ANGUIL™

Taking the Carbon Out of Combustion

Introduction

Why now?

As more companies voluntarily embrace ESG (Environmental, Social, Governance) standards, many are adopting green technologies as part of their corporate objectives and to maintain a positive public perception. Investors, stakeholders, and consumers are increasingly prioritizing companies that demonstrate environmental responsibility, making ESG-aligned strategies a key driver for long-term success.

Industry professionals have relied on air pollution control systems like oxidizers and fume incinerators to meet regulatory standards. However, these combustion technologies have historically used fossil fuels such as natural gas, propane, fuel oil or diesel to generate the necessary heat for combustion of air pollutants within the device. Byproducts of combustion from traditional fossil fuel burners contain greenhouse gases such as NOX and CO2 as well as SOX when there is Sulphur present in the fuel.

As customers look to lower their carbon footprint, they are seeking alternative methods to remove greenhouse gas emissions from the heating element within their oxidizer systems. Transitioning to alternative fuel sources allows businesses to adapt quickly in evolving regulatory landscapes and market trends, as well as prioritizing environmental responsibility. Except for electrically heated catalytic oxidizers, the industry has been slow to integrate lower carbon options thus far.

With decades of experience supplying alternative heating methods for oxidizer technologies, Anguil is at the forefront of low-carbon solutions for both catalytic and thermal systems. To better serve manufacturers, and the environment, Anguil continues to push innovation with their fully electrically heated Regenerative Thermal Oxidizers (RTO).

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Environmental and Energy Solutions that Ensure Cleaner Air and Water for Future Generations.

Founded in 1978, Anguil Environmental Systems, Inc. is a second generation family owned and operated environmental technology supplier headquartered in Milwaukee, WI USA with offices in Asia and Europe. With annual sales in excess of $150 million globally, Anguil has been a trusted air and water solutions supplier for nearly 50 years.

Acronym List

CFD - Computational Fluid Dynamics

CO – Carbon Monoxide

CO_2 - Carbon Dioxide

DFTO - Direct Fired Thermal Oxidizer

EPA – United States Environmental Protection Agency

GHG - Greenhouse Gas

HAP - Hazardous Air Pollutants

LEL - Lower Explosive Limit

NO_x - Nitrogen Oxides

PLC - Programmable Logic Controller

RCO - Regenerative Catalytic Oxidizer

RCTO – Rotary Concentrator Thermal Oxidizer

RTO – Regenerative Thermal Oxidizer

SCR - Silicone Control Rectifier

SO_x - Sulfur Oxides

VOC – Volatile Organic Compounds

Picture 1 Anguil LoCarb-eRTO in Israel

Analysis

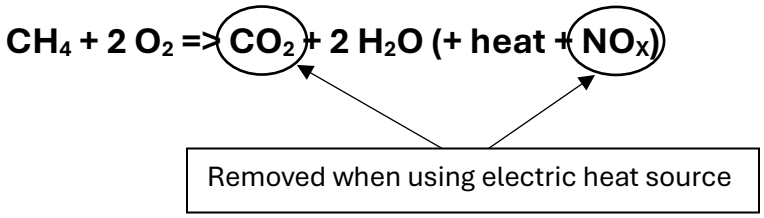
Oxidation is the process by which hydrocarbons are broken down into carbon dioxide and water vapor through oxygen and heat. A general equation showing this relationship is presented in the equation below.

$$Cn\ H2m + (n + m/2)\ O_2 \rightarrow n\ CO_2 + m\ H_2O + Heat$$

The particular **n** and **m** subscripts of the equation are used to define the number of carbon atoms and hydrogen atoms. The number of oxygen atoms convert to **n** molecules of carbon dioxide and **m** molecules of water vapor and heat.

This equation highlights the oxidation reaction that is occurring in a gas fired burner that is historically used in thermal and catalytic oxidizers. The oxidation equation for burning natural gas (methane) is shown in the below equation.

Methane Oxidation:



In addition to the formation of CO_2, NO_X is also produced due to the high temperature of the burner flame. Replacing a gas fired burner with an electric heater eliminates the CO_2 and NO_X that are generated from the heating source. CO_2 will still be produced from the oxidation of the VOCs themselves in either a gas or electrically heated oxidizer but greenhouse gas emissions at the combustion device are greatly reduced.

History of Electrically Heated Oxidizers

Electrically heated oxidizers are not a new technology. In fact, Anguil has been designing and manufacturing electrically heated catalytic oxidizers for over 25 years.

Catalytic oxidizers operate at lower temperatures than thermal oxidizers. The catalyst lowers the activation temperature required to destroy a given VOC. A catalytic oxidizer typically operates within the range of 600 – 1100° F (316 – 593°C) depending on the specific VOCs. There are multiple catalyst formulations available including precious metal, base metal, and various catalyst geometries including monolith block and pelletized beads. The catalyst is selected based on the specific application and anticipated VOCs.

Catalytic technology is ideal for process streams that do not contain catalyst poisons or masking agents. The catalyst operates within a finite temperature window which limits its loading capability to approximately 25% LEL. Because the operating temperature is lower than a thermal oxidizer, lower grade materials of construction can be utilized.

Picture 2 Anguil LoCarb-eRTO / 5,000 SCFM (8,500 Nm³/h)

This lower operational temperature is an advantage when providing electrically heated catalytic oxidizers. Nickel alloy heating elements can be used. Anguil has successfully utilized electric heaters in catalytic oxidizers in both a vertical and horizontal oriented configuration.

This experience has given Anguil an unprecedented advantage in being able to offer the next generation of fully electrically heated thermal oxidizers, namely an electric Regenerative Thermal Oxidizer.

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Anguil Electric Regenerative Thermal Oxidizer

Anguil, a worldwide leader in oxidation equipment, has always been at the forefront of providing systems designed for each customer's needs. As demand increased for a lower carbon footprint RTO, Anguil was ready to meet this challenge.

Anguil has a standard product line of gas fired Regenerative Thermal Oxidizers with a range of 2,500 SCFM (3,900 Nm^3/h) up to 70,000 SCFM (110,000 Nm^3/h) in a single system. The Anguil two bed RTOs guarantee 99% VOC destruction efficiency: an unmatched performance in the industry. Anguil has been able to leverage this successful RTO product line with modifications for electric heaters to offer a flameless design.

Anguil is pleased to announce the next generation of lower carbon footprint RTOs: the fully electrically heated RTO, the LoCarb-eRTO. Anguil offers electrically heated units for both Two Bed and Three Bed RTO models. The electric RTO guarantees not only regulatory compliance, but the lowest carbon production of any system on the market.

The electric RTO is a field proven and tested design. Anguil engineers conducted analysis and modeling and pilot testing of the new electrically heated RTO design.

Anguil Electric RTO Features

- Reduces GHG produced from fossil fuel heating source (NO_X, CO_2, SO_X)
- High thermal efficiency to reduce heater sizing
- High VOC destruction efficiency
- No products of incomplete fossil fuel combustion
- Eliminates need for gas connections, fuel trains, burners and combustion air fan
- Same footprint as a gas fired RTO
- Dual heating source functionality is an option for redundancy

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GHG Reduction in an Electric RTO

The benefit of an electrically heated RTO is apparent when looking at the CO_2 and NO_X production estimates against a traditional natural gas fired RTO. Anguil has compared our Model 50 two-chamber gas fired RTO against our Model 50 LoCarb-eRTO with the same process conditions. The CO_2 generated in tons per year from the natural gas fired burner has been charted against the VOC loading in the process, Chart #1.

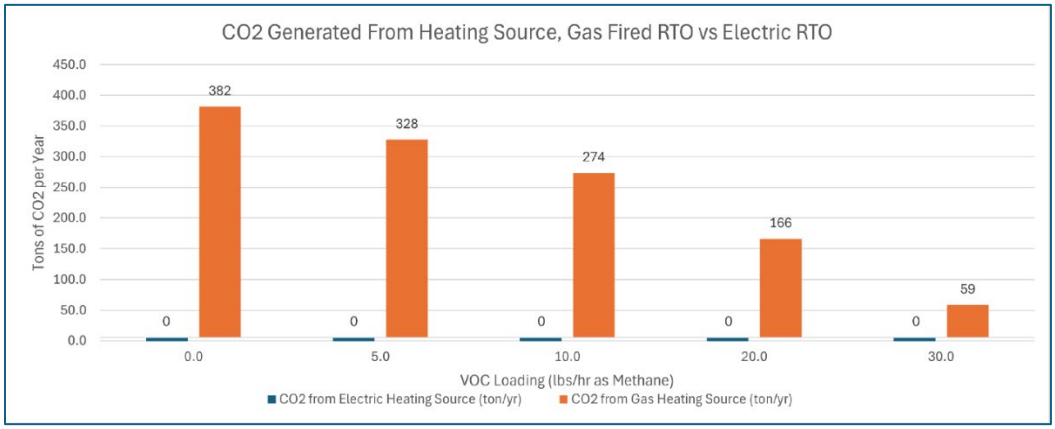
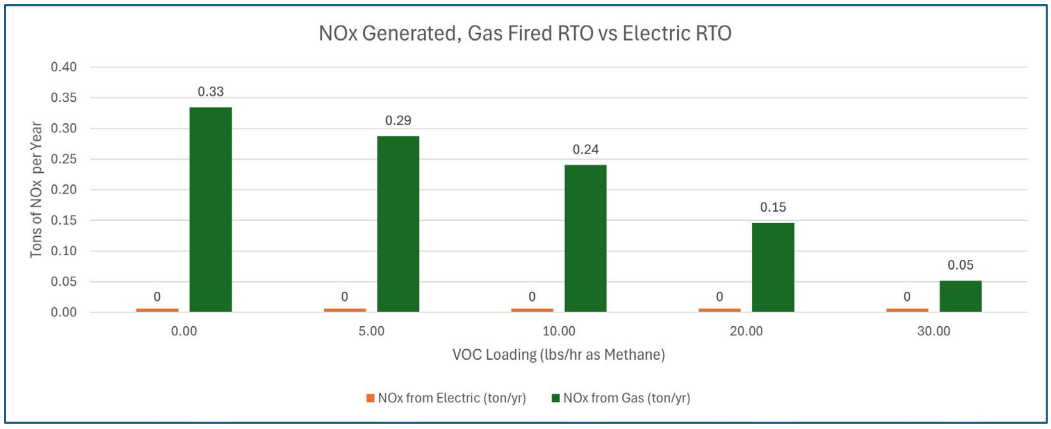


Chart 1 5,000 SCFM (8,500 Nm³/h), 70°F (21°C) process temperature, 8,760 hours per year

This only considers the CO_2 generated from the burner itself, not the CO_2 produced from the oxidation of the VOCs. Using an electric heater in the eRTO eliminates the CO_2 produced from the heating source.

Similarly, the NO_X generated in tons per year from the natural gas fired burner has been charted against the VOC loading in the process, Chart #2. This assumes that there are no nitrogen bearing VOCs present such that the only NO_X produced is from the burner flame. The electrically heated RTO does not produce any NO_X in comparison.



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How an Electric RTO Works

The Anguil Regenerative Thermal Oxidizer (RTO) destroys Hazardous Air Pollutants (HAPs), Volatile Organic Compounds (VOCs), and odorous emissions that are discharged from industrial processes. Emission destruction is achieved through the high temperature thermal oxidation reaction. The RTO reuses the thermal energy generated to reduce operating costs.

The VOC laden process gas enters the oxidizer through an inlet manifold to flow control poppet valves that direct this gas into energy recovery chambers where it is preheated. The RTO is equipped with two beds of ceramic media which serve as heat sinks, scavenging much of the thermal energy from the process stream as it exits the oxidizer cooling the exhaust steam and heating the media. The process gas and contaminants are progressively heated in the ceramic media beds as they move toward the combustion chamber.

Once oxidized in the combustion chamber, the hot purified gas releases thermal energy as it passes through the media bed in the outlet flow direction. The outlet bed is heated, and the gas is cooled so that the outlet gas temperature is only slightly higher than the process inlet temperature. Poppet valves alternate the airflow direction into the media beds to maximize energy recovery within the oxidizer. The high energy recovery within these oxidizers reduces the auxiliary energy input requirement from the electric heater and saves operating cost.

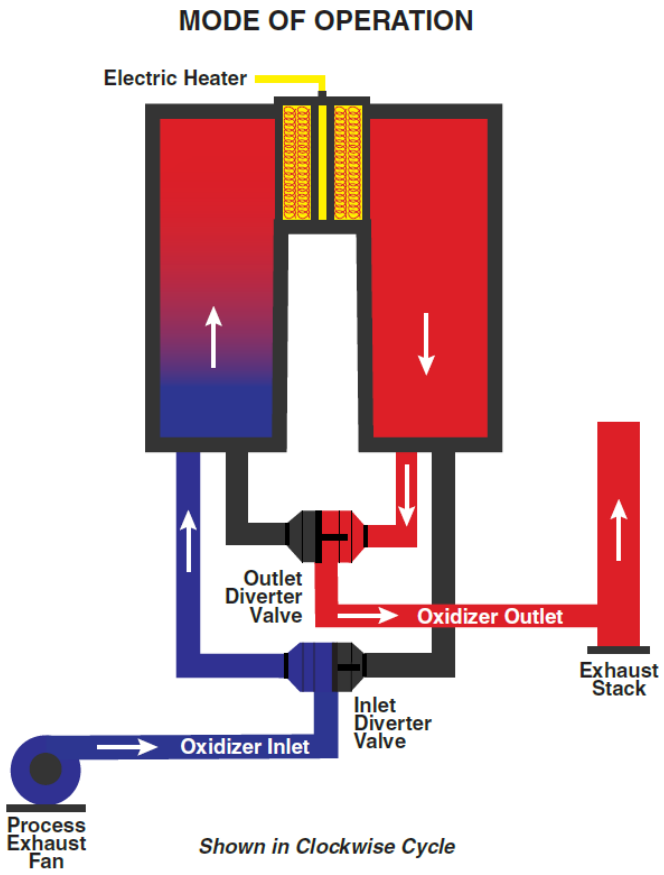


Figure 1 Airflow and heat distribution diagram in an Anguil two-bed RTO with electric heaters

The Anguil oxidizer achieves high destruction efficiency and self-sustaining operation with no auxiliary energy input to the electric heater at concentrations as low as 3-4% LEL (Lower Explosive Limit).

Heater Configurations

Anguil has experience supplying lower temperature electric heaters with catalytic oxidizers. These heaters are designed for maximum temperatures of approximately 1200°F (650°C). However, designing heaters for use in the higher temperature environment that is encountered in Regenerative Thermal Oxidizers, comes with additional challenges.

The heater needs to provide sufficient power during startup and normal operating conditions while also being able to withstand the temperatures in a thermal oxidizer combustion chamber: 1400 – 1800 °F (760 –982°C). The materials used in its construction are critical for operational success.

As the heater is critical in the electric RTO, Anguil field tested several different heater styles over an extended timeframe. Anguil put the different electric heater styles through the varying operating conditions expected in a Regenerative Thermal Oxidizer. This provided invaluable operational data to recommend the best heater for a customer's given application.

For example, heaters can be sized for full process flow, with no VOC loading. The RTO can also be designed with more ceramic media to increase the thermal energy efficiency to reduce the heater size. For applications with continuous VOC loading, a startup only heater can be supplied.

Anguil offers heaters that allow for ease of replacement of individual elements to decrease equipment downtime. The electric RTO system is designed to ensure ease of access for maintenance.

Electric RTO Performance

In addition to testing the heaters from a material of construction standpoint, Anguil was able to confirm the electric heater placement provided the desired results. Extensive temperature and flow monitoring instrumentation was placed through the electric RTO including the media beds, combustion chamber, and outer reactor skin wall. The RTO was operated at various flow and VOC loading conditions and the data recorded.

Picture 3 Three chamber, Anguil LoCarb-eRTO

This testing confirmed the electric heater element placement provided the proper velocities, flow, and temperature distribution for high destruction efficiency. Anguil electric RTO designs are Computational Fluid Dynamics (CFD) modeled. Anguil pilot tested the electric RTO to ensure that its performance matched the CFD predictions. This enables Anguil to adapt future CFD analyses to predict field results.

Anguil offers the same high VOC destruction efficiency whether the RTO is gas fired or electrically heated. Field testing on the electric RTO confirmed high destruction efficiency with no byproducts of combustion. A two-bed Anguil RTO achieves 99% DRE while a three chamber RTO can provide over 99.5% DRE, regardless of the fuel source.

The heater profile across the RTO was calculated with the heat losses from the RTO confirmed and plotted against the power draw against the heater. This was compared against the theoretical calculations for the overall RTO thermal efficiency. Anguil can ensure that the electric heater will provide adequate energy for the required operating conditions.

Heater Controls

The electric heater and its operation are critical to the electric RTO operation. All Anguil electric heaters are controlled using a silicone control rectifier (SCR). This modulates the individual elements for optimum performance and temperature control. Thermocouples are adjacent to the heater elements and monitored through the RTOs PLC to prevent overheating.

The elements are separately fused with the voltage and current of each being monitored. PLC (programmable logic controller) logic has been developed to detect a blown fuse, or loss of element, and sends a signal to alert the operator. Logic also has been developed by Anguil to predict end of life for the heater element, sending a notification of the need for new heater elements.

Anguil has developed a proprietary start-up procedure to minimize the cold start-up time for an electrically heated RTO. For customers who want to further reduce the start-up time, Anguil can also incorporate a supplemental fuel injection system operating on natural gas or propane.

Picture 4 Electric RTOs require separate panels for heater controls

CFD Proven Designs

Anguil utilizes Computational Fluid Dynamics (CFD) to analyze and optimize flow and temperature distribution across the electric RTO media beds and heating elements. By visualizing how air moves through the bed, Anguil can fine-tune the system for maximum thermal recovery, heater effectiveness, and minimal pressure loss.

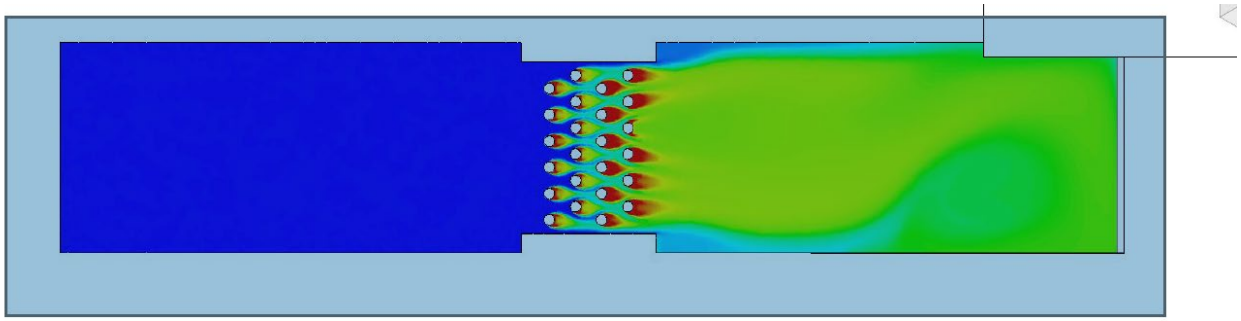


Figure 2 CFD modeling of an electric RTO

Anguil used CFD modelling to analyze different electric heater element configurations and types in the electric RTO. This allowed us to simulate airflow patterns, velocities, and temperature gradients throughout the electric RTO. Even temperature and flow uniformity is critical to ensuring the RTO performance. Optimal flow uniformity enhances heat transfer, reduces energy consumption, and improves the system destruction efficiency. Anguil was able to eliminate several heater styles based on the CFD results.

After selecting the heater element configuration, Anguil was then able to field test the electric heaters. Actual temperature and performance data were measured to compare against the predicted CFD results. In addition to proving the heater performance, valuable running data was obtained to make CFDs on future electric RTOs even more accurate.

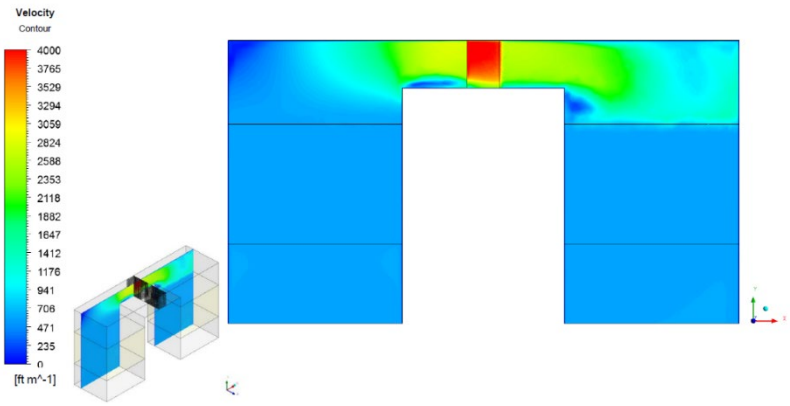


Figure 3 CFD modeling of an electric RTO

Electric Catalytic Recuperative Oxidizer

There are two types of catalytic oxidizers depending on the heat recovery included. A **Catalytic Recuperative Oxidizer** utilizes a metallic heat exchanger that typically recovers 50-70% of the heat generated. A **Regenerative Catalytic Oxidizer (RCO)** utilizes the same ceramic media beds of an RTO for over 95% energy recovery.

The advantage of the **Catalytic Recuperative Oxidizer** is that it is a compact, lightweight design. It can easily be adapted to a fully electrically heated system. It can accommodate multiple catalyst configurations including monolith blocks or pelletized beads while achieving destruction efficiencies over 99.5% for process streams with catalyst friendly VOCs. It is ideal for processes with emission concentrations in the range of 8 –12% LEL.

Picture 5 Electric Catalytic Recuperative Oxidizer

In a catalytic recuperative oxidizer, the VOC and HAP laden process gas is either pushed or pulled into a metal heat exchanger by a system fan. The plate or shell and tube heater exchanger preheats the process as it travels to the catalyst chamber. An electric heater provides any additional energy needed to ensure the process enters the catalyst chamber at the required inlet temperature. As the heated gas passes through the catalyst an exothermic reaction takes place. The hot, purified gas then passes through the opposite side of the heat exchanger and transfers thermal energy to the incoming process stream. The electric heater can be sized to provide the energy input needed at full process flow with no exothermic reaction. For applications with continuous higher VOC loading, a startup only heater can be supplied. Anguil will custom design the system for a customer's given application and utility needs.

Electric Catalytic Oxidizers for Formaldehyde

One industry that has successfully used electric catalytic recuperative oxidizers is formaldehyde manufacturing. In the chemical manufacturing process of formaldehyde production, methanol reacts with air in the presence of catalyst to produce formaldehyde. Some emissions by products are generated during this process that require treatment including carbon monoxide, methanol and formaldehyde. These compounds can be destroyed using a precious metal catalyst that operates at a catalyst inlet bed temperature as low as 525°F (275°C). The relatively high concentrations of CO and VOCs allow the catalytic oxidizer to operate without any supplemental energy with the 65% effective shell and tube heat exchanger. An electric heater is provided to start up the system only. Once the system is at the ready operating temperature oxidation from the VOCs is enough to keep the system operating and the heater is turned off. This chemical company has successfully implemented Anguil's electric catalytic recuperative oxidizer at over 25 of their facilities worldwide.

Electric Regenerative Catalytic Oxidizer

When a Regenerative Thermal Oxidizer (RTO) needs supplemental energy to operate during normal design conditions, a Regenerative Catalytic Oxidizer (RCO) can be a good alternative. The RCO utilizes the same ceramic media beds of the RTO that offer the high thermal energy recovery of up to 97%. Catalyst is installed in the RCO that allows the system to operate at a lower combustion chamber temperature, normally 800°F (427°C). The catalyst lowers the required activation temperature for destroying the VOCs. There are many catalyst formulations available including precious metal and base metal. The catalyst structure can be blocks, beads or impregnated saddles. The RCO is capable of operating with no supplemental energy at lower VOC concentrations than the RTO.

Picture 6 Anguil LoCarb-eRCO in Norway

Anguil has been supplying fully electrically heated RCOs for years. The lower operating temperature of the RCO allows for lower grades of material being utilized. Nickel alloy electric heaters have been successfully used in Anguil RCOs while providing the same high level of destruction efficiency. The Anguil RCO can operate over a wide range of VOC concentrations.

Electric RTO/RCO Hybrid

Anguil can also offer fully electric systems designed to operate as both an RTO and RCO. High temperature heater elements are used to withstand the thermal oxidizer temperatures in the combustion chamber during thermal operation. The electric heater is also capable of operating at catalyst ready temperatures of 800°F (427°C) when catalyst is installed on the ceramic media beds.

This offers customers the ultimate in processing flexibility. For example, if the customers' process changes to emitting non catalyst friendly VOCs, the catalyst can be removed from the system, and the unit operates in thermal mode. as an RTO while still maintaining the benefits of a fully electric system.

Electric Thermal Oxidizer

In addition to electrically heated RTOs, Anguil has also developed custom designed electrically heated Direct Fired Thermal Oxidizers (DFTOs) and thermal recuperative oxidizers as part of the LoCarb product line. This complete line of fully electric thermal oxidizers enables Anguil to offer lower carbon footprint solutions on even the most challenging of applications.

Anguil has solutions for inert process streams and oxygen rich streams at various VOC loading conditions. DFTOs are typically the technology of choice for inert process streams with high levels of VOC loading, many of which are inert. Several electric heater configurations are available. Anguil has developed a proprietary inlet mixer design where the heater elements can be placed within the mixer. This achieves uniform heat distribution while ensuring the proper mixing of the oxygen required for oxidation. Stack gas recirculation and secondary heat exchangers can also be incorporated to reduce the heater size.

For larger process flows with lower VOC concentrations a rotor concentrator wheel can be used in conjunction with a thermal recuperative oxidizer. One such Anguil electronics customer looking to use the most energy efficient, and lowest carbon footprint, implemented this approach. Anguil was able to recommend a fully electric rotor concentrator wheel coupled with an electric thermal recuperative oxidizer (RCTO) system.

The thermal oxidizer incorporated high temperature heater elements to withstand the combustion chamber environment while providing the required heat load to ensure high VOC destruction efficiency. The oxidizer incorporates multiple shell and tube heat exchangers to minimize the energy needed from the heaters. CFD modeling ensured optimal heater placement for the required temperature distribution for high destruction efficiency. The Anguil system provides 98% destruction efficiency while not producing any products of combustion.

Picture 7 This Anguil LoCarb-eRCO is used in conjunction with emission concentrators to further reduce energy consumption and carbon output.

Hydrogen Fueled Oxidizers

For customers with hydrogen capacity, Anguil also offers specialty hydrogen fueled burners which eliminate SO_X and CO_2 emissions with near-zero NO_X output. Many commercial burner suppliers have designed their burners to be able to operate on either natural gas or hydrogen with minimal changes.

Anguil can offer all the benefits of this lower carbon footprint fuel, with the same high-energy recovery and destruction efficiencies seen from using natural gas burners.

Redundant Fuel Systems

Dual-fuel functionality is also an option for situations where redundancy is required. Anguil has the necessary experience and established RTO designs with multiple heating system capabilities.

A customer wanted an electrically heated RTO but wanted to retain the ability to run on natural gas. On this system Anguil was able to design the RTO with electric heaters but also supplied a natural gas supplemental fuel injection system along with a gas burner in the combustion chamber.

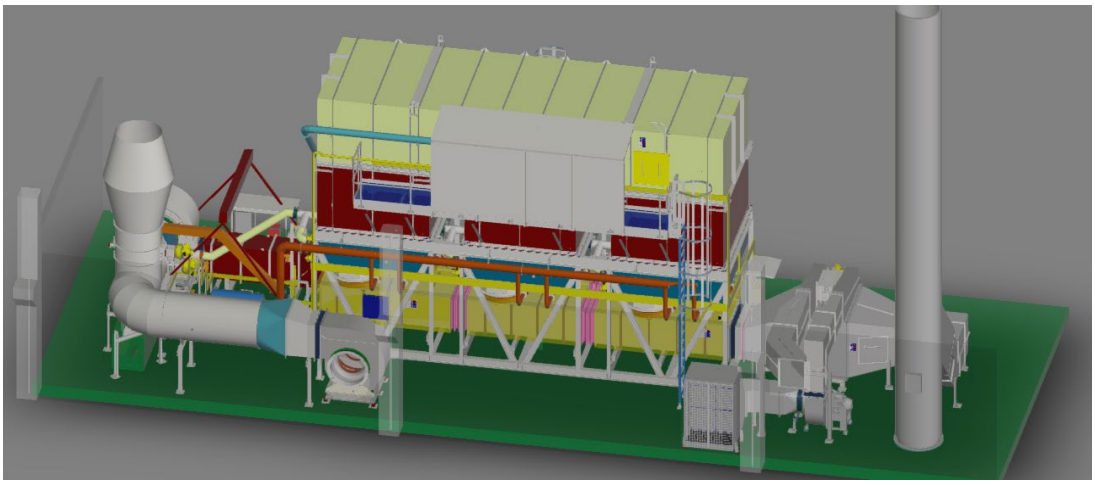


Diagram 1 This 3-chamber RTO, in Anguil's LoCarb product line, can operate on hydrogen, natural gas, or electric heat.

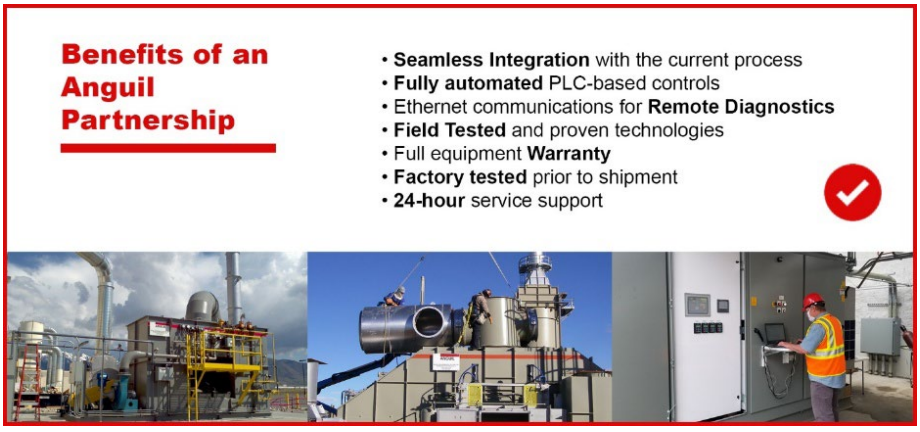
For a lower carbon production RTO, an electric heater could also be used in conjunction with a hydrogen supplemental injection system.

Conclusion

Want to determine if an Anguil LoCarb oxidizer technology will work for your application? Let us help your company achieve its' climate objectives with a technology analysis. Anguil would be pleased to provide a preliminary technological evaluation between a gas fired oxidizer versus an electric oxidizer. Included in that analysis there will be an estimate for both capital and operating costs, as well as provide utility use numbers.

About Anguil

Anguil Environmental Systems offers a complete range of air pollution control and water treatment technologies for industrial processes and manufacturing operations. On vapor combustion applications, Anguil is a global provider of industrial air pollution control and emission abatement systems with almost five decades of experience. We design, manufacture, service, and install thermal and catalytic oxidizers for a variety of air pollution control applications and industries. In addition, Anguil also specializes in energy recovery systems that reduce a company's operating costs, lower their carbon footprint and decrease energy consumption by utilizing waste heat from manufacturing processes.



On the water side, Anguil provides turnkey water treatment and reuse systems for industrial and remediation applications that target Total Petroleum Hydrocarbons (TPH) including emulsified oils/grease, light organics, GRO and DRO range organics, chlorinated and halogenated solvents, inorganics metals, deposit and scale control, suspended solids removal (TSS).

The company is uniquely capable of supplying integrated air and water treatment solutions. Headquartered in Milwaukee, Wisconsin, USA; Anguil also has offices in the United Kingdom, India, Asia and an extensive network of agents located domestically and throughout the world. With an emphasis on engineering and problem solving, our goal is to provide solutions today that help customers remain profitable tomorrow.