Choosing the Right Emissions Control Option
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Determining the most economical option to control airborne emissions during chemical process operations presents several unique challenges. As with any add-on control system, the goal is to minimize the annualized total costs while maintaining proper operation. However, the highly variable nature of many industrial emission sources and the potential for wild fluctuations among particular exhaust stream variables (such as air volumes, pollutant loadings, and varying combinations of pollutants) create additional challenges in terms of choosing the optimum system, managing stable operations and managing costs.

The types of industrial exhaust streams that present particular pollution-control challenges include:

- Emissions from multiple sources, which are often spread out over a wide area
- Emissions from batch operations
- Unpredictable fugitive emissions

For the most economical treatment by the centralization of the treatment system, disparate airborne sources are often collected and concentrated. The goal is to create as few streams as possible with the lowest overall air volume requiring treatment.

For some sites this calls for an extensive ductwork system to collect and deliver the various emissions streams to one location. An example is a product storage facility that has multiple tanks or vessels, each of which vents small, irregular exhaust volumes whenever product is loaded and displaces the vapor phase in the tank or vessel. Another example is a facility that has many batch processes, each of which vents pollutant-laden emissions in unpredictable concentrations whenever the process is initiated or terminated.

Fugitive emissions should be collected in the lowest air volume possible to minimize cost. Toward this end, closely designed capture systems, or add-on concentration technologies, can be used effectively.

**Exhaust stream variables**
Since industrial emissions often vary in terms of fluctuating air volumes the
presence of multi component emissions and the nature and concentrations of hydrocarbons present, the emissions control system must be designed to accommodate such variables. Other variables that affect technology and feature selection include the operating characteristics of the emitting process, the method of emissions collection and the number and magnitude of the different sources. How each of these factors affects technology selection is examined more closely below.

Control systems for airborne emissions can either recover or destroy organic pollutants. If reuse of the chemical species is possible or presents some economic opportunities, then recovery is generally preferred. In most cases, however, the only recovery value for the airborne organics is as a fuel source; the recovered hydrocarbons are eventually burned to offset fuel consumption at the facility.

**Destruction options**

For hydrocarbon emissions, the most commonly applied form of destruction is thermal oxidation. In this process, hydrocarbons are converted at an elevated temperature to carbon dioxide and water vapor. Several types of oxidation systems are widely used today (each is discussed below):

- Recuperative thermal oxidizers
- Regenerative catalytic oxidizers
- Regenerative thermal oxidizers
- Variable exhaust destruction systems capable of efficiently treating liquid gas, or even solid waste streams

**Recuperative thermal oxidizers (Recups)** include a combustion chamber with a primary heat exchanger to recover waste heat from the hot incinerated exhaust air and use it to preheat the incoming emissions-laden air stream (Figure 1). These oxidizers typically include a shell-and-tube heat exchanger that is capable of up to 70% primary heat recovery.
FIGURE 1.
Cut-away view of a typical recuperative thermal oxidizer

With an oxidation temperature of about 1,400°F, such systems often yield sufficient waste heat for secondary heat recovery, even after primary heat recovery. This heat is typically employed for process heating, or to generate steam or hot water. Recuperative oxidizers are typically best suited for those applications where the excess heat that is generated can be used to offset the relatively high operating (fuel energy) cost for the unit.

A typical recup can handle a wide variety of solvent blends, as well as the fluctuating solvent concentrations that are typically produced in CPI applications. As the inlet temperature increases, the temperature leaving the preheat exchanger also increases. If this preheat temperature gets too high, pre-ignition of the solvents may occur, resulting in thermal stress and possible damage to the heat exchange tubes. Therefore, for high inlet temperatures, (i.e., above 400°F), the oxidizer heat recover may have to be redesigned to lower the heat recovery, thereby lowering the preheat temperature and the threat of preignition.

A recup will efficiently destroy halogenated compounds, but if such compounds are present, more-exotic metallurgy is needed, often making the recup a less economical alternative. Pressure drop through recuperative thermal oxidizers is steady, requiring no automatic volume control. However, if the emitting process produces exhaust streams of variable volume, automatic control will be required to ensure steady burner operation.

**Regenerative catalytic oxidizers** operate on the same principle as recuperative oxidizers, but use a catalyst to promote the oxidation process at
lower temperatures (Figure 2). The catalyst -either a noble or base metal type - can reduce the necessary oxidation temperature from 1,350°F or greater to 600-800°F or lower. This can reduce natural gas consumption, and hence operating cost, compared to a recuperative thermal oxidizer, and allows the oxidizer to be built from less-expensive steels as well, resulting in lower equipment fabrication costs.

**Figure 2.**

*In a five-chambered catalytic oxidizer such as this one, a noble or base metal catalyst promotes oxidation of the exhaust stream at a temperature that is several hundred degrees less than that’s required by a regenerative thermal oxidizer. Lower oxidation temperatures reduces fuel needs and operating costs, and allows the oxidizer to be built from less-exotic steels, reducing fabrication costs.*

The major disadvantages of a catalytic oxidizer are the higher maintenance costs that result from the need to monitor the catalyst to ensure performance. Heavy metals and halogens are known to deactivate catalysts, as do certain organic silicones, although some newer catalysts have been developed to operate in the face of halogenated streams.

In general, before a catalytic oxidizer can be specified, the user needs to be very knowledgeable about the various organic and inorganic compounds in the exhaust stream. Also, the catalytic thermal oxidizer is not recommended for air streams containing changing hydrocarbon blends and fluctuating concentrations, and is a poor technology for many of the exhaust streams found in the CPI.
Regenerative thermal oxidizers (RTOs) consist of a purification chamber located above three separate chambers (Figure 3). These three energy-recovery chambers are filled with ceramic heat exchange media. The hydrocarbon-laden air enters the inlet header and is directed to one of the energy-recovery chambers through an inlet control valve. The air passes through the heat exchange media, absorbing heat. It then enters the purification chamber at a temperature very close to the oxidation temperature, typically 1,400 -1,550° F. If the incoming gas contains sufficient concentration of solvents, the energy content of those organics provides the necessary heat to raise the temperature of the exhaust stream to the combustion set point. In this case, the burner will shut off, leaving only a small pilot flame burning.

Figure 3.
Inside a three-chambered regenerative thermal oxidizer (RTO), such as the one shown here, the chambers are filled with ceramic heat exchange media, which captures heat in the treated exhaust stream and uses it to reduce overall fuel needs. To ensure continuous operation, the chambers operate in an alternating sequence so that at least one chamber is operating in inlet mode while the other is in outlet mode.

The purified air leaves the unit by passing through the heat exchange media in an adjacent chamber. The heat in the air is transferred temporarily to the heat exchange media. The clean air is discharged through a stack to the atmosphere. The temperature of the air as it leaves the unit is typically only 60-120°F greater than the temperature of the polluted air entering the RTO, signifying good heat recovery and, thus, a very low natural gas requirement.

During operation, multiple chambers of an RTO operate in an alternating sequence, so that at least one chamber is always operating in inlet mode while
the second is in outlet mode. The third chamber, necessary for elevated destruction efficiency, is on purge mode, as explained below.

The RTO is equipped with a purge system that allows the evacuation of solvent-laden air that may become trapped below the heat exchange media to be evacuated. The automatic purge cycle forces this polluted air into the purification chamber where the hydrocarbons are destroyed. This feature ensures continuous high destruction efficiency up to 99%.

The advantages of an RTO include very high thermal and destruction efficiency, NOx emissions as low as 20% of levels produced by other oxidizers, lower susceptibility to attack from hydrocarbons, and lower overall operating costs. The disadvantages of an RTO include large size (resulting from the need for very large ceramic heat exchange surface), more expensive installation and higher capital cost, and more moving parts. Despite these disadvantages, many features of the RTO make it an ideal technology for the CPI.

In some cases, design modifications are necessary for the unit to safely handle the wide range of exhaust stream characteristics. The high thermal efficiency of the RTO means fuel costs are low for exhaust streams with very dilute pollutant loads. However, if the exhaust stream that the RTO unit treats can at times emit very high hydrocarbon concentrations, the thermal efficiency of the unit drops sharply. As the organic concentration increases, the excess energy available from the heat of combustion must be exhausted to the atmosphere. In this situation, some form of heat-rejection capability must be built in.

When directed into the RTO through the ceramic-filled tower (its usual path), the process air enters the combustion chamber at over 1,300°F. During periods of high hydrocarbon concentrations, the heat-rejection system routes process air at inlet conditions directly into the combustion chamber of the unit, bypassing the ceramic-filled tower. By doing this, the inlet air acts as a cooling medium for the excess combustion energy, maintaining control over the combustion chamber temperature.

The excess combustion energy must still be exhausted to the atmosphere. A result, the stack temperature gradually increases during periods of high hydrocarbon concentrations, indicating heat rejection.

Multiple emission sources, such as process vents or small batch operations
that have been ducted together, can usually be treated with an RTO. Among its other advantages are these: the RTO has no exposed metal in the combustion chamber, reducing its susceptibility to acid attack; excess heat from high solvent loads can quickly be rejected from the combustion chamber; and its burner can quickly fire should solvent levels fall. In short, this approach remains a flexible option during the oxidation of most hydrocarbon mixes or concentrations.

Additionally, the RTO can handle a wide range of air volumes, typically as low as 5-10% of design. Generally, recycle capabilities can be installed to ensure that even with inlet flow as little as 2 to 4% of design, the unit will operate at steady state with continued design destruction efficiencies.

**Rotary concentrators** are used for air streams roughly 20,000 scfm or greater, with hydrocarbon concentrations less than 3% of the lower explosive limit to concentrate the emissions into smaller air streams that can be handled more economically (Figure 4). The hydrocarbon-laden air passes through the rotary adsorption unit where the hydrocarbons are adsorbed by zeolite or carbon media. The purified air is exhausted to the atmosphere, and the hydrocarbons that have been adsorbed by the media are then removed by periodic desorption running a small volume of higher-temperature air through the adsorption media. The desorbed air that now contains the highly concentrated stream of organic pollutants is then delivered to the oxidation unit for destruction.

**Figure 4.**
Exploded Flow Diagram of a skid mounted rotary concentrator system. A rotary concentrator provides a more economical final treatment choice—either solvent destruction or recovery.
The rotary concentration system is designed to continuously adsorb organic pollutants from an air stream onto the zeolite or activated carbon, and to discharge purified air through the center of the cylinder. The adsorbent is carried on a moving adsorbing wheel, a section of which is simultaneously desorbed while adsorption is being carried out. This design eliminates the need for twin beds operated in an alternating sequence.

During operation, a portion of the rotating cylinder is simultaneously desorbed by passing hot air through a section of the cylinder. The section being desorbed is sealed off from the remainder of the wheel by rotor seals, so that very high efficiencies can be obtained in the continuously operated system. For example, organic-capture efficiencies for this type of system may be as high as 99%.

Rotary concentration systems can be designed using either zeolites or activated carbon as the adsorption media. In certain applications -such as when higher-boiling hydrocarbons are present -a granular activated carbon (GAC) prefilter is used up stream of the honeycomb rotor. Similarly, if the process emits hydrocarbons in widely varying concentrations, a GAC prefilter can also smooth out the concentration fluctuations so that the pollutant-laden stream reaching the rotor is more consistent in composition (thereby improving the overall removal efficiency of the system).

The advantages of rotary concentration systems include relatively low energy consumption and low operating costs compared to regenerative or recuperative oxidizers, an absence of byproduct NOx formation (because no combustion is involved), low pressure drop, good reliability, and ease of operation and maintenance due to few moving parts and reduced heat stress with any adsorption system, the incoming stream must have particulate levels below approximately 0.6 grains per thousand scfm. Otherwise, particulate filtration is required upstream of the adsorber to prevent blinding of the media. Simple bag filters are generally acceptable for that purpose.

Today, many CPI facilities use hybrid systems, which combine rotary concentration adsorbers to concentrate dilute levels of solvents in large volume air streams, and oxidizers to destroy the concentrated hydrocarbon stream. This combination is a very cost-effective option for treating large exhaust streams with relatively dilute levels of organic emissions.
Variable exhaust destruction systems offer a cost-effective and able method for the treatment of exhaust air or liquids in the chemical, petrochemical and pharmaceutical industries (Figure 5). Because they feature direct combustion with no exchange of air, variable exhaust destruction systems normally achieve a destruction efficiency of 99.9%

Typically, such systems are used for:

- Exhaust gases with fluctuating flow rates and pollutant concentrations high enough to be within the explosive range
- Exhaust gases with an oxygen content of 0-21 vol.%
- Exhaust gases burning only with a backup flame, self-burning lean gases and self-burning rich gases
- Exhaust gases containing halogenated compounds, nitrogen and/or sulfur (this group includes all toxic and carcinogenic substances)
- Residual liquids and waste solvents, plus waste water with dissolved or emulsified organic and/or inorganic substances difficult to remove
- Waste and residual liquids that contain or form salts and/or salt-binding substances

Figure 5.
Cut-away view of a typical horizontal gas/liquid oxidation system with flue gas cooling systems. Gas/liquid oxidizers are applied mainly in the chemical, petro-chemical, and pharmaceutical industries and in related branches where exhaust gases of explosive composition and residual liquids have to be treated

In the variable exhaust destruction systems, the combustion chamber can be either a single or multi pass combustion unit that is insulated with a refractory
lining and designed to withstand extremely high temperatures. It provides a safe environment in which to oxidize multiple types of gas, liquid and waste pollutants. This combustion chamber and burner form the heart of the system.

Generally a variable exhaust destruction system uses a multi-fuel burner that combines organics-laden combustion air with natural gas or oil as primary fuel source. Liquid and exhaust gas streams are added as auxiliary fuel and oxidized at temperatures ranging between 1,500 and 2,000°F.

In a single-stage variable exhaust destruction system, all of the liquid wastes, exhaust gases and combustion air are fed into the system through the burner that is located at the back of the combustion chamber. If the waste stream contains very low oxygen levels, the system is specially designed to meet the combustion air requirements for the specific waste streams. If the process gases or liquids are corrosive, then the burner and combustion chamber may require special materials for construction.

Dual-stage combustion systems are used to combust both process gases and liquids in the same system when a primary and secondary combustion zone is required. This might be the case where the formation of secondary products of combustion, such as NOx, is an issue. In a dual-stage system, the process gas or liquids are injected tangentially into the secondary zone, and mixed with natural gas fuel from the primary combustion zone.

The variable exhaust destruction system has been proven to safely and reliably process exhaust streams laden with extremely difficult or dangerous materials. Numerous add-on enhancements (such as heat recovery), safety devices (such as flame arrestors), flashback suppression, water seals, steam generators, NOx-removal systems, lower explosive level (LEL) monitoring, and dilution air injection can also be considered during system design.

A major advantage of the system is its ability to operate at oxygen concentrations as low as 4%, often firing successfully using the waste fuel itself, or with very little support fuel (such as residual liquids or solvents) while simultaneously minimizing the formation of NOx.
**Applying the right technology**

Here is an example of how the best option for a given situation was selected and applied. A chemical manufacturer has an onsite product storage facility. As product is loaded into the various tanks and vessels, hydrocarbons trapped in the vapor space are vented to the atmosphere. This hydrocarbon laden air is exhausted in small, irregular volumes and contains a wide range of hydrocarbon concentrations.

By means of an extensive system routed throughout the facility, all sources of airborne emissions were collected and concentrated. The total air volume fluctuated between 10 and 100% of design over the course of routine facility operations. At any given time, the hydrocarbon mix within the stream virtually unknown and contained concentrations ranging from almost zero to several thousand ppmv.

The total air stream was ducted to a regenerative thermal oxidizer. To ensure consistently high destruction efficiencies as well as smooth operation in the face of fluctuating inlet conditions, several features were designed into the unit. A heat-rejection system was incorporated to control combustion temperatures even with extremely high hydrocarbon concentrations. A variable-frequency drive was also included with the exhaust fan to automatically compensate for air volume changes. For extremely low air volumes, an exhaust recycle feature interfaced with a fresh air inlet to provide stable operation at ultra low volumes.

The resulting system oxidizes more than 98% of the incoming hydro carbons to carbon dioxide and water vapor. Operation is smooth and steady-state, and requires no operator intervention. To date, no problems related to the wide range of inlet conditions have been experienced.

When evaluating technologies to address airborne emissions, first begin with sampling to determine the types and concentration of hydrocarbons and/or toxics being emitted. Tests should be conducted under a variety of operating scenarios. Future production needs must also be evaluated. A careful review of current regulations and any changes that are being anticipated by industry groups is necessary. Finally, local site constraints must be evaluated. Then, and only then, can the most appropriate technology option be selected.
Author

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As an independent business unit of Dürr Systems, Environmental and Energy Systems is an innovative manufacturer of over 3500 systems for air purification worldwide. For more than 35 years, Dürr’s environmental technologies have provided clean air and reduced emissions for a wide variety of industry.