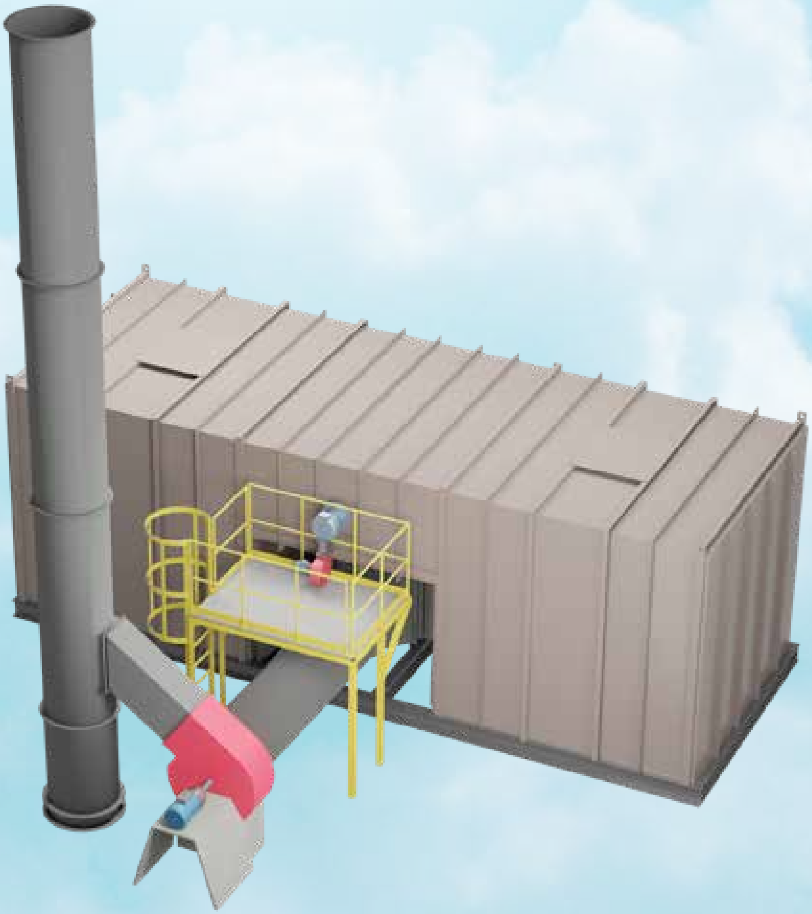
PROCESS COMBUSTION CORPORATION

An Introduction to Regenerative Thermal Oxidation



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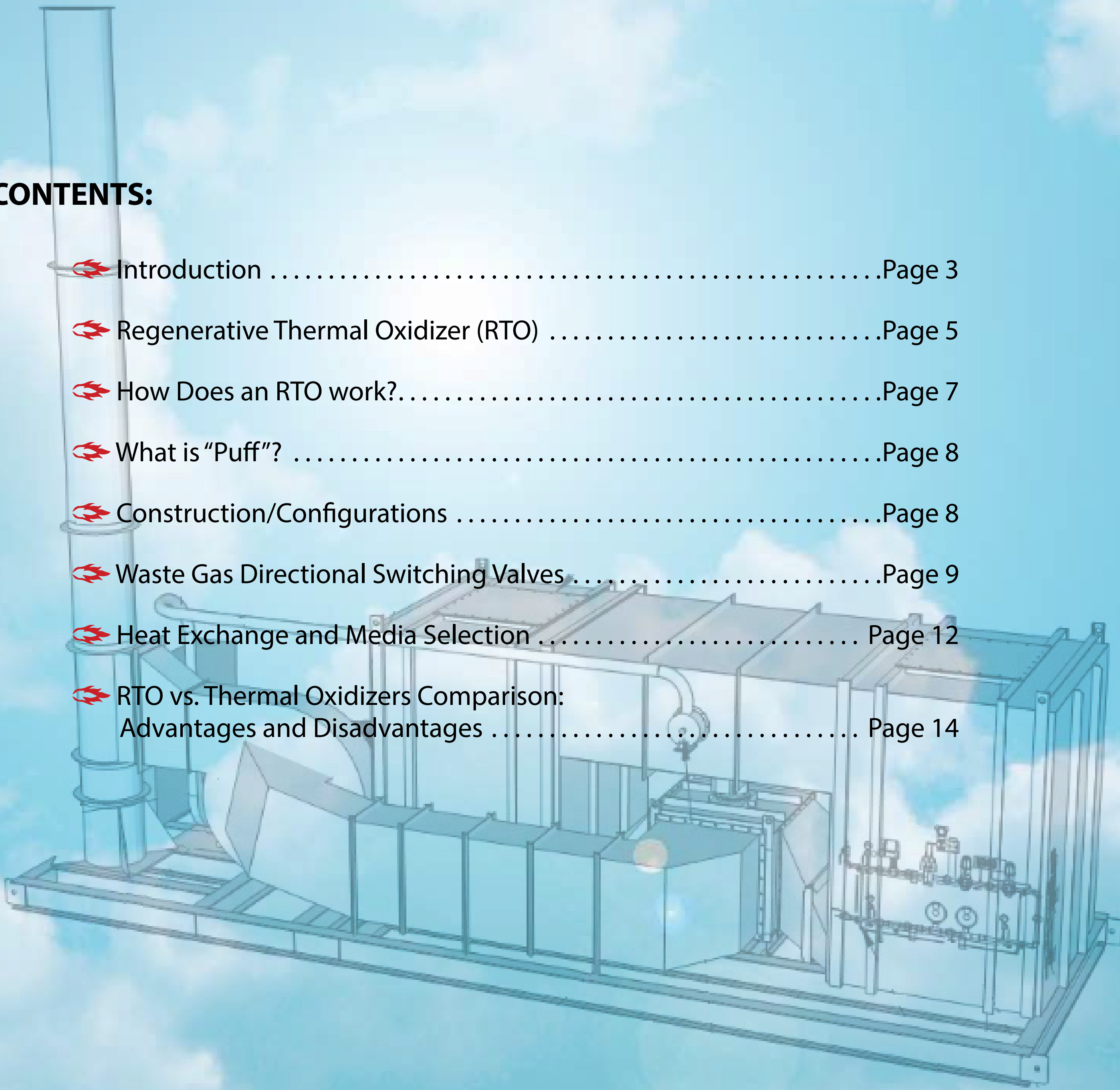
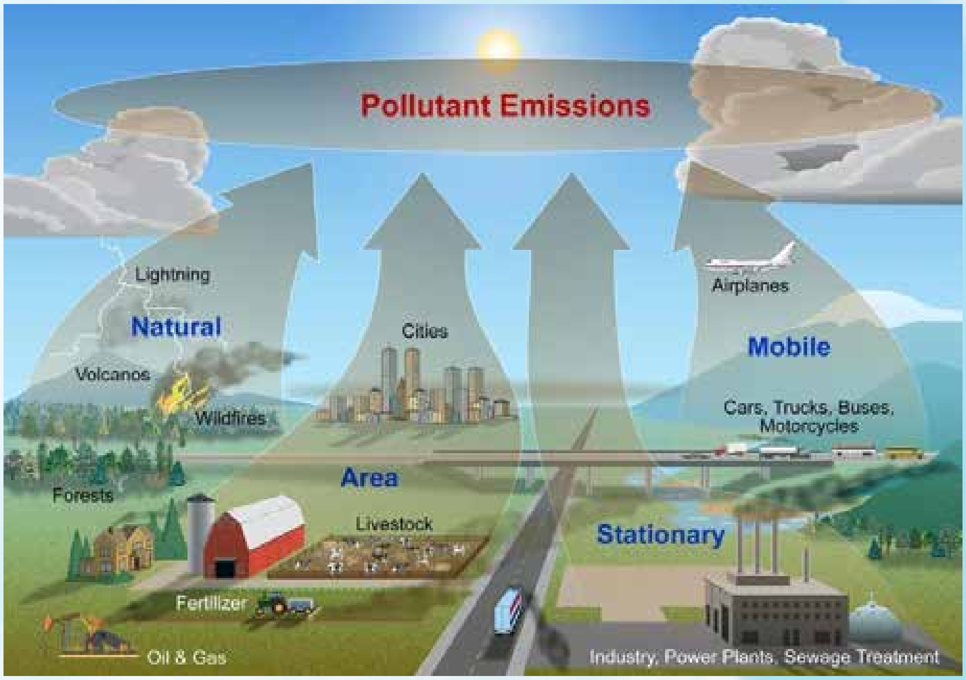


CONTENTS:

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

The eBook will focus on RTO Systems.

Regenerative Thermal Oxidizers

35,000 scfm Painting Application RTO

REGENERATIVE THERMAL OXIDIZERS

A Regenerative Thermal Oxidizer (RTO) is an industrial system that destroys volatile organic compounds (VOCs) in process exhaust air. Historically, RTOs have been used extensively in industries producing large waste stream volumes containing low VOC concentrations such as paint manufacturing, printing ,food processing and engineered wood products among others.

The system consists of a set of refractory lined beds filled with a ceramic media. The beds are designed to capture and release heat. Heat recovery is achieve by passing the waste gas stream through a packed ceramic bed at the inlet to the incinerator that was previously heated with the gases existing the incinerator. As the untreated exhaust stream travels through the first bed of ceramic media, the exhaust stream absorbs the heat energy stored in the ceramic media mass, which pre-heats the exhaust stream. The exhaust stream then enters the burner reactor chamber, where heat energy is added from the burner to reach the system operating temperature. After the temperature has been elevated, the clean, treated exhaust stream then passes through the second energy recovery chamber. The gas flow is reversed, based on a preset time.

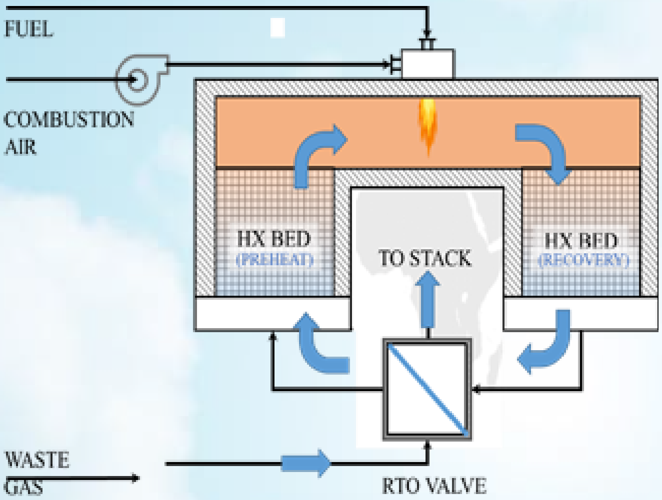
RTOs are very versatile and extremely efficient - thermal efficiency can reach 97%. Regenerative Thermal Oxidizers are ideal in a range of low to high VOC concentrations. A properly designed RTO can achieve up to 99% Volatile Organic Compound (VOC) destruction efficiency.

RTO systems work especially well for industries including::

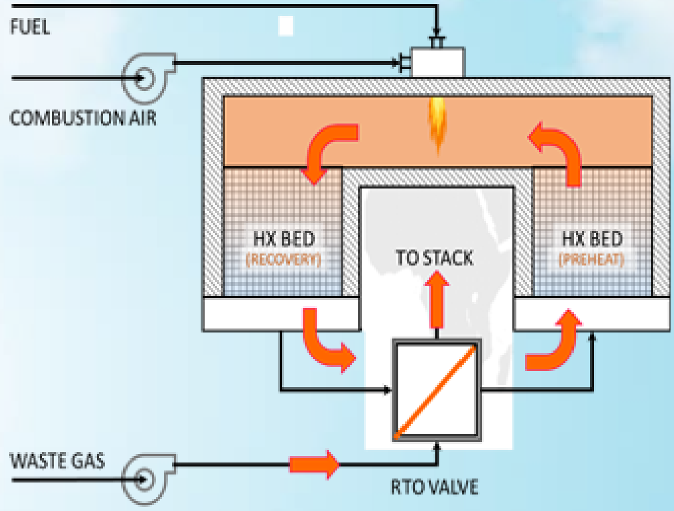
- Paint booths
- Coating processes
- Automotive
- Ethanol production
- Pharmaceuticals
- Various other manufacturing processes

How does the RTO work?

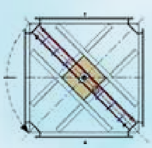
The RTO takes 1-2 hours to heat up. When the combustion chamber reaches the oxidation temperature set point, and the beds as thermally stabilized, the waste gas is introduced into the system.



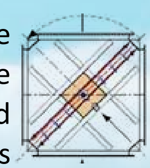
Phase I Clockwise Flow



Phase II Counter-Clockwise Flow



In the Phase I, clockwise operating mode, the valve initiates and the waste gas is directed through the bottom of the pre-heated ceramic media bed (left bed). The waste gas is pre-heated and enters the combustion chamber where the oxidation reaction is completed. After complete oxidation occurs, the gas flows downward through the right bed. In this bed, the heat from the treated gas is transferred into the ceramic media.



Once the right bed is fully saturated with heat, the RTO valve switches position, diverting the waste gas to the bottom of right bed (Phase II counter-clockwise operating mode). The right bed is now the hot bed and will pre-heat waste gas. Again, the waste gas passes through the oxidation chamber and is directed through the left bed. Heat is then transferred from the treated gas into the left bed as the gas flows downward. The cycle repeats on a 2-5 minute cycle continuously during the operation of the RTO.

The system operates at a thermal efficiency of up to 97%. This minimizes the need for supplemental fuel, which in turn, reduces the operating cost of the system.

The RTO can yield a Destruction Removal Efficiency (DRE) greater than 98.0%. A DRE of 99.0% can be guaranteed with the addition of a Puff Capture system. The puff capture will redirect the untreated waste stream that is released during the valve switching cycle, into the waste stream inlet. In no case will PCC guarantee a DRE of higher than 99.0% for an RTO system. To the best of our knowledge, no RTO suppliers will guarantee a DRE greater than 99.0%

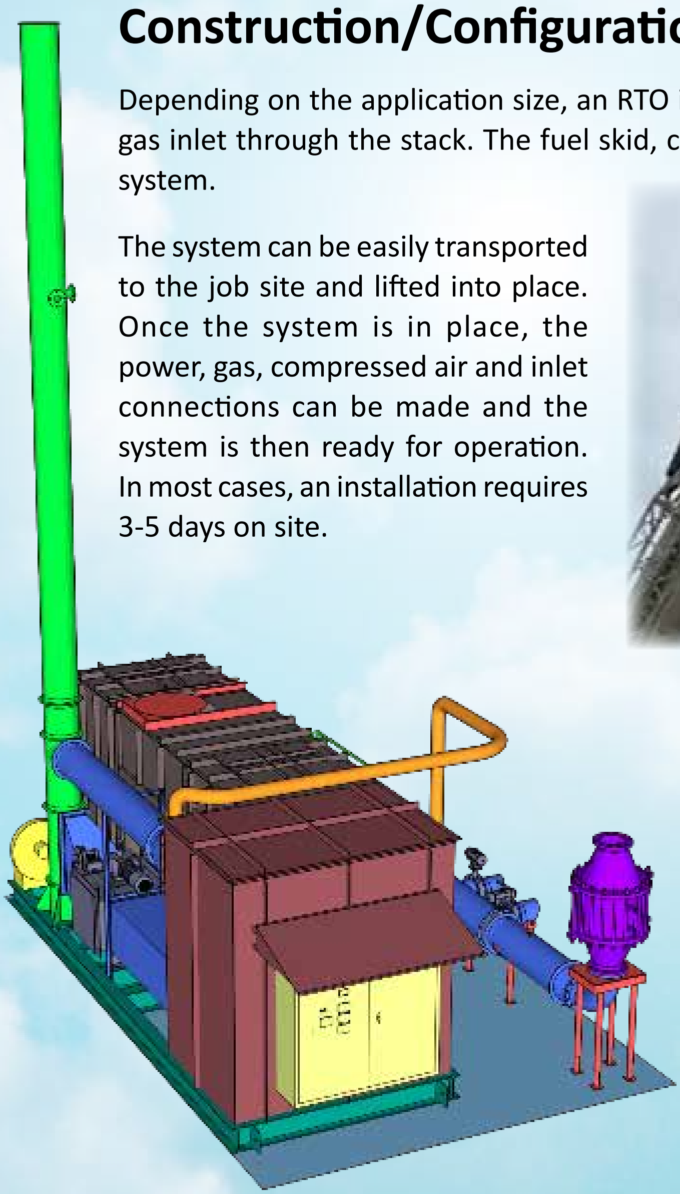
What is “Puff” and what is the impact it has on DRE?

Puff Creation: For the split second that it takes for the valve switch to occur, a “puff” of untreated gases is released to atmosphere. This small concentration of VOC lowers the removal efficiency in standard two chamber systems. The addition of a “Puff Capture” Chamber between the RTO and the exhaust stack allows recirculation of the “puff” (untreated gases) to the RTO inlet, achieving 99% VOC destruction rate efficiency.

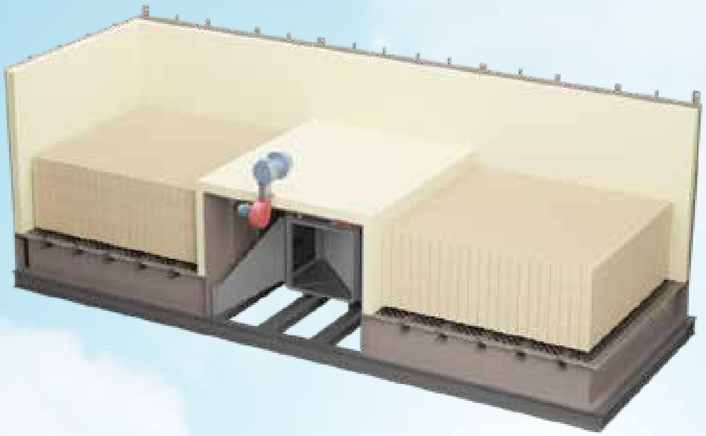
Construction/Configurations

Depending on the application size, an RTO is designed to be fully integrated to include the waste gas inlet through the stack. The fuel skid, controls and BMS systems are all part of the packaged system.

The system can be easily transported to the job site and lifted into place. Once the system is in place, the power, gas, compressed air and inlet connections can be made and the system is then ready for operation. In most cases, an installation requires 3-5 days on site.



Modular Design for easy shipping and quick installation



Most designs incorporate rigid skid mounting for the RTO and components. Steel media bed supports eliminate bed sag or failure and are used in designs to ensure a longer structural life. An open grating and steel perforated plate media platform facilitate optimum gas distribution.

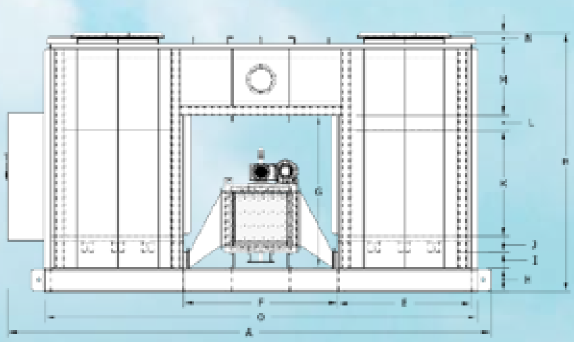
Waste Gas - Directional Switching Valves

The valving mechanism is used to change the direction of flow of the waste gas stream at the inlet to the RTO. The valve diverts the waste stream to the heated thermal transfer bed to facilitate preheating of the waste gas. On a set cycle, typically 2-5 minutes, the valve switches the direction of the waste gas flow. The stream then passes through the heated bed allowing the previous bed to reheat prior to the next cycle change.

There are a wide variety of valves utilized to accomplish the directional switching of the waste gas. Some of the more common are detailed below.

Quick-Switch - Rotary, Indexing, Air Sealed Valve

The Quick-Switch valve uses an industrial stepper motor to quickly and accurately control the position of the flow diversion vane. The switch time is extremely fast. The total time is 0.5 seconds, which includes a 0.3 second acceleration and a 0.2 second "Kiss-Close" Software deceleration. The electric stepper motor eliminates freezing problems associated with pneumatically operated poppet cylinders and ensures correct positioning. There are no harsh stops on valve seats which can cause fatigue failure over time.

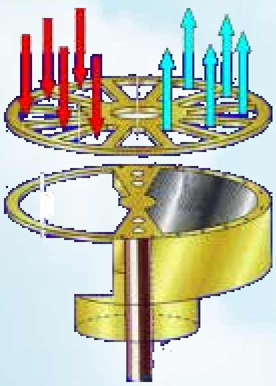


The hollow vane plate creates an air seal and virtually eliminates any leakage.

Vane wear is minimal and maintenance requirements are significantly less than that required on other valving types. The valve is smaller than poppet valves so it can be fit on the RTO skid under the combustion chamber minimizing the overall system footprint.

Rotary Valve:

A single outlet diverter valve replaces all butterfly or poppet valves on a conventional RTO. This heavy-duty valve features machined, metal seats with a unique air seal, whose close tolerance minimizes leakage. The valve is configured with an electric drive system that replaces the hydraulic and pneumatic drives commonly found on RTOs. This provides for minimal pressure fluctuations on process exhaust.



The system sits on top of the valve. The valve rotates and diverts the waste gas flow. The typical design features a single rotary diverter valve, twelve heat recovery chambers enclosed in a single tower, and a pre-piped, pre-wired package that maximizes quality and minimizes field assembly.

Maintenance can be an issue due to the location of the valve, the positioning of the vessel and the associated logistics.

Poppet Valves:

Poppet valves have been applied to RTOs for many years and consist of a flat circular plate that is raised or lowered typically by a pneumatic actuator. When the flat plate is in the closed position, it provides a gas seal by pressing against a seat shaped like a short cylinder. Gas attempting to pass through the cylinder is blocked. When the damper is open, there is a gap between the flat plate and the cylinder opening. Poppet valves are used for on-off control only; they are not appropriate for modulating applications.

Their purpose is to seal a gas path while diverting gas in another direction. RTO systems designed with two-way poppets should have one inlet and one outlet valve.

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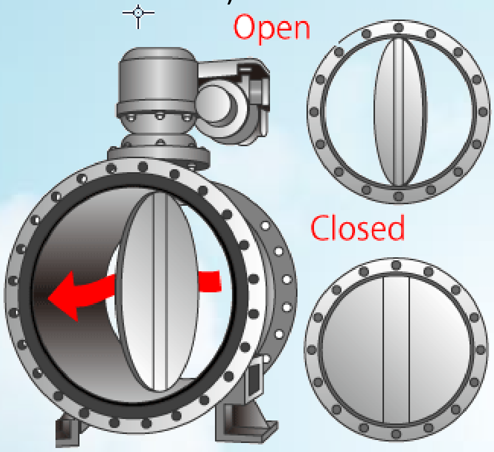
Butterfly Valves:

Butterfly valves consist of a flat plate inserted in a gas stream. It is rotated by means of a motor and linkage (often called an actuator) in order to control the gas stream flow. When the damper is in the closed position, it almost completely blocks gas flow. When it is in the fully open position, the flat plate is aligned with the direction of gas flow and therefore provides very little flow restriction.



Butterfly valves are relatively tight-sealing without excessive operating torque requirements. They offer simple and reliable means for both modulating and on-off types of applications.

Butterfly dampers used in the RTOs are the on-off type with two design variations: single-blade dampers, the most common type used in the industry; and double-blade dampers, usually used in applications where very high destruction efficiencies are desired.

Waste Gas - Directional Switching Valves Comparison:

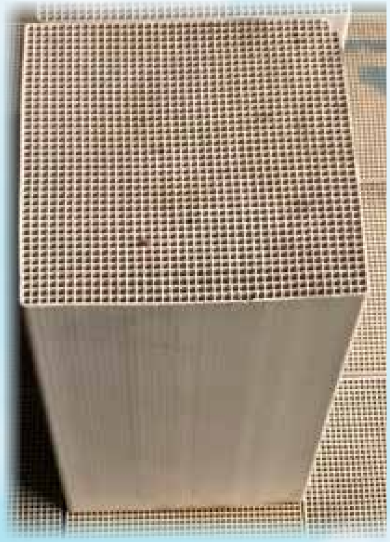
Valve Type	Leakage	Up-Time	Maintenance Requirements	Footprint
Rotary, Indexing Air Sealed	None	95%	Minimal	Minimal
Rotary	Minimal	90%	Moderate	Minimal
Poppet	Yes	85%	High	Large
Butterfly	Yes	90%	Moderate	Moderate

Heat Exchange and Media Selection

An RTO ins designed to operate around multiple energy recovery chambers. To effectively accomplish this, a heat recovery and transfer media must be incorporated into the design. The ceramic heat recovery media), acts as a heat exchanger for the system. Due to the direct gas to solid contact, the heat exchange is very efficient. The multiple chambers operate under a "swing bed" absorption principle. The heat is transferred through multiple beds by the use of flow reversal facilitating heat capture and transfer depending on the direction of flow.

There are multiple configurations/types of ceramic media used to facilitate the heat transfer function. The following are the two most common types currently in use in RTOs today.

Structured Ceramic, Block Media



A structured heat exchange media that provides a high density of ceramic into a small area while offering a very low pressure drop. Vertical channeled flow allows this type of media to provide much better heat transfer at significantly higher velocities than with random media. This means that much less media is needed to provide the required heat transfer.

The structured media provides the most open area and the lowest pressure drop. Changes in the cell density, materials of construction, and wall density flexibility of the monolith bloc, allow for custom designs for optimization when challenging applications exist.

These structured designs offer a variety of performance advantages including:

- ✓ Low pressure Drop reduces Electrical Consumption
- ✓ High Velocity reduces Equipment Size
- ✓ Up to 50% Alumina increases Heat Transfer and reduces thermal shock and breakage

The main disadvantage of structured media is the labor associated with initial installation and replacement if fouling occurs. Fouling is an undesired accumulation of the condensables and/or solid particulate on the media heat exchange surfaces and in the ceramic pores. Accumulations such as this will cause a buildup in pressure drop and, in some cases, can result in media degradation. Removal and replacement of structured media are more time consuming when compared to that of random packed, saddle media.

Random Packed - Ceramic Saddles

Random packed ceramic media has been used in RTO applications for a number of years. The most common form of random packing is the saddle although there are several other shapes that are employed. The advantages of this type of media are:

- ✓ Good resistance to plugging
- ✓ Lower initial cost
- ✓ Available for Dirty Applications
- ✓ Allows for Easy Installation and Replacement with Vacuum Truck
- ✓ More resistant to thermal shock due to smaller length

The main disadvantage is that random packing requires relatively low gas velocity which means an RTO designed with random packing media needs a large area to maximize its heat exchange properties. Typically, an RTO designed for +95% Thermal Energy Recovery (TER) with random packing will require a random media depth of 6'. This 6' depth contributes to a high pressure drop associated with the RTO fan that moves air through the system.

Energy Comparison - Thermal Energy Recovery Impact

The following Thermal Energy Recovery (TER) analysis provides an overview of comparative technology's use and resulting operating costs. TER has a tremendous impact on operating costs.

Process Design Specification

Process Flow Rate: 10,000 scfm
VOC Concentration: 750 ppmv
VOC Loading: 54.5 lb/hr
VOC Heat Contribution: 0.616 MM Btu/hr

Case	TER = 0%	TER = 65%	TER = 95%
Gas Consumption	17.5 MM Btu/hr	5.6 MM Btu/hr	0.201 MM Btu/hr
Estimated Gas Cost[2]	$78.75/hr	$25.45/hr	$0.90/hr
Gas Phase ΔP	5" w.c.	11" w.c.	19" w.c.
Electrical Consumption[3]	7.73 kW	17.0 kW	29.4 kW
Electrical Cost	$0.46/hr	$1.02/hr	$1.76/hr
Total Operating Cost	$79.21/hr	$26.47/hr	$2.6/hr

[1]Contaminant LHV assumed to be 11,525 Btu/lb, contaminant molar mass assumed to be 46.
[2]Gas cost assumed to be $4.5/MM Btu
[3]Electrical cost assumed to be $0.60/kWhr

An RTO at 95% TER yields the lowest operating cost when compared to a DFTO or a Recuperative TO.

RTO vs Thermal Oxidizer Comparison: Advantages and Disadvantages

Consideration	RTO	Thermal Oxidizer
Thermal Efficiency	97%	70% - with the incorporation of secondary heat recovery due to high exhaust temperatures
Destruction Rate Efficiency (DRE)	Typical regenerative incinerator design efficiencies range from 95-99% for RTO systems	Typical recuperative incinerator design efficiencies range from 98-99.99% and above.
Additional system requirements to achieve up to 99% DRE	Typically, a standard two-chamber RTO attains up to 98% DRE. Using a puff chamber" can increase the DRE up to 99%.	No additional components are required to attain 99.99% DRE.
Operating reactor temperature range	An RTO uses natural gas to heat entering waste gas to approx. 1400°F to 1600°F, however, it is capable of operating up to 2000°F for those cases where maximum destruction is necessary.	Most thermal oxidizers are operated at 1600°F - 2200°F to ensure nearly complete destruction of the organics in the waste stream.
Effect of particulate matter or condensable compounds entering system	Sustained exposure to even small amounts of particulate matter or condensable materials will eventually build up on the "cold face" or inside the ceramic bed, increasing system pressure drop. Over time severe or permanent damage to ceramic media can occur. Ceramic media replacements are both costly and time consuming. Bake-outs can be employed to volatilize organic particulate matter in the ceramic beds.	Shell and tube heat exchanger tubes have a much larger and more accessible open area, and are not severely affected by contaminants. Condensable materials or particulate matter can typically be easily identified and removed without need for "bake-out" from the shell and tube heat exchangers during planned shut downs. There is never a need for costly and time-consuming ceramic media replacements.
Typical gas flow ranges (process air volume)	Typical gas flow rates for regenerative incinerators are 5,000 to 500,000 scfm	Typical gas flow rates for recuperative incinerators are 500 to 50,000 standard cubic feet per minute scfm (or larger if applicable)

RTO vs Thermal Oxidizer Comparison: Advantages and Disadvantages

Consideration	RTO	Thermal Oxidizer
Additional components required to allow for higher concentrations of VOCs for short duration interrupt conditions	Due to their high thermally efficient nature, RTO systems have great difficulty averting "over temp" conditions within the reactor during rapid increases in VOC concentration. Additional equipment to allow them to ride through elevated VOC conditions are often required. Normally, a "hot gas" bypass comprised of additional duct and valves and actuators are required.	No additional components are needed to "ride through" a higher VOC concentration. These conditions are more easily avoided in a thermal oxidizer due to its lower thermal efficiency and ability to shed heat more easily.
Mechanical components not common to both systems	Waste gas directional valving systems and associated ancillaries are required on an RTO.	No additional mechanical components which are not common to both types of systems.
On-stream reliability	RTO systems can be highly mechanically intensive systems. RTOs incorporate many additional components not common to other oxidizer designs. This can have an impact an RTO's overall reliability.	Thermal oxidizers are the most proven and reliable method available. Thermal oxidizers operate in a significantly more stable state.
Applicable disadvantages	- Potential for High initial cost - Large size and weight - Potentially high maintenance demand for moving parts.	Even with recuperating waste heat energy, incinerator operating costs are relatively high due to supplemental fuel costs.