Cycle Therm **White Paper**

Debunking RTO Operating Cost Sales Rhetoric

There is more to evaluating different vendors' RTO proposals than selecting the low bidder. It is important to know a few things in order to effectively compare one vendor's RTO proposal with another. While one vendor may appear to be the low bidder in up front capital equipment expenditures, they may end up being the most expensive when looking at the life cycle cost of the equipment.

There are two components to consider when determining RTO utility consumption and operating cost:

1. Fuel usage (natural gas or other) to fire the burner
2. Electricity cost to power the fan

Sales proposals usually do not give you the proper information to make an accurate cost comparison. Here's how to debunk the sales rhetoric regarding RTO operating costs and evaluate the true life cycle cost of your purchase:

Fuel Usage

The laws of physics always prevail in a fuel (gas) usage comparison. Assuming that all variables are the same in each operating scenario (inlet temperature, airflow, solvent load, solvent calorific value, operating temperature and thermal efficiency of the RTO); one vendor's RTO isn't much different from any other with respect to gas consumption.

Electricity Cost

Electrical costs can vary greatly. From vendor to vendor, there can be a whopping 250% difference in electricity consumption. In the case of a 16,000 SCFM RTO running two shifts per day, this amounts to over $23,000 per year difference in operating cost.

This paper details how to calculate fuel and electrical consumption to understand the true operating cost for an RTO. In order to begin, we must first talk about nominal versus actual thermal efficiency.

Thermal Efficiency – Nominal vs. Actual

Regenerative thermal oxidizers (RTOs) are rated in nominal thermal efficiency, often referred to as Total Energy Recovery (TER), and typically expressed as a percentage such as 95% TER. Understanding thermal efficiency, and how it relates to natural gas operating cost, is critical to properly evaluating the true operating expense and overall life cycle cost of a proposed RTO.

In the sales proposal, the RTO is rated on its **nominal** thermal efficiency, which is the thermal efficiency of the regenerative heat exchanger as if it were a standalone device. However, the heat exchanger is not a standalone device and, in reality, many factors affect it during operation. These factors or 'losses' must be taken into account when calculating the **actual** thermal efficiency and how it relates to fuel usage.

When there is sufficient VOC Btu content from the process to overcome the standard 5% exchanger loss and the radiation heat lost through the shell and no air infiltration, the RTO is said to have a balanced mass flow and the nominal thermal efficiency is achieved.

This is the only time nominal equals actual. When we consider all losses, the difference in fuel gas usage between nominal and actual can be a factor of 1.8 to 1.9.

Nominal Efficiency

Example: A 95% TER, 16,000 SCFM RTO with no VOC fuel content from the process will require 268 SCFM of combustion air premixed with 21 SCFM of natural gas (based on 13:1 air fuel mixture) to maintain 1500°F.

To calculate nominal thermal efficiency:

$$\text{TER} = \frac{\text{Combustion chamber temp} - \text{exhaust temp}}{\text{Combustion chamber temp} - \text{process (inlet) temp}} \times \frac{\text{process flow} + \text{combustion air flow} + \text{gas flow}}{\text{flow in}}$$

Combustion chamber temperature = 1500°F
Exhaust temperature = 171°F
Process (inlet) temperature = 70°F
Process flow = 16,000 SCFM
Combustion air flow = 268 SCFM
Gas flow = 21 SCFM

$$\text{TER} = \frac{1500°\text{F} - 171°\text{F}}{1500°\text{F} - 70°\text{F}} \times \frac{16{,}000\ \text{SCFM} + 268\ \text{SCFM} + 21\ \text{SCFM}}{16{,}000\ \text{SCFM}} = .9462 \text{ or nominal } 95\%$$

A Look at Losses

Heat Exchanger Loss

The heat exchanger recovers 95% of the heat energy, and so it could be said to lose 5% of that energy.

To calculate that 5% loss in Btu/h for our example:

process flow x 1.08 Btu/h/°F/SCFM x (combustion temp-inlet temp) x exchanger efficiency loss

Process Flow = 16000 SCFM
Combustion Temp = 1500°F
Process Inlet Temp = 70°F
Regenerative exchanger efficiency loss = 5% (0.05)

16000 SCFM x 1.08 Btu/h/°F/SCFM x (1500°F -70°F) x 0.05 = 1,235,520 Btu/h

Fuel Efficiency Loss

Natural gas is purchased with a gross heating value of 1,000 Btu/cu. ft. However, usable heat or net heating value, after accounting for energy discharged through the stack as water vapor, is 870 Btu/cu. ft. At a stack discharge of 171° F with 0% excess air, 13% of gas Btu content will be lost by way of 10% conversion to $H_20 + Co_2$, and approximately 3% additional gas required to heat the combustion air.

To calculate additional fuel required to compensate for the fuel efficiency loss of 13% for our example:

$$\frac{\text{Net fuel usage}}{\text{Fuel efficiency}} - \text{Net fuel usage} = \text{Fuel efficiency loss}$$

Net fuel usage =
5% exchanger loss + Heat radiation loss + Mass unbalance loss

1,235,520 Btu/h + 225,000 Btu/h* + 494,208 Btu/h* = 1,954,728 Btu/h

Fuel efficiency = 100%–13% = 87% (0.87)

*Heat radiation loss and mass unbalance loss calculations are shown in the next two sections.

$$\frac{1{,}954{,}728 \text{ Btu/h}}{0.87} - 1{,}954{,}728 \text{ Btu/h} = 292{,}086 \text{ Btu/h}$$

Mass Unbalance

An obvious, but often overlooked infiltration source is the burner. When there is insufficient fuel content in the process stream to maintain the combustion chamber temperature, the burner must fire.

In an RTO, fuel (natural gas) is supplied to the burner with 13 SCFM of combustion air per cu. ft. of natural gas input (30% excess air) at 1500°F for combustion to occur. The addition of combustion air unbalances the mass flow and reduces the thermal heat exchange efficiency by about 2%, to about 93%. This small unbalance will increase overall fuel usage depending on the amount of excess combustion air used.

To calculate mass unbalance loss using our example:

1. Convert nominal fuel usage to (gas volume) SCFH by dividing the Btu/h fuel usage by the Btu content per cu. ft. of fuel (natural gas = 1,000 Btu/cu. ft.).

$$\frac{\text{Nominal fuel use Btu/h}}{\text{1,000 Btu/cu. ft.}} = \text{cu. ft./h (SCFH)}$$

Nominal fuel use = 1,235,520 Btu/h

$$\frac{\text{1,235,520 Btu/h}}{\text{1,000 Btu/cu. ft.}} = \text{1,236 SCFH}$$

2. Calculate the combustion air requirement based on the percent of excess air supplied to the burner.

$$\frac{\text{SCFH (of gas) x air to fuel ratio}}{\text{60 min./h}} = \text{SCFM combustion air}$$

SCFH (of gas) = 1,236
Air to fuel ratio = 13:1 (30% excess air)

$$\frac{\text{1,236 SCFH x (13/1)}}{\text{60 min./h}} = \text{268 SCFM}$$

3. Find the mass unbalance loss:

$$1 - \frac{\text{Process flow}}{\text{(process flow + combustion air flow)}} = \text{Mass unbalance loss}$$

Process flow = 16,000 SCFM
Combustion air flow = 268 SCFM

$$1 - \frac{\text{16,000 SCFM}}{\text{(16,000 SCFM + 268 SCFM)}} = \text{.0165 or 2\%}$$

4. Finally, find the mass unbalance loss in Btu/h for our example:

Process flow x 1.08 Btu/h/°F/SCFM x (combustion temperature – inlet temperature) x % mass unbalance

16,000 SCFM x 1.08 Btu/h/°F/SCFM x (1500°F – 70°F) x .02 = 494,208 Btu/h

Heat Radiation Loss

Heat radiation loss from the outside surface of the RTO can vary depending on overall surface area, angle of the surface, insulation type and thickness and wind velocity. Typically, staying within the OSHA requirement of no outside surface temperature greater than 140°F yields an average hourly loss of 125 Btu/sq. ft.

If an average 16,000 SCFM, 2-chamber RTO yields a surface area of 1800 sq. ft., the estimated heat loss is 225,000 Btu/h.

Surface area x Average hourly loss = Estimated heat radiation loss

1800 sq. ft. x 125 Btu/sq. ft./h = 225,000 Btu/h

Thus, at 6,000 h/year and $7/million Btu (mmBtu) the loss equals $9,450/year.

$$\frac{\text{Estimated heat loss}}{1{,}000{,}000} \times \text{Fuel cost} \times \text{Annual hours of operation} = \text{Annual cost of heat radiation loss}$$

$$\frac{225{,}000 \text{ Btu/h}}{1{,}000{,}000} \times \$7.00/\text{mmBtu} \times 6{,}000 \text{ h/yr} = \$9450.00$$

Now that we have identified the heating requirements, we can compare nominal vs. actual fuel consumption for our example:

Nominal fuel usage for the 16,000 SCFM RTO:

Exchanger loss	1,235,520	Btu/h
Heat radiation loss	NA	
Mass unbalance loss	NA	
Fuel efficiency loss	NA	
Nominal fuel usage	1,235,520	Btu/h

Actual fuel usage for the 16,000 SCFM RTO:

Exchanger loss	1,235, 520	Btu/h
Heat radiation loss	225,000	Btu/h
Mass unbalance loss	494,208	Btu/h
Fuel efficiency loss	292,086	Btu/h
Actual fuel usage	2,246,814	Btu/h

From this example, we can clearly see that actual fuel consumption is nearly double the nominal fuel usage calculated. Having determined the actual fuel usage, we are now able to calculate the actual thermal efficiency.

OVERALL RTO ACTUAL THERMAL EFFICIENCY:

$$\frac{\text{Btu/h @ 100\% efficiency loss – actual fuel usage}}{\text{100\% efficiency loss}} = \text{Actual thermal efficiency}$$

$$\frac{\text{24,710,400 Btu/h** - 2,246,814 Btu/h}}{\text{24,710,400 Btu/h}} = \text{.9091 or 91\%}$$

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$$\frac{\text{Heat Exchanger Loss}}{\text{5\%}} = \text{Btu/h at 100\% Efficiency}$$

$$\frac{\text{1,235,520 Btu/h}}{0.05} = \text{24,710,400 Btu/h}$$

Electrical Power Consumption

As stated earlier, there can be a whopping 250% difference in electricity consumption among RTOs. Buyers should look at the amount of electricity required to power the fan in order to weigh the electricity use differences among vendors' RTOs.

In many sales proposals, fan horsepower use is not converted to dollar per year operating expense by the vendor, and therefore is easily overlooked when comparing cost of operation. To yield artificially low operating costs, only **fuel usage** (which we have shown is roughly the same for each vendor) is spelled out. This 'oversight' is generally attributed to improving what we call Price Page Economics, but does little to help the client truly evaluate the proposal.

Why can electrical consumption vary as much as 250% from vendor to vendor? The answer lies in the sizing of the RTO and heat recovery media selected.

To appear very competitive, the low bidder will usually use smaller recovery chambers with heat recovery media that impede the flow of air through the chambers. The chamber sizing coupled with the type of media may cost less and generate the desired heat recovery, but create a large pressure drop, which in turn requires up to 1/3 more horsepower to run the RTO's fan. More horsepower requires more electricity, resulting in higher operating costs.

This means that an initial $25,000 in capital cost 'savings' gained by selecting the low bidder can turn into $467,523 in excess electricity costs over the 20-year life expectancy of the RTO. Thus, if you spend the extra $25,000 to purchase the more energy efficient RTO, you nearly make up for that initial expense in operating costs over the first year alone!

How to Calculate Electricity Cost

What follows is a formula to calculate electricity operating cost comparison between vendor quotes:

Step 1: Determine the fan motor brake horsepower difference

Step 2: Calculate the kilowatt hours

$$\frac{\text{brake horsepower differential X 746 watts per Bhp}}{1000} \div \text{fan motor efficiency} = \text{kWh}$$

Step 3: Calculate the annual cost based RTO operating hours

kW x kWh cost x annual RTO operating hours = annual electricity cost

Sample Electricity Cost Calculation
Fan horsepower: Vendor 1 = 75 Bhp Vendor 2 = 125 Bhp
Fan motor efficiency: 90% (0.90)
RTO operation: two 8-hour shifts per day, 5 days per week = 4160 annual hours
kWh cost = 13.56¢ average cost industrial sector in New England as of February 2009

Step 1: Brake horsepower differential:

125 Bhp – 75 Bhp = 50 Bhp differential

Step 2: Kilowatts:

$$\frac{\text{50 Bhp X 746 watts}}{1000} \div 0.90 = 41.44 \text{ kW}$$

Step 3: Annual cost differential:

41.44 kW x $0.1356 per kWh x 4160 hours = $23,376 per year

$467,523 over the 20-year lifecycle of the RTO

As you can see, while it can take some effort to accurately compare RTO operating costs, the potential long-term savings far outweigh the savings on initial investment. Protect your company’s bottom line by understanding the overall expenses including operating costs for the life of your RTO along with the initial capital investment. These cost comparisons will help you to obtain the information you need before purchasing your next RTO.

Cycle Therm's Answer: Cell Stone® Ultra

Cycle Therm's answer to reducing electricity consumption while still maintaining Price Page Economics is to use our patented, ultra low pressure drop, random packed heat recovery media known as Cell Stone® Ultra.

Random packed Cell Stone® saw its first commercial use in a conventional regenerative thermal oxidizer in 1997. Other than tinkering a bit with the air to media ratio, the patented product remains the same today.

Cell Stone® is an extremely efficient heat transfer media because of its uniquely configured high open area and thick individual piece structure. Unlike higher density saddles requiring huge pressure drops and thin walled structured medias, that require short time cycles, Cell Stone® Ultra makes efficient use of its stored heat, allowing elongated six-minute time cycles, removing only a small amount of the media's stored heat after each RTO cycle. This residual heat is more than adequate to generate stable 95% heat recovery.

Here are some advantages of Cell Stone® Ultra:

- Impervious to thermal shock- unlike structured media, random packing allows the media freedom of movement to expand and contract during heating and cooling. This means the system may be brought up to temperature as fast as the burner system will allow without thermal degradation of the media.
- Unlike structured media, it is random packed, thus eliminating the labor necessary to place each individual piece (or remove it).
- Unlike structured media, it affords the turbulence necessary to assist with VOC destruction, thus improving destruction efficiency.
- On an equal air/media ratio it requires ½ the volume of conventional saddles to obtain 95% nominal heat recovery efficiency.
- Unlike structured media with three-minute timing cycles, cycle times can be extended to as long as six minutes. This achieves a 50% reduction in VOC spikes while maintaining 95% thermal efficiency.

About Cycle Therm

Cycle Therm is an international leader in the design, fabrication and installation of Regenerative Thermal Oxidizers (RTOs). The RTO we bring to market today is the culmination of over 30 years of design experience focused on a single product.

In addition, Cycle Therm provides turnkey installation services, repair and refurbishment and is a distributor of Cell Stone® heat recovery media and tower packing.

For More Information

Visit our website at www.cycletherm.com to use our exclusive RTO Operating Cost Calculator and learn more about Cell Stone® ULTRA heat recovery media.

Retail electricity prices can be obtained from the Energy Information Administration, which is part of the Department of Energy, website at www.eia.doe.gov.

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