

About RTOs (Regenerative Thermal Oxidizers)

Summary:

An RTO burns very lean waste gases without using much fuel. Operating temperature is about the same as a normal thermal oxidizer (say 1600°F), but the hot flue gas passes through a heat exchange module before reaching the stack.

At least 2 of these modules are used – one is always absorbing heat from the flue gas and one is always shedding heat into the waste gas. The modules are insulated boxes full of heat exchange media – usually ceramic packing. When a box has absorbed all the heat it can, it is taken offline and waste gas is sent through it *backwards* until it is cool again. Once cooled, it is taken offline and hot flue gas is again sent through it. Two boxes are needed so the flue gas always has a path to the exhaust stack – each box switches from heating to cooling every 5 minutes, or so. Specialized “airflow switching valves”, set on a timer, are used to make the flow changes.

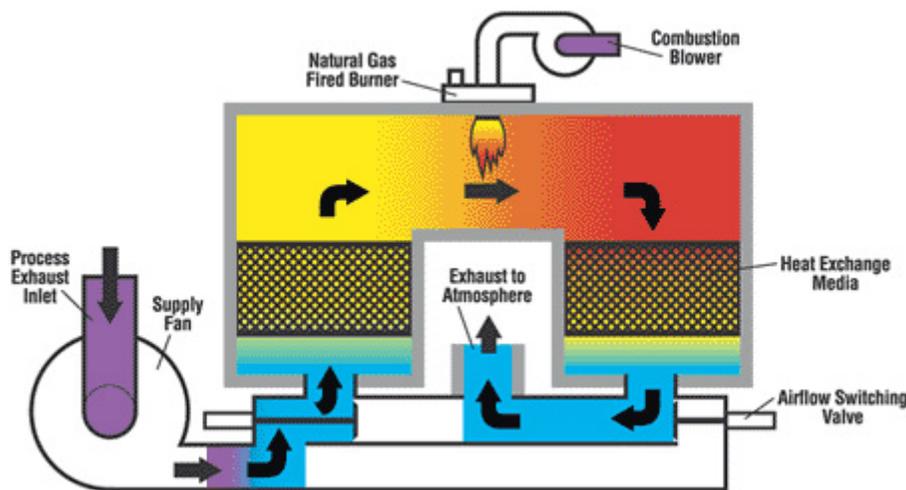


Figure 1 – Two Bed RTO Cartoon, courtesy CMM Group

In this way, if one pound of waste gas enters at 70°F, one pound of flue gas exits at 200°F. With other thermal oxidizer designs, the pound of flue gas may exit at 500°F or 1600°F – a lot more heat is lost up the stack. If the waste gas is lean, most of this heat comes from firing auxiliary fuel. Thus the popularity of RTO units

A Little Combustion Theory:

Waste gas incinerators react oxygen with waste hydrocarbons at high temperature, producing a clean flue gas. A small amount of the original hydrocarbons always remains. If 1% remains, the DRE (Destruction and Removal Efficiency) is 99%. Some carbon monoxide (CO) and nitrogen oxides (NO_x) are always produced.

A perfect incinerator would have:

- DRE = 100%
- zero fuel usage, and
- zero emission of NO_x and CO

The perfect incinerator doesn't exist, so the EPA and local air boards require DRE values ranging from 95% upward, and NO_x and CO emissions measured in the "tons per year" range. Fuel usage is up to the operator, but more fuel means more operating cost and more greenhouse gases, so lower is better. Note: NO_x emissions are lower for an RTO than for almost any other type of thermal oxidizer.

For good DRE values, the furnace temperature must be high enough, the furnace "residence time" of the flue gas must be long enough, and 2% or 3% oxygen must remain in the flue gas leaving the stack. Stack temperature doesn't matter – furnace temperature is all that's important.

For most incinerators, furnace conditions are:

- Temperature = 1400-1600°F. Higher temperatures require more expensive refractory to avoid heat damage.
- Furnace residence time = 0.5 – 1 second. More time might be needed for hydrocarbons that are hard to burn, like pesticides.
- Oxygen content is about 3% by volume, or more. As low as 2% oxygen might be OK.

If the waste gas is "dirty air" then it will contain all of the oxygen needed. Otherwise outside air has to be added.

Types of Thermal Oxidizer:

Thermal Oxidizer Type	Waste Types	Heat Recovered	Stack °F	Maximum DRE	Recovery Method
Direct Fired	Any gas or liquid	No	1200-2200	98 - 99.99+	None
Catalytic	Lean waste gases	Yes	500 +/-	95 - 99+	Metal gas/gas Heat Exchanger
Recuperative	Lean waste gases	Yes	500 +/-	95 - 99.9+	Metal gas/gas Heat Exchanger
Boiler	Any gas or liquid	Yes	350 +	98 - 99.99+	Boiler & Economizer
RTO	Lean waste gases	Yes	200-300	95 - 99+	Packed Beds

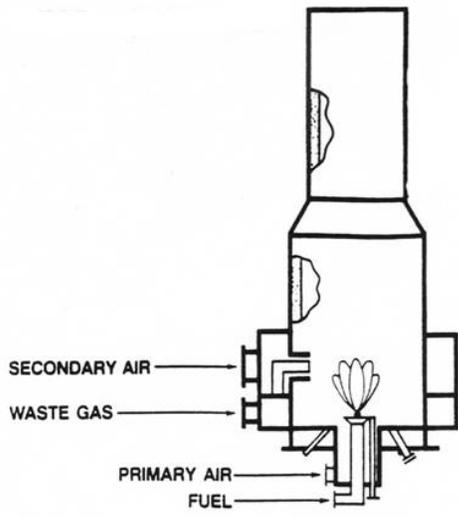


Figure 2. Direct Fired Thermal Oxidizer

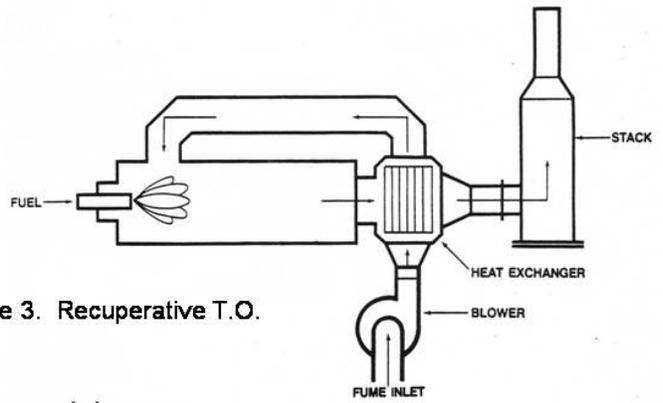


Figure 3. Recuperative T.O.

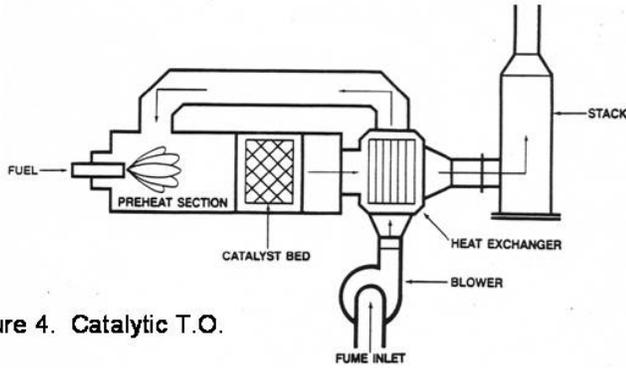


Figure 4. Catalytic T.O.

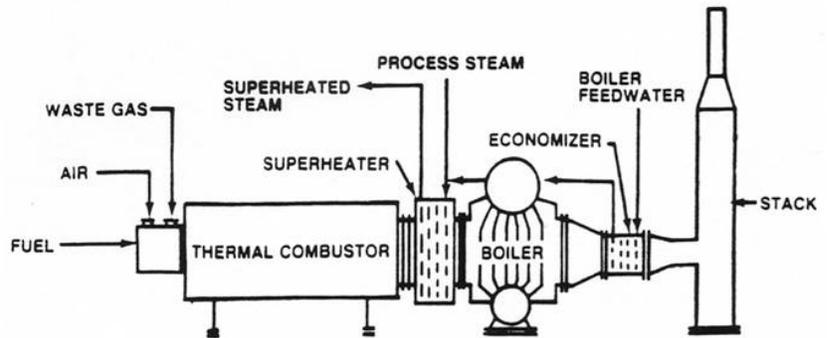


Figure 5. Direct Fired T.O. With Boiler

If the waste gas is rich with hydrocarbons, all it needs is a small burner for an ignition source. No heat recovery is needed, but you can add a boiler if you need steam for process heating or to generate electricity.

If the waste gas is “lean”, a large burner may be required, and some sort of heat recovery would be nice. In this case, the cooler your stack gas, the lower your net operating costs.

If an RTO can be used, it always is more fuel-efficient than any other type of oxidizer!

Why Not Use an RTO To Burn All Waste Gases?

1. If the waste gas has entrained particles or droplets, the heat exchange media may be fouled. Cleaning the media “in place” is difficult or impossible. Fouled media means pressure drop and efficiency problems. A direct fired oxidizer would be better.
2. If the waste gas is intermittent, the RTO has to “idle” or be shut down when waste is not flowing. It can take several hours to heat an RTO system for operation. A direct fired oxidizer probably would be better.
3. If the waste gas is too rich, the RTO may be too efficient, resulting in furnace temperatures too high to avoid refractory damage. Pure natural gas heating value is about 910 btu per cubic foot and clean air heating value is zero btu/cu.ft. If the waste gas heating value is much more than about 20 btu/cu.ft., an RTO is a bad choice. Most RTO designers want waste gas no richer than 25% of the Lower Explosive Limit.
4. If the waste gas contains chlorinated hydrocarbons (like methyl chloride) or sulfur bearing compounds (like H₂S) it will form a stack gas that might form acid droplets if cooled enough. RTOs make cooler stack gas than other types of oxidizer. If acid droplets are expected, special construction will be needed, driving up the cost.

Why don't RTO systems get “four 9's” destruction efficiency?

A DRE of about 99.5% is the limit for an RTO. If you measure the stack gas, you see 99%+ DRE sometimes and less than 90% other times and the average value may be 95% or 98%.

With a 2 bed RTO, when the beds are switched, waste gas that has entered the inlet bed, but not been burned, is pushed backwards to the stack. That may not be much unburned waste gas, but it's enough to affect the overall DRE. A plain 2 bed RTO will have a DRE value of about 98%.

To improve things, an RTO can be built with an odd number of beds (3, 5 and 7 bed RTO designs are operating). After each bed transfers its heat to incoming waste gas, it is taken out of service for one cycle, while clean stack gas is piped through it, purging the trapped waste gas back into the waste gas plenum. That keeps the stack cleaner, and raises the average DRE number to as high as 99.2 – 99.6%. Only one bed at a time is purged this way. The others are operating normally. That means a 5 bed RTO effectively has the capacity of a 4 bed RTO, but a cleaner stack gas can be guaranteed.

Can an RTO handle waste gas that does not contain oxygen?

Waste gases may consist of carbon dioxide, nitrogen or other inert gases with traces of hydrocarbons. An RTO can treat these streams, but outside air has to be mixed in before treatment.

If an RTO is treating contaminated air, like from a dryer or painting operation, the waste gas will contain almost 21% oxygen. Only a little oxygen is needed to burn the traces of hydrocarbon present, so stack O₂ will be around 20%. Clean combustion requires 2% - 3% O₂ remaining in the stack gas, so 20% is plenty.

If the waste gas is mostly carbon dioxide or nitrogen, with traces of hydrocarbons mixed in, a little fresh air is mixed with the waste gas, so the stack gas will end up with 2 – 3% oxygen.

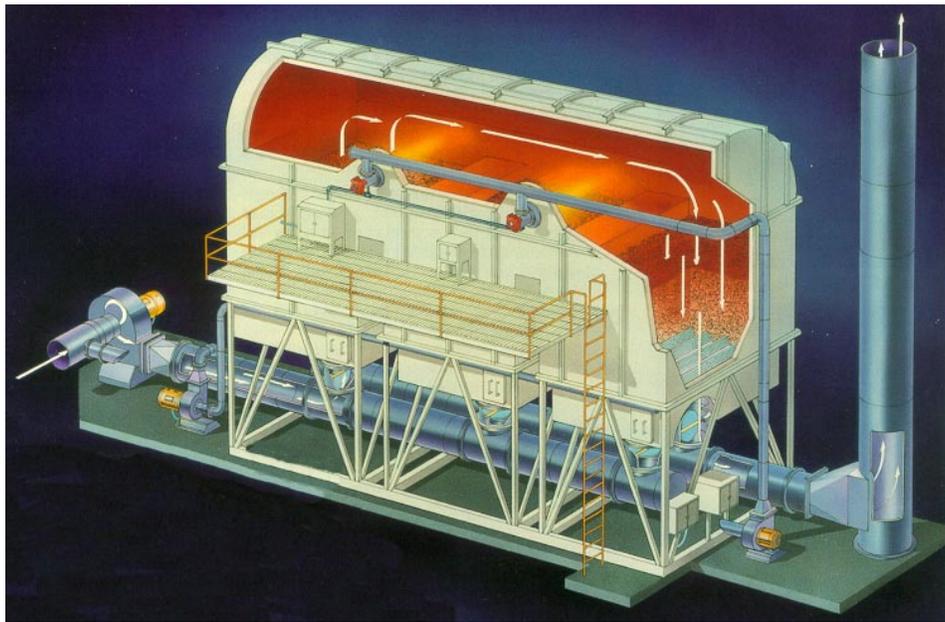


Figure 2 Three Bed RTO, courtesy Pro-Environmental

Why are beds of packing used in an RTO?

By directing the lean waste gas through a packed bed, its temperature can be brought up close to the target furnace temperature using only residual heat left in the bed by the hot flue gas. Sometimes this results in the waste gas hydrocarbons igniting on their own, achieving a further rise in temperature. A fuel gas burner is always installed in the RTO furnace, but with good design, fuel gas consumption might be zero during normal operation.

Note: If all of the heat exchange packing is removed from an operating RTO, it would perform like an ordinary incinerator – fuel usage to reach the needed furnace temperature would be high with a lean waste gas. More bed packing means less fuel gas needed and/or higher furnace temperatures reached.

Note: If the beds were never switched, an RTO would perform like an ordinary incinerator – the hot flue gas would heat the bed it is flowing through up to flue gas temperature and the lean waste

gas would draw all of the heat out of the other bed. Fuel consumption would be high with a lean waste gas. Shorter bed switching time means less fuel gas needed and/or higher furnace temperatures reached.

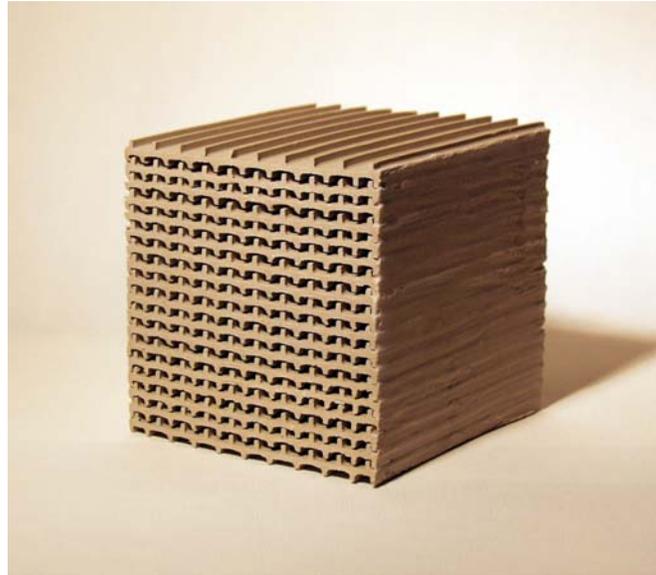


Figure 3 Typical RTO ceramic packing block, courtesy Lantec

Bed size and packing type are selected based on waste gas flow and composition. Enough pounds of packing have to be used to absorb the heat from the full flow of stack gas – once a layer of packing is heated to combustion chamber temperature, it can't pick up any more energy and another layer has to be added. The designer sets the pounds of packing in each bed according to the rate of stack gas flow and the time the bed is absorbing heat before it is switched. The type of packing used is an economic decision – random packing is cheaper, but structured packing blocks (Fig. 7) take up less room for an equal amount of heat transfer.

Bed switching time is selected based on bed construction and waste gas flow and composition. For greater heat transfer efficiency, switching time needs to be shorter. But with larger beds, switching time can be extended since there is more packing to absorb the heat. Every time the beds switch, there is a small burst of unburned waste gas flowing to the stack – when high DRE is required, longer switching times are needed, which results in larger packed beds.

What if the waste gas is usually lean but can be richer occasionally?

For waste gas with more hydrocarbons, less heat recovery is needed to maintain low fuel gas consumption. Bed packing is difficult to remove, so either Cold Gas Bypass (CGB) or Hot Gas Bypass (HGB) might be used to reduce the heat recovery efficiency of the system.

- With CGB, part of the cold waste gas is ducted directly to the furnace, bypassing the heat recovery section of the RTO.
- With HGB, part of the hot furnace exhaust is ducted directly to the stack, bypassing the heat recovery section of the RTO.

CGB and HGB are ways to alter RTO operation to reduce the built-in heat recovery efficiency when the waste gas has more hydrocarbons than are needed to achieve zero fuel gas usage. CGB and HGB are also used to avoid excessive temperature in the furnace – if furnace temperature rises too much, a different grade of refractory might be needed to avoid permanent damage. A typical high temperature shutdown setpoint might be 1800°F.

With HGB, the stack temperature is higher than for most RTO designs. Special stack construction (stainless or refractory lined carbon steel) may be required to avoid damage.

During normal operation, RTO furnace temperature and stack temperature vary over a narrow range. This is because when the beds switch, the waste gas entering the furnace (and the furnace gas entering the stack) are now flowing through the alternate bed. The waste gas is suddenly hotter because it is flowing through the bed recently in contact with the hot flue gas. The flue gas is suddenly colder because it is flowing through the bed recently being cooled by the incoming waste gas. If the beds switch every 3 minutes, the “average” flue gas and combustion chamber temperatures are reached approximately 1.5 minutes after the switch.

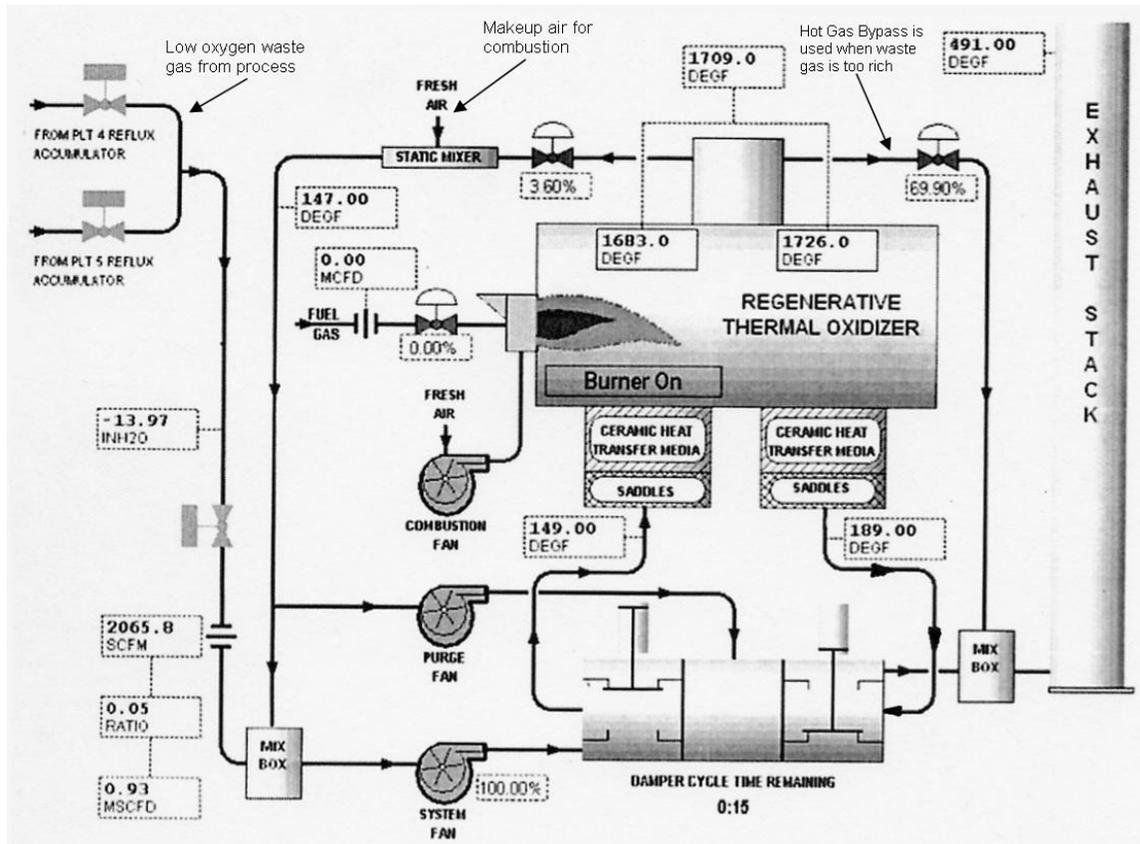


Figure 4 RTO Control Schematic with HGB and Make-up Air

How is RTO control loop tuning different than tuning for a direct fired incinerator?

To control stack temperature in a direct fired incinerator, increasing fuel flow results in hotter stack gas within 5 or 10 seconds. In an RTO, increasing fuel gas flow to the burner immediately heats the furnace, but the stack gas temperature rise is delayed by the heat absorbed in the packed beds. The increased RTO furnace temperature puts more heat in the packed bed receiving the

flue gas. At the end of the cycle, that bed is hotter than at the end of the previous cycle; when the waste gas is switched back into it, the waste gas temperature entering the furnace will be higher than in the previous cycle. The stack temperature, as well as the furnace temperature, will swing around an average value as the bed switching proceeds. In fact, a step change in fuel flow may require several cycles of bed switching before stable average stack temperature and furnace temperature are reached.

This type of delayed response happens with any change to RTO operation. These include changes to waste gas flow, waste gas hydrocarbon content, burner fuel or air flow, CGB flow and HGB flow.

Energy In = Energy Out (For a quick check, ignore the packed beds)

Regardless of the energy efficiency features of an RTO, or the control loop tuning, there has to be conservation of mass and energy. Every pound of waste gas, air or fuel gas entering is matched by a pound of flue gas out the stack. Every BTU entering the RTO (as sensible heat due to a heated waste gas, or as hydrocarbon heat release) has to show up as a BTU in the stack gas or as heat loss through the vessel shell. What happens in the packed beds or the switching valves is important for saving fuel, but taken as a whole, “what goes in has to equal what comes out”.

For instance:

- If it is impossible to feed enough air to produce around 3% oxygen in the stack gas, then the RTO can't operate as intended.
- If the stack temperature measured is higher or lower than predicted by the BTU balance, then there is some other input not being considered – maybe the waste gas is richer or leaner than expected.

Given a specific waste gas, a specific air flow, a specific fuel gas flow and a specific heat loss through the vessel refractory and insulation, the stack gas flow, composition and temperature can be calculated even if nothing is known about the bed packing, switching times, bypass flow or any other detail.

RTO Design Steps:

1. Perform a heat & material balance on the waste stream, including min/max flow, min/max hydrocarbon load, etc. Determine if any of the cases excludes use of an RTO – for instance, is the waste gas hydrocarbon load so high that a different type incinerator would be the right choice?
2. Specify the packing types and amounts, along with the bed switching times to achieve the heat recovery efficiency needed for all operating cases. Packing vendors (like Lantec) will provide these calculations, based on their products.
3. Size the combustion chamber, stack, inlet ducting, any bypass ducting, etc.
4. Size and specify the waste gas blower, fuel gas burner, combustion air blower.
5. Specify the type and amounts of refractory lining and external insulation.
6. Prepare the P&I Diagram and Process Flow Diagram(s)
7. Prepare spec sheets for purchase of blowers, burners, instruments, etc.
8. Prepare fabrication drawings, parts lists, operating instructions and other documentation.

RTO Suppliers (partial list – alphabetical order):

Anguil Environmental Systems
www.anguil.com

CMM Group
www.thecmmgroup.com

Eisenmann Corporation
www.eisenmann.com

Langbein Engelbracht America
www.l-eamerica.com

MEGTEC Systems
www.megtec.com

Pro-Environmental, Inc.
www.pro-env.com

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www.banksengineering.com.