EXTENDED ABSTRACT

Heat Recovery Options for VOC Oxidizer Systems

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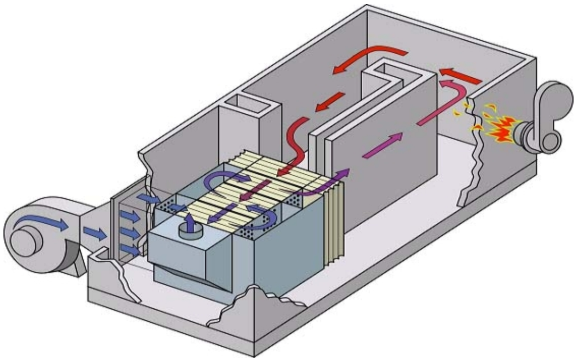
OXIDIZERS 101
Why we use Oxidizers and Definition of Terms

When released into the atmosphere, **Volatile Organic Compounds (VOCs)** tend to degrade in the presence of sunlight and oxides of nitrogen to form ground level ozone. This type of ozone is toxic to humans and animals, damaging to crops and is the basic ingredient of smog. A proven method of treating VOCs prior to their release is Oxidation. Oxidizers are designed to convert VOCs to Carbon Dioxide and Water Vapor. As an example, the formula for the oxidation of Toluene is shown below.

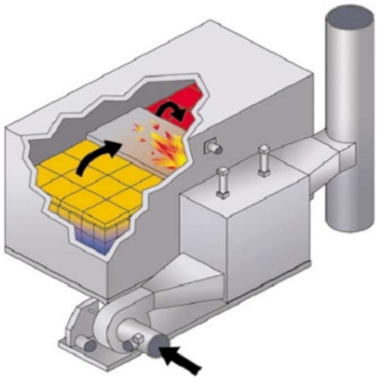
$$C_7H_8 + {}_{(9)}O_2 \Rightarrow {}_{(7)}CO_2 + {}_{(4)}H_2O$$

Simply put, Thermal Oxidizers use elevated temperatures (1400 F to 1800 F typical) to drive this chemical reaction to extremely high levels of conversion. At it’s core, a Thermal Oxidizer is a ‘burner in a box’ designed to heat a **Solvent Laden Airstream (SLA)** up to temperatures typically above 1400 F. However, the act of continually heating an SLA above 1400 F quickly becomes cost prohibitive. As a result, thermal oxidizers have evolved over the years to include different forms of heat recovery.

Thermal Recuperative Oxidizers add a (typically stainless steel) air to air heat exchanger to ‘recuperate’ the heat from the outgoing purified air and use it to help pre-heat the incoming SLA. Typical thermal efficiencies for this class of thermal oxidizers are anywhere from 35% to 70%.



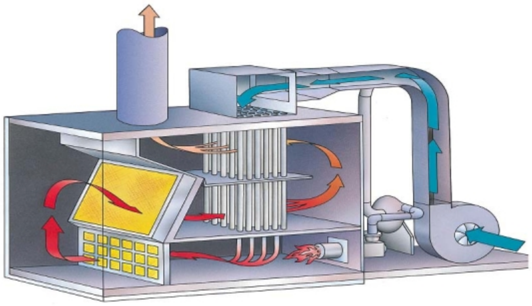
Thermal Recuperative Oxidizer



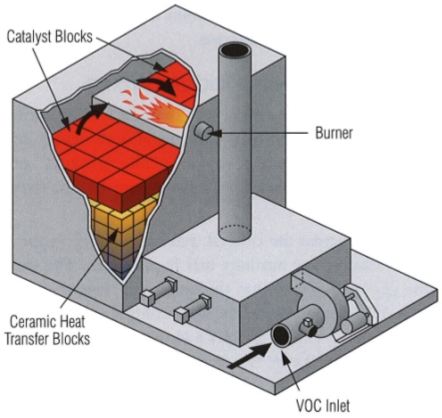
Regenerative Thermal Oxidizer (RTO)

Regenerative Thermal Oxidizers (RTOs) use ‘heat sinks’ in the form of large masses of ceramic heat recovery media to store heat within the system. Typical thermal efficiencies for this class of thermal oxidizers are anywhere from 80% to 96%.

Catalytic Oxidizers employ catalyst to enable the oxidation reaction and get the same VOC conversion efficiencies at lower temperatures (550 F to 1100 F typical). Catalytic systems can recover heat in much the same way as thermal oxidizers do – that is to say there are **Catalytic Recuperative Oxidizers** and **Regenerative Catalytic Oxidizers (RCOs)** as well.



Catalytic Recuperative Oxidizer



Regenerative Catalytic Oxidizer (RCO)

The integral heat recovery methods discussed so far in which the outgoing purified air is used to preheat the incoming SLA is typically referred to as **Primary Heat Recovery** and both Thermal and Catalytic Recuperative Oxidizers and Regenerative Oxidizers are typically advertised with a primary **TER %** (for Thermal Energy Recovery %).

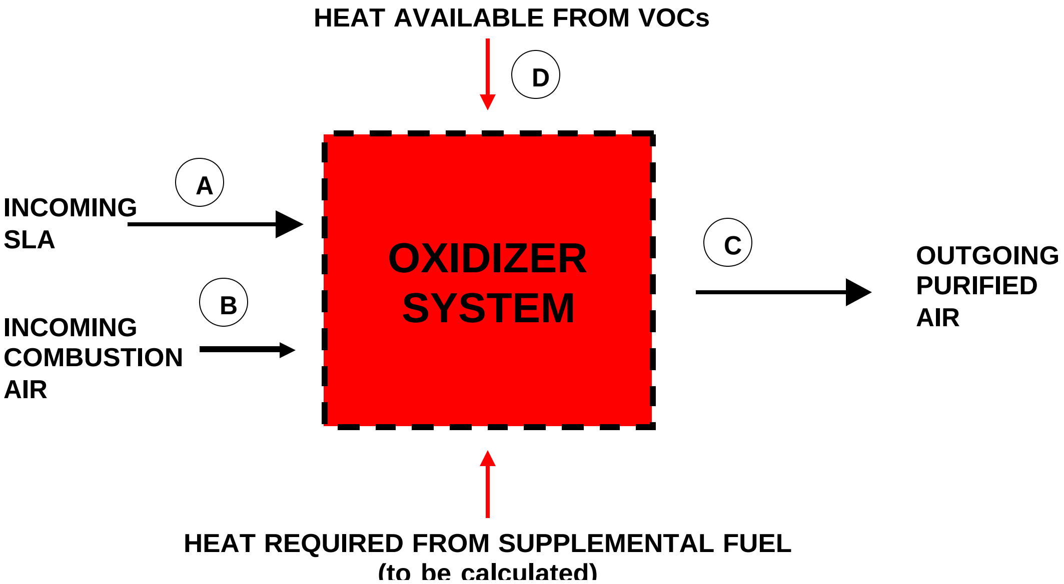
OXIDIZER ECONOMICS

A basic model for evaluating oxidizer system operating cost.

Taking a thermodynamic 'system approach', one can start to build a very basic model for analyzing the operating cost of existing oxidizer systems. This is not meant to replace the level of detail to which an oxidizer manufacturer will model an oxidizer system, but rather to empower an oxidizer end user to:

- Do a basic check of system operating costs
- Start to examine opportunities for improving efficiency

If a box is drawn around the oxidizer as a whole we can provide an energy balance, regardless of what type of oxidizer is used.



For this basic model, the important data is:

Point	Airflow (SCFM)	Temperature (F)		Point	VOC Load (lbs/hour)	VOC Heat Value (BTU/lb)
A				D		
B						
C						

With this simplified model, the following equation can be used:

Energy Required (BTU/hr) = Mass Flow Rate (lb/hr) x Specific Heat (BTU/lb F) x Delta T (F)

= Vol Flow (cf/min) x 60 (min/hr) x Density (lb/cf) x Specific Heat (BTU/lb F) x Delta T (F)

= [SCFM] x 60 (min/hr) x 0.075 (lb/cu ft) x 0.24 (BTU/lb F) x [DELTA T] (F)

Combining terms and canceling units – this simplifies to:

Energy (BTU/hr) = 1.08 x [SCFM] x [DELTA T]

By simply knowing the airflow and change in temperature across an oxidizer system, one can begin to quantify the expected energy usage of that system.

To carry the analysis a little deeper – one should also know:

- Typical Hours of operation (per year)
- Price of burner fuel (typically Natural Gas or Propane)

Armed with the simplified model of an oxidizer system and the formula presented above, an operator can estimate how much that system is costing them to operate as well as begin to evaluate potential ways of reducing that cost.

The methodology is as follows:

1. Use the formula to calculate the Heat Energy Required to raise the incoming SLA airflow and temperature to the Outgoing Purified Air Temperature.
2. Use the formula to calculate the Heat Energy Required to raise the Combustion Air Airflow and temperature to the Outgoing Purified Air Temperature.
3. Estimate the heat input from the oxidation of VOCs.
   A table of the Heat of Combustion from some common VOCs is included here:

Compound	Heat of Combustion (BTU/lb)	Compound	Heat of Combustion (BTU/lb)
Acetone	13,228.92	Methyl ethyl ketone	14,490.00
Ammonia	11,435.29	Methylene chloride	2,265.88
Benzene	18,053.08	Mineral spirits	16,363.64
Butanol	15,533.51	Phthalic anhydride	9,547.30
Carbon Monoxide	4,368.86	Propane	21,662.05
Ethane	21,895.19	Propylene	21,037.07
Ethyl acetate	11,122.81	Styrene	18,122.72
Ethanol	12,819.13	Toluene	18,252.04
Ethylbenzene	17,813.21	Turpentine	16,857.14
Methane	21,577.50	Vinyl acetate	10,423.26
Methanol	9613.13	Xylene	17,725.00

4. The remaining balance of heat input is an estimate of what is required from supplemental fuel.

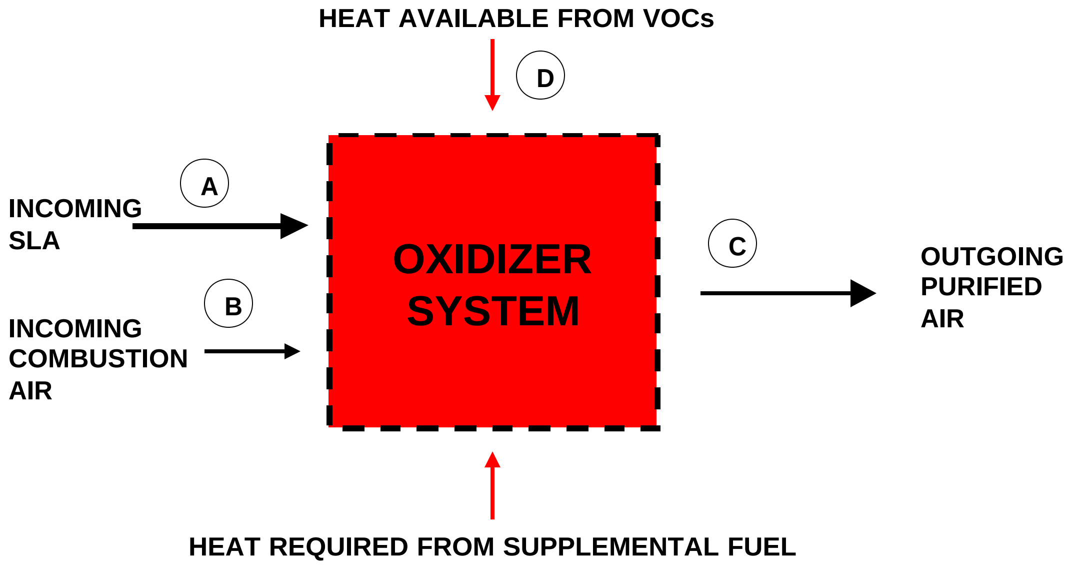
Let's look at this in practice.

The 'Basic Model' in Practice

We recently received a call from an AIMCAL member company questioning the energy usage of their 6-year-old Regenerative Thermal Oxidizer (RTO) for which the original manufacturer is no longer available. The company representative presented us the following data:

-RTO processes approximately 40,000 SCFM of exhaust air
-RTO processes 500 lbs/hour of VOCs (Main constituents: MEK and Toluene)
-Typical Temperature at the inlet of the RTO is 150 F.
-Stack Temperature is averaging 275 F.
-24/7 operation.
-Natural gas is costing $10/MM BTU.

From just this information we can start to use the 'Basic Model' to determine the expected operating cost for this oxidizer.



Point	Airflow (SCFM)	Temperature (F)		Point	VOC Load (lbs/hour)	VOC Heat Value (BTU/lb)
A	40,000	150		D	500	16,000 (MEK=14,500, Toluene = 18,250)
B	1000	60				
C	41,000	275				

1. Use the formula to calculate the Heat Energy Required to raise the incoming SLA airflow and temperature to the Outgoing Purified Air Temperature.

   Energy Required = 1.08 x 40,000 x (275-150) = 5.4 MM BTU/hr

2. Use the formula to calculate the Heat Energy Required to raise the Combustion Air Airflow and temperature to the Outgoing Purified Air Temperature.

   Energy Required = 1.08 x 1000 x (275-60) = 0.23 MM BTU/hr

We'll pause here for a minute to discuss the economics of what we've calculated so far. Essentially, if you consider the oxidizer as a very basic 'system', the heat input required to raise the combined inlet airflow from close to 150 F to the exit temperature of 275 F has been calculated to be approximately 5.6 MM BTU/hr. Multiplying this by the hours of operation per year and the average cost of Natural Gas shows:

Yearly Natural Gas Cost = 5.6 MM BTU/hr x $10/MM BTU x 8400 hours/year
= $470,400.00 per year!

The reason we paused here is because the representative did report that the company spent approximately $460,000.00 per year in natural gas usage to operate this system.

However, we have not yet calculated the heat contribution from the VOCs being processed.

3. Estimate the heat input from the oxidation of VOCs.

Heat Available from VOCs = 500 lbs/hr x 16,000 BTU/lb
= 8.0 MM BTU/hr

This calculation shows that the Heat Available from the Oxidation of the expected VOC loading should be more than enough to provide the total heat required by this RTO system! With that much available heat from the Oxidation of VOCs, this system should theoretically be able to sustain its operating temperature without the need for additional burner heat at all.

Alarm bells should be going off here. Given the data we have been provided to this point there is close to a one-half million dollar per year discrepancy in the operation of this oxidizer system. It is absolutely worth the time in this case to do further analysis of the system. In this particular example, data on VOC loading, airflow rates and temperatures need to be checked for accuracy. A more formal operating analysis including radiant and convective heat loss of the system, moisture content in the SLA, the heating value of the natural gas at the chamber control temperature, etc. is in order.

This example was picked to illustrate how an oxidizer end user can use this simplified model of an oxidizer to determine approximately how much their oxidizer should be costing them to operate. As shown, one can establish a range of operational costs with and without the contribution of VOCs and determine whether a particular system falls with in that range. It can also be a good indication of when one might want to bring in outside help to analyze the situation further.

OXIDIZER OPTIMIZATION

The presentation will discuss case studies of how oxidizers have been retrofit for increased energy efficiency. The ‘basic model’ presented in this abstract will be used to analyze the potential opportunity for savings with each of the retrofits discussed.

Cases to be presented:

- Improve Primary Heat Recovery and Preheat Combustion Air – Thermal Recuperative Oxidizer
- Improve Primary Heat Recovery – Thermal Recuperative Oxidizer
- Improve Primary Heat Recovery – RTO
- Supplemental Fuel Injection to Eliminate Combustion Air in an RTO
- Secondary Heat Recovery at the discharge of a Catalytic Recuperative Oxidizer to preheat process dryer supply
- Secondary Heat Recovery at the discharge of an RTO
- Economizer added to Catalytic Recuperative Oxidizer to preheat Boiler Feed Water