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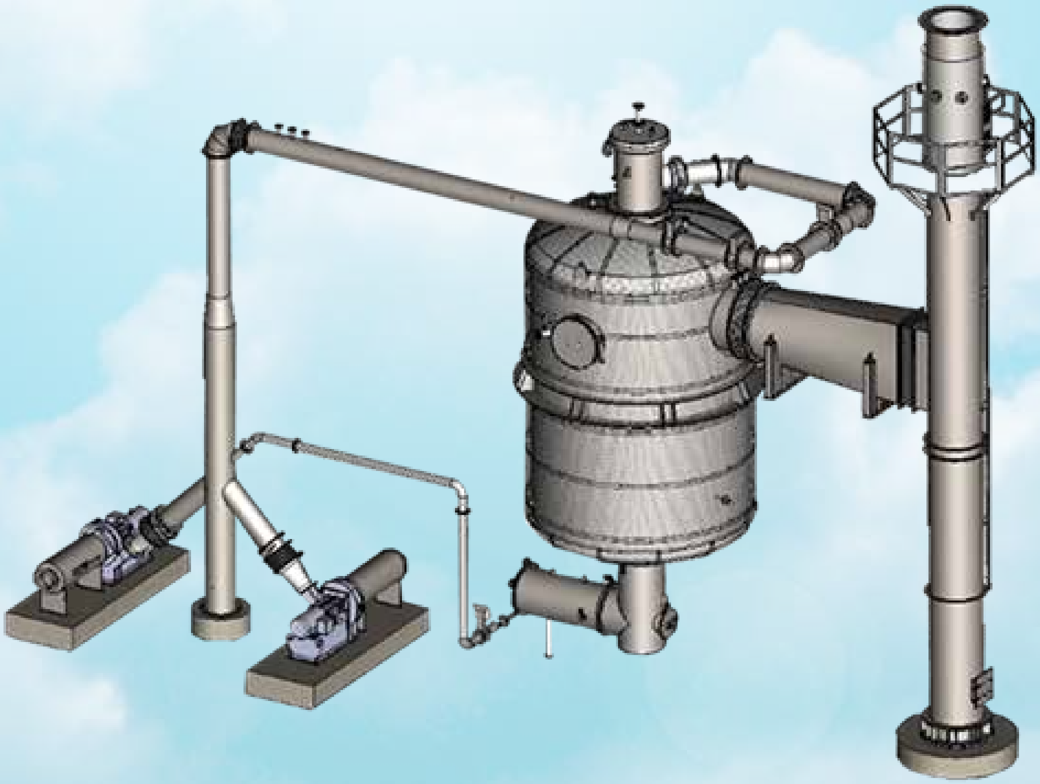
An Introduction to Flameless Thermal Oxidation



An eBook generated to provide the reader with a generic overview of the common technologies utilized to control Industrial and Commercial air pollution. PCC continues to provide educational material in support of Industry and the need to utilize properly designed and configured Air Pollution Control equipment.

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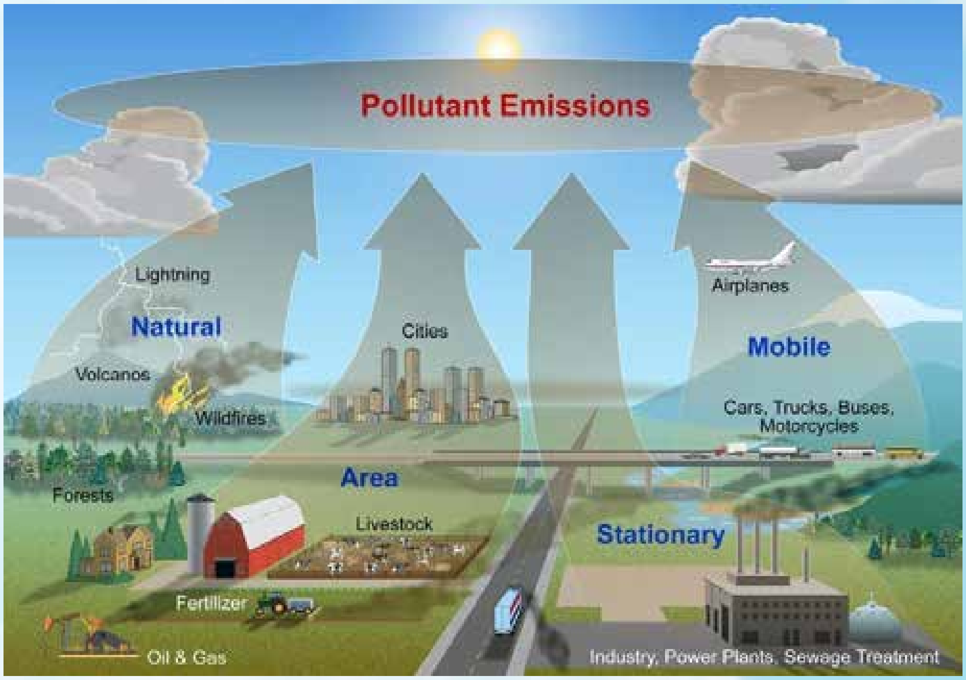
Introduction:

What is an Air Pollutant?

Answer: Any substance in the air that can cause harm to humans and the environment. Pollutants can be in the form of solid particles, liquid droplets, or gases. In addition, they may be natural or man-made.



Pollutants can be classified as primary or secondary. Usually, primary pollutants are directly emitted from a process, such as ash from a volcanic eruption, the carbon monoxide gas from a motor vehicle exhaust or sulfur dioxide released from factories. Secondary pollutants are not emitted directly. Rather, they form in the air when primary pollutants react or interact. An important example of a secondary pollutant is ground level ozone — one of the many secondary pollutants that make up photochemical smog. Some pollutants may be both primary and secondary: that is, they are both emitted directly and formed from other primary pollutants.

Air pollution is controlled to protect the environment from the harmful effects of industrial and municipal pollutants. We must eliminate the impact air pollution has on humans, animals, plants and all other life supporting systems.

Air Pollution Control (APC) can be described as a “separation” technology. The pollutants, whether they are gaseous, aerosol, or solid particulate, are separated from a carrier gas which is usually air. The pollutants are categorized as follows:

- Gaseous pollutants are compounds that exist as a gas at normal conditions.
- Aerosols are finely divided solid and liquid particles that are typically under 0.5 microns in diameter. They often result from the sudden cooling of a gaseous pollutant.
- Solid particulates can be evolved through combustion or through common processing operations such as grinding, roasting, drying, coating, forming or metalizing

Pollutants are commonly referred to as Volatile Organic Compounds (VOC's) or Hazardous Air Pollutants (HAPs). As defined by the US EPA, "Volatile organic compounds (VOC) means any compound of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate, which participates in atmospheric photochemical reactions." On the other side of the equation, APC defines HAPs, also known as toxic air pollutants or air toxics, as those pollutants that are known or suspected to cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental effects.

The following industries commonly employ Air Pollution Control (APC devices as an integral part of their manufacturing process.

- Paint and Coatings Manufacturers
- Wood Products Manufacturing
- Petroleum Refining
- Chemical/Petro-Chemical Manufacturing
- Pharmaceutical Manufacturing
- Semi-Conductor and Solar
- Food and Beverage Industry
- Industrial and Municipal Waste Water

Typical industrial and municipal air streams contain a very diverse and wide range of compound pollutants. As a result, numerous technologies have been developed to address the specific control needs as determined by local, regional, state and national regulatory agencies.

APC systems can be very specific relative to their treatment capability, broad based and can effectively treat a wide range of compounds. APC is broken into two functional categories, Particulate Control and Gaseous (Waste gas) Pollutant Control

The information presented in this overview is intended to provide the reader with a general understanding of the current technologies available for the control of air pollution. The technologies presented are currently being utilized by Industrial and Municipal companies globally. Control is specific to the compounds found in the air stream, the loadings associated with each compound and the level of removal that must be achieved. As such, each system must be configured to meet the desired results based on the specifics associated with the air stream.

The following technologies are typically used to control VOCs and HAPs emissions:

- Wet Scrubbers
- Incineration
- Bio Scrubbers/Bio trickling Filters
- Carbon Adsorption

This eBook will focus on Flameless Thermal Oxidizer Systems.

An Innovative Technology for the Future

FLAMELESS THERMAL OXIDATION

Flameless Thermal Oxidation is a destructive technology for the treatment of volatile organic compounds (VOC's) in waste gas streams. The process converts VOCs, through oxidation, to carbon dioxide and water without exposing the vapors to a flame. This is accomplished by heating the compounds above their auto ignition temperature (AIT) under very controlled conditions. A specially designed reactor, filled with ceramic media, absorbs and dissipates the heat of reaction. A stable oxidation zone is maintained at a precise temperature and residence time with the ability to treat variations in waste flow and composition.

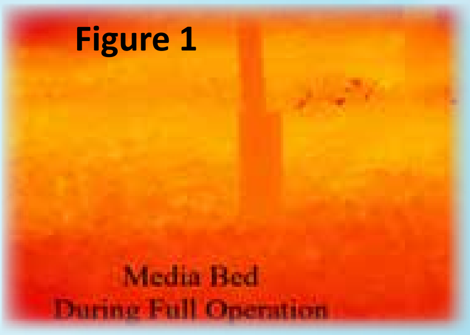
In a flame device (e.g. Thermal Oxidizer), the right time, temperature, and turbulence must be achieved simultaneously to obtain desired levels of organic-compound destruction. Due to the FTO's large thermal mass and outstanding convection characteristics, a homogenous temperature profile develops within the reactor. The waste gas is then oxidized when it comes into contact with the heated bed of ceramic media. Bed temperatures are typically maintained at 1700°F - 1900°F. The consistent temperature, extended reaction time and excellent mixing yield destruction removal efficiencies (DRE) at levels equal to or greater than 99.9999%. This represents the highest DRE's achievable among commercially available air pollution control systems.

Fundamental Design and Operation

Feed Forward Control:

The FTO process utilizes a "Feed Forward Control" (FFC) technology to optimize the control of the oxidation process. This control system is designed to analyze, adjust and premix the waste gas, ambient air, and auxiliary fuel to a set enthalpy and total flow. By doing so, the oxidation environment is stable and controlled even as process changes occur.

The adjusted waste stream ensures the FTO will operate safely and reliably below the composite LFL while also maintaining a constant system flow and temperature. Depending on the waste composition, dilution air and fuel are trimmed so the mixture never exceeds 85% of the lower flammability limit (LFL). This also ensures that the velocity of the gases flowing through the ceramic media equals the velocity of the reaction to maintain a stable reaction zone within the reactor media bed.



The media bed, (Figure 1) is a glowing mass of ceramic media at a temperature of 1700°F - 1900°F typically. There is no flame, just a mass of radiant heat.

The following chart (Chart 1) provides an overview of how the FFC control system differs from the more traditional controls typically found on conventional thermal oxidizers. It also details the inherent advantages the FFC provides.

Chart 1 - FFC Comparative Overview:

Feed forward Control Flameless Thermal Oxidizer	Feedback Control Traditional Thermal Oxidizer
Measure Fume LEL and calculates/modulates air and fuel to achieve a constant enthalpy/flow into system	Measure the chamber temperature, calculates the deviation from setpoint, adjusts Air/Fuel to get desired output.
Also known as Predictive Control - the output (temperature) is predicted, based on relationship to mixture enthalpy	Also known as Reactive Control - The controller reacts to the process error (temperature deviation from setpoint)
Corrective action taken before process disturbance enters system	Corrective action taken after process disturbance causes setpoint deviation
Example - Sudden increase in waste gas heating value would be countered by a change in air/fuel flow before a high temperature trip could occur.	Example - Sudden increase in waste gas heating value would result in high temperature trip, before adjustments could be made
Preventing high temperature trips ensures a Flameless oxidation environment, reducing thermal NOx generation.	

Waste gas streams experience multiple seconds of residence time at high temperatures leading to measured destruction removal efficiencies that exceed 99.9999%. Premixing all of the gasses prior to treatment leads to thermal NOx as low as 2 ppmv by eliminating localized high temperatures common in systems that involve a flame.

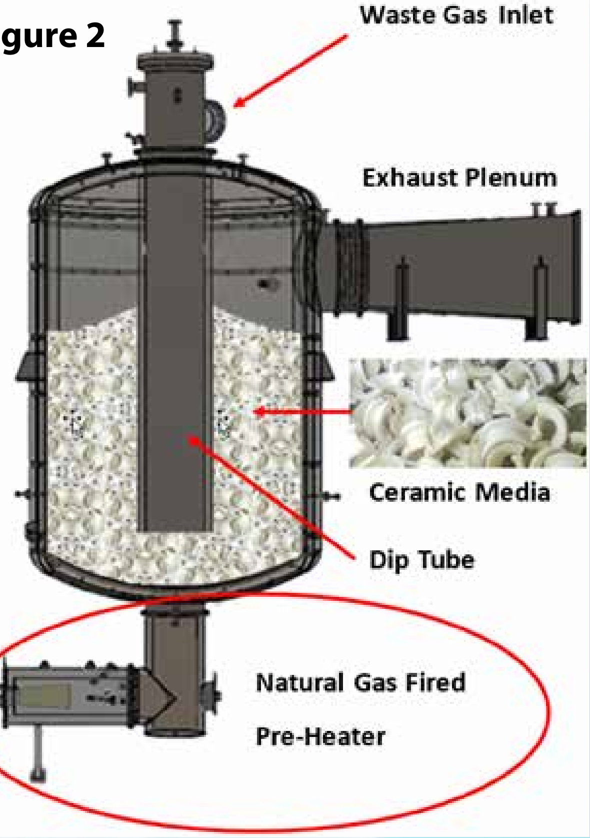
Reaction Design:

The FTO reactor (Figure 2) is made up of a refractory-lined, cylindrical vessel (material of construction varies with application) with a centered inlet dip tube. The vessel is approximately half full of randomly packed inert ceramic media (Figure 3) to form a uniform matrix below and around the dip tube.

When the startup temperature has been achieved within the reactor media bed, the pre-analyzed waste gas is introduced into the system along with the appropriate amount of air and natural gas.

The chamber volume and the corresponding quantity of ceramic media above the oxidation zone are designed to ensure a total retention time of 3 to 4 seconds occurs at the designed total system capacity. The system operating turndown typically ranges from 100% to 33%. The waste gas flow turn down is 100% for maximum process flexibility.

Figure 2



Basis of Operation - Preheat & Start-up:

The FTO's ceramic bed must be preheated when the FTO is started from a cold start condition. This is accomplished with a burner at the bottom of the FTO vessel which fires air and fuel until the bed reaches its preheat temperature.

Figure 3

Note: The burner is shut down and is not used during normal operation of the FTO. Preheat Temperatures: The preheat temperature should be 1400°F minimum near the top of the bed before transitioning from Preheat to Profile steps. This will ensure that there is enough thermal mass to handle the air purging and initial formation of the bubble in the bed and that there is enough temperature in the ceramic to stay above the waste gas auto ignition temperature (AIT).

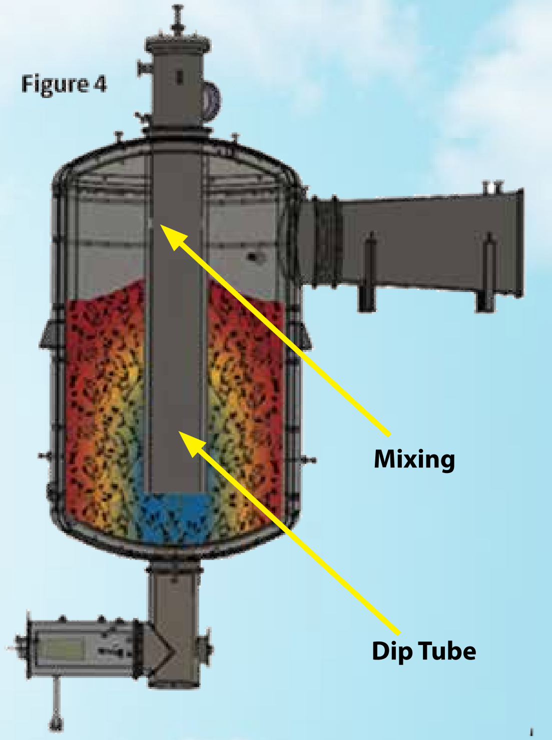
Normal Operation: Fume, air and fuel are premixed at the top of the dip pipe and via mixing tabs as they flow down the dip pipe (Figure 4).

Control loops maintain a constant volume of gas (by modulating the air against the fume's volume) and constant enthalpy (by modulating the fuel against the fume's enthalpy) down the dip tube.

The enthalpy is controlled so that the dip tube mixture never exceeds 85% of the mixture's LFL as calculated by the La Chatelier's principle for composite mixtures. This controlled enthalpy also dictates a final bulk temperature of the POCs which is commonly operated at ~1700°F - 1900°F.

The fume, air and fuel mixture enter the ceramic media at the bottom of the dip pipe under modest pressure and flow outward and upward from the source towards the relatively low-pressure outlet. The velocity slows as the gas expands through the ceramic media until it reaches the laminar flame speed of the mixture.

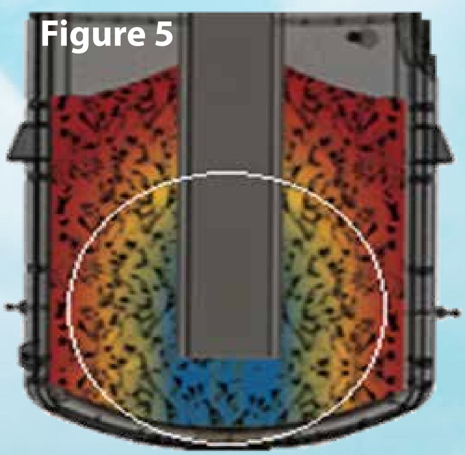
Figure 4



The gases exiting the dip tube and entering the ceramic media are in a turbulent flow condition and accelerate at that interface. On exit, they transition from a planar velocity to a shallow bowl like shape as they expand in the center of the flow (Figure 5). The gases form eddy currents around the circular edge of the dip tube creating vacuum effects that draw more flow according to a localized uneven pressure drop. The dip tube's area creates a dead spot above the growing bubble which forces flow downward and sideways from the source.

As the flow travels further from the end of the dip tube, these effects lessen with distance and a more even and radial type flow is established as the gas' slow in the bulk media. The bubble is roughly 10 inches in width from its hot leading edge to its cold trailing edge.

Figure 5



At that location in the ceramic matrix, the velocity of the gas moving outward is perfectly balanced by the flame speed of the oxidation wave traveling toward the fuel source.

The oxidation wave occurs in a 3-dimensional onion shape "bubble" and is approximately 10 inches in thickness. As the cold gas mixture exits the dip pipe and approaches the oxidation wave, it absorbs heat from the media until it reaches the Auto Ignition Temperatures (AIT) of each of the composite components in the mixture and oxidation occurs releasing heat back into the media. The ceramic media acts as a heat sink and all the ceramic outside the oxidation wave remains at ~1700°F-1900°F.

The FTO is controlled operate with a constant volume down the dip tube. The air modulates against the fume flow to give a constant volume in the dip tube. This, coupled with the constant enthalpy keeps the bubble in one position.

Thermocouples must pierce through the bed from the bottom, the sides and the top of the FTO to monitor the three basic axis. There are two sets from the bottom, two sets around the sides and one set from the top. Each set will have both "control" points and "guard" points. The control points will be within the boundaries of the bubble's 10-inch width and the guards will be between the bubble and the refractory walls.

Figure 6 - Ceramic fiber blanket, dip tube and reactor walls

A ceramic fiber blanket is pinned to the outside surface of the dip tube all the way from the ceiling entry to the bottom discharge point. (See Figure 6)

When the air, fume and fuel mixture is flowing down the dip tube, the ambient temperature keeps the inside surface of the dip tube cool preventing any premature oxidation in the dip tube from occurring. During preheat, the dip tube is kept relatively cool via a constant small airflow inside the dip tube which prevents auto ignition in the dip tube from occurring when the FTO is transitioned from preheat to operation. The FTO steel shell is protected by insulating ceramic board and "Z-Block" type ceramic fiber modules fastened onto threaded anchors which are protected by ceramic "cup-locks". This refractory design minimizes heat loss and shell temperature and is lightweight and appropriate for the flow velocities of the FTO.

Why would you consider using a Flameless Thermal Oxidizer:

Within today's air pollution control technical portfolio, there are a number of potential technologies to choose from. It is important for companies to understand their options and to recognize that environmental regulations will only get more stringent in the future. Forward -thinking companies, with a strong sense of corporate stewardship, want the Best Available Control Technology (BACT) at their manufacturing facilities. Lowest Achievable Emission Rate (LAER) standards are also applicable to the FTO technology. Your local, state and federal agencies will provide you with these designations.

Top view of the Reactor vessel, dip tube and exhaust duct.

Flameless Thermal Oxidation has proven to be the best control technology for the Pharmaceutical and Specialty Chemical Industries. The ability to consistently achieve DRE (destruction removal efficiency) values in the 99.999% range, coupled with thermal NOx values of less than 2 ppmv make FTO technology the preferred choice.

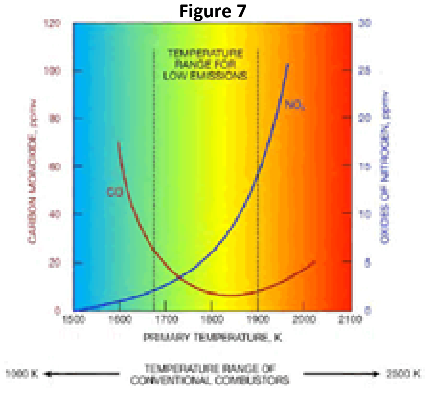
Performance and Advantages:

The premixed VOC, fuel and air in the FTO will experience 3+ seconds of residence time at a high temperature with excellent turbulence (mixing). Together this results in 99.9999% or greater DRE of the VOC's while also avoiding any peak localized high temperatures which would produce excessive NOx.

The Zeldovich curve (Figure 7) details the exponential rate at which thermal NOx generation increases with temperatures greater than 1500°K (2240°F) Since the FTO operates at a maximum temperature of 1900°F (1350°K), there is minimal to no thermal NOx generated.

A traditional thermal oxidizer with a burner will have hot spots in and around the flame well above the 1500°F temperature. As a result, thermal NOx generation in these systems is much higher and can pose regulatory concerns (and in some cases, require post-treatment with additional equipment).

Figure 7



The hot products of combustion (POCs) exit the ceramic matrix at 1800°F and leave the FTO from the exhaust vent and either vent to atmosphere or enter a Waste Heat Recovery Boiler (WHRB) to make steam.

There are no moving parts in the FTO which makes it highly reliable and the heat sink of the ceramic matrix makes the FTO very stable and resilient to temperature fluctuations. Since the ceramic stays either hot or cold with little variation, the ceramic bed does not experience thermal cycling and hence has a long life. The advantages in performance and reliability set the FTO technology far apart from conventional incineration.

Features and Benefits of the FTO Technology:

Properly designed FTO technologies have repeatedly demonstrated an organic waste destruction efficiency of 99.9999%. NOx and CO emissions are significantly reduced. Dioxin and furan emissions significantly reduced. This unique performance assures regulatory compliance with a high degree of reliability.

- ✓ 99.9999% or greater destruction of efficiency - including methane and halogenated organics
- ✓ Low NOx - less than 2 ppm - Undetectable CO emissions
- ✓ Dioxins and furans - less than 0.1 ng/m^2 TEQ for halogenated waste
- ✓ Long refractory life due to the high DRE
- ✓ Decreased maintenance on the downstream equipment e.g., boiler fouling will be very limited as the inlet gas will be very clean.
- ✓ Destructive process produces no secondary organic waste stream
- ✓ Flameless - can be installed in classified areas near the emission source
- ✓ Operates below the lower explosive limit and with safeguards
- ✓ Stable operation when responding to variable organic loading
- ✓ Matrix and dip tube design prevents potential flashback to process
- ✓ Matrix is completely inert - no catalyst to foul
- ✓ No internal moving parts or diverting valves
- ✓ Integrated microprocessor control
- ✓ Treats batch or continuous streams
- ✓ Superior turndown capability - reduces operating cost

Value	Feature	Benefit
Destruction Removal Efficiency (DRE)	Highest DRE of any thermal air pollution control technology	Can achieve 99.9999% DRE ensuring total compliance with your permit requirements
Thermal NOx Reduction	Thermal NOx levels below 2 ppmv	Allows the end user the ability to easily meet the NOx limits and in some cases provide a means to sell or trade credits on the open market
Was Gas Control System	Feed Forward Control of the Waste Gas	The system can handle multiple waste gas vent streams on a continuous or variable introduction rate/schedule without causing high or low temperature system trips.
System Up-Time	Stable/Resilient Oxidation Environment; No Moving Parts; ensures there is no lost production time	Greater than 99% due to the life of the media and refractory, overall system design and selected materials of construction.
Waste Heat Capture and Utilization	Ability to generate steam, heat air, oil or other applicable waste heat transfer options	Utilize the waste heat to reduce the costs associated with the burning of natural gas or electricity to generate steam or other heat requirements.

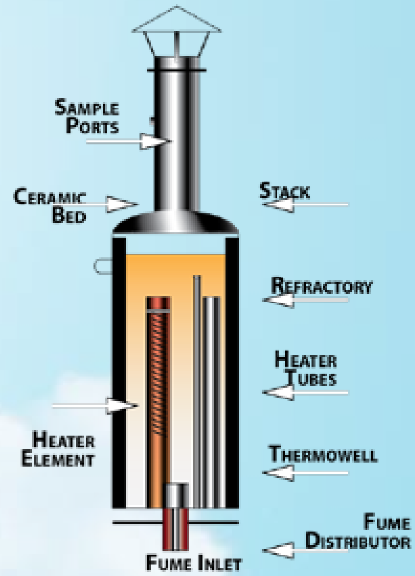
FTO System Models:

There are two different types of Flameless Thermal Oxidizer models based on the volume of waste being treated:

Model	Treatment Capacity
Electric FTO	Up to 350 scfm
Elliptical FTO	From 750 - 100,000+ scfm

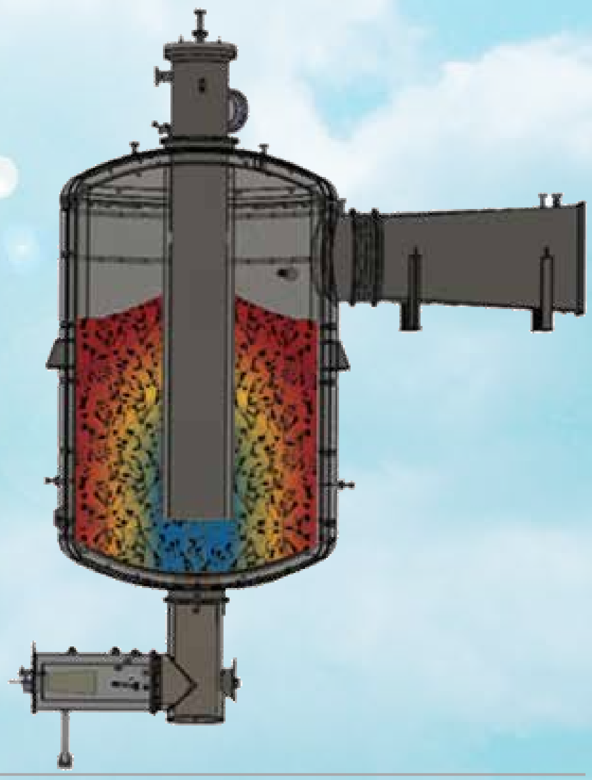
Electric FTO:

- ✓ The electric model consists of a vertical refractory-lined vessel filled with ceramic media
- ✓ Ceramic media is preheated through the use of electric resistance heaters.
- ✓ Waste gas and ambient air are premixed at the bottom of the unit and introduced into the unit.
- ✓ Organic compounds in waste gas are oxidized and discharged to atmosphere via a stack extension on the top of the vessel.
- ✓ Suitable for total flow rates up to 350 scfm



Elliptical FTO:

- ✓ The Elliptical model is a refractory lined cylinder partially filled with ceramic media.
- ✓ Ceramic media is preheated through the use of an auxiliary natural gas burner.
- ✓ Waste gas, ambient air, and natural gas are premixed at the top of the vessel and delivered to media bed through use of a central dip-pipe.
- ✓ Heat is generated via the oxidation of natural gas and waste gas.
- ✓ Destruction Removal Efficiencies up to 99.9999%.
- ✓ Thermal NOx emissions of less than 2 ppmv.
- ✓ Ceramic media bed is stable and resilient to temperature fluctuations.
- ✓ Waste stream feed forward control ensures stability and prevents nuisance shutdowns.



FTOs provide emission solutions for the following industries:

- ✓ Plastics and Olefins
- ✓ Chemical
- ✓ Refining
- ✓ Pharmaceutical
- ✓ Paper
- ✓ Printing
- ✓ Plant producers and users
- ✓ Textile manufacturing and printing
- ✓ Metals

FTO Reference Table

Parameter	Flameless Thermal Oxidizer
Diameter (Typical)	10' OD - 22' OD
Environmental Classification for Combustible Compounds	Best Achievable Control Technology (BACT) & Lowest Achievable Emission Rate (LAER)
Environmental Definition	Thermal Reactor
Safety in Operation	Very good - meets customer, industry and PCC safety standards
Destruction Efficiency (DE)	99.9999%+
Thermal NOx Generation	Can achieve less than 2 ppmvd at 3% (v) O_2
Chemical NOx Generation	Average
Operating Temperature	1700°F to 1900°F
Residence Time	Over (>) 3 seconds
Temperature Profile	Excellent due to the ceramic bed
Fuel Efficiency	Average to High
Chamber Orientation	Vertical
Refractory Lining	Ceramic fiber - excellent insulator, impervious to thermal shock and has a long useful life (minimal thermal cycling)
Shell Temperature	Intrinsically safe from acid dew point corrosion
Waste Turndown	Infinite
Ability to Handle Variable and Wild Waste Streams	Excellent due to feed forward control (no temperature excursions)
Ability to Handle Streams with Particulate Loadings	Poor, due to plugging concerns with the ceramic media. Requires pre-treatment with a filter system or baghouse
System Reliability	Excellent
Maintenance	Limited moving parts, long thermal life of media