemental energy is required to heat the reactor chamber to the required oxidization temperature, typically between 1200 to 1500 degrees F. As low VOC concentration in the stream does not contribute much energy towards raising the reactor chamber to the required temperatures, higher energy efficiency is beneficial for reducing the need for supplemental gas consumption. Some of the more common RTO industrial applications include paint and finishing operations, ethanol production, and coating operations.

Alternatively, the RTO's high energy efficiency is not as beneficial in streams that contribute significant amounts of their own energy. RTOs can be applied in these situations by modifying the equipment and the way they typically operate. "Work-arounds" include adding significant amounts of dilution air to provide a cooling effect, permanently reducing the thermal efficiency of the system by installing less ceramic media, or adding a hot gas by-pass system to periodically and temporarily reduce the RTO's thermal efficiency. Adding excess dilution air requires a much larger system than would otherwise be necessary, while adding a hot gas by-pass leads to challenges maintaining chamber temperature and destruction efficiency.

CASE STUDY 1 – NATURAL GAS PROCESSING FACILITY

A natural gas processing facility operated by a company which provides midstream natural gas and natural gas liquid (NGL) services needed to treat a waste gas stream from one of its processing facilities. Pollution Systems provided a portable thermal oxidizer as a temporary solution to treat the process exhaust until a permanent solution could be evaluated and implemented.

Several major equipment manufacturers provided proposals. The two main technologies evaluated were Regenerative Thermal Oxidizers and Recuperative Thermal Oxidizers. The stream to be treated was relatively small, ~900 scfm, but is devoid of oxygen. It contained methane, ethane, propane, benzene, and several other organic compounds of significant heating value. The major equipment performance objectives were as follows:

- VOC destruction efficiency of 99%
- Automated and Continuous Operations with minimal interface requirements
- Cost effective, highly reliable design considerations

Without oxygen, it is necessary to add some level of oxygen (air) to the process exhaust to achieve oxidation. In the regenerative thermal oxidizer, excess air was also necessary to control the temperature. As noted previously, the high thermal efficiency is not necessary, so the regenerative thermal oxidizer proposal incorporated a larger system with higher amounts of dilution air. The RTO system design also required a hot gas bypass to provide options if the concentrations of the organics fluctuated. Although the system claimed a high thermal efficiency, the energy was used to heat a large amount of unneeded dilution air. The recuperative thermal oxidizer easily met the performance objectives above and did not include as much dilution air thereby allowing for a much smaller system. After evaluating the various proposals, Pollution Systems was selected to provide a recuperative thermal oxidizer for the application.

Pollution Systems worked closely with the client's technical and operating group. The customer was provided a more detailed design including the P&ID, General Arrangement and Equipment Specifications for feedback and approval. Their feedback was incorporated into the design prior to commencement of manufacturing the equipment. The equipment was installed at the end of 2011 and has exceeded customer expectations.

CASE STUDY 2 – CHEMICAL PRODUCTION FACILITY

A chemical production facility was exploring a more fuel efficient and effective way to treat their VOC laden waste gas. Currently there had two flares that handle the VOC abatement needs. However, they are very fuel intensive and carry high ongoing operating costs. Multiple reactors produce the waste gas, which is collected into an equalization tank prior to VOC abatement. They were interested in pursuing a regenerative thermal oxidizer to reduce their operating cost.

The process exhaust stream contains Toluene, Heptane, Acetone, Isopropyl Alcohol, Hexane, Xylene and a number of monomers. After carefully reviewing the customer's process conditions, including possible upset conditions, Pollution Systems concluded that a high VOC recuperative thermal oxidizer was a better selection. The system would be sized to handle both average and maximum peak loadings efficiently through the use of a Variable Frequency Drive (VFD) controlling dilution air. The High VOC Recuperative Thermal Oxidizer version is designed to handle waste gases above 50% LEL and significantly reduce the amount of dilution air added to the process stream. NFPA requirements state that a stream entering the oxidizer chamber be below 25% LEL but up to 50% if they use an LEL monitor. However, if used as a fuel stream for the burner there is no requirement. The High VOC oxidizer uses the process exhaust as fuel.

Although the customer was predisposed to using a regenerative thermal oxidizer they selected the high VOC recuperative thermal oxidizer after comparison to other proposals. The size of the regenerative thermal oxidizer recommended in other proposals was significantly larger due to the dilution air requirements and the RTO did not offer the flexibility to handle the potential process upsets. Thermal efficiency is not meaningful when large amounts of dilution air are added as a heat sink.

ADDITIONAL CONSIDERATIONS

A recuperative thermal oxidizer's steady operation and flexibility of design and control allow it to become a more integral part of a production process when there is the opportunity to preheat incoming air. A secondary heat exchanger can be used to preheat process air requirements such as preheating fresh air for use in ovens or dryers. Using automated controls, the target temperature of the oven air is consistently maintained. Although secondary heat recovery is also an option for an RTO, there is little control over the exit temperature from an RTO and the exhaust is constantly cycling through a temperature and pressure range.

CASE STUDY 3 – ANIMAL FEED PRODUCTION FACILITY

A company that produces animal feed minerals desired to increase its production by adding a new line in its facility and required air pollution control equipment for odor control from its process. Pollution Systems was selected to provide a recuperative thermal oxidizer to effectively reduce odors in 40,000 SCFM of VOC laden process generated in the production of animal supplements. Additionally, long term reliability and ongoing operating cost, particularly energy consumption, were a major considerations in equipment selection and design.

The system provided was a high efficiency recuperative thermal oxidizer with an additional 75% secondary heat exchanger to substantially reduce ongoing operating cost. The recovered energy was designed to preheat air for the manufacturing drying process. A regenerative thermal oxidizer was not a good fit for this application due to potential for particulates in the air stream and the desire to maintain consistent temperatures to the process ovens.

Many other energy saving features, including proportioning air to fuel valves on the gas train and high efficiency fans with variable frequency drives, were incorporated in the system.

SUMMARY

Our experience is that the general perception in the US is that RTOs are the cure-all solution for VOC abatement. However, all oxidizer technologies have particular niches which suit those products well. Flares and direct-fired oxidizers are good in applications with high energy loads, RTOs are well suited for larger flows with low energy contribution, and Recuperative Thermal Oxidizers perform well in treating streams with moderate energy contribution. The composition of the gas stream, destruction efficiency requirements, and the required on-stream time are also important considerations to evaluate prior to making a decision on the appropriate technology.