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Thermal Oxidizers – Were They Ever a Panacea for VOC Control?

ABSTRACT

The efficiency with which thermal oxidizers destroy the broad spectrum of organic gases has made them the definitive technology for reducing emissions of volatile organic compounds. So enamored has been the air pollution control community that their undesirable environmental properties have been ignored, are not fully characterized and seldom, if ever, considered in development of air pollution regulations. This seeming indifference is an unintentional consequence of the U.S. Environmental Protection Agency's programs wherein individuals and teams were assigned responsibilities on a pollutant by pollutant basis. In their zeal to reduce their assigned pollutant, the potential effect on other pollutants was largely unexplored. It's now clear that a more holistic approach is needed before healthful air will be available to all citizens.

ARTICLE

After its founding by the 1970 Clean Air Act, the U.S. Environmental Protection Agency immediately focused on reducing emissions of three health-related, non-cancerous pollutants whose plumes could often be traced for miles across the sky. Referred to as "criteria pollutants" because they meet specific health-related criteria specified in the Act, particulate matter, sulfur oxides, and nitrogen oxides were the target of the first regulatory programs. Carbon monoxide and hydrocarbons, the two other criteria pollutants (lead was added to the list years later), are usually invisible and less alarming to the public.

Listing of "hydrocarbons" as a criteria pollutant was odd in that it did not meet the criteria. It was, however, to be the means for reducing ambient ozone, a pollutant that should have been (and later was) listed. Ozone is unique in that there are no significant man-made sources. It is formed in the atmosphere as the reaction product of two other air pollutants, organic gases and nitrogen oxides. Early atmospheric science indicated ambient ozone concentrations were more sensitive to changes in the availability of the organic precursor; ozone could be reduced by limiting availability of the organic reactant. Perhaps "hydrocarbons" was listed to focus attention on the avenue for reducing ambient ozone. Whatever the reason, "hydrocarbons" was later acknowledged inappropriate for the near-limitless variety of organic gases that can react to form atmospheric ozone and replaced by the more inclusive "volatile organic compounds" or VOC.

It was not until early drafts of the 1977 Amendments to the Act made clear that Congress considered ozone reduction a priority that EPA established a program to reduce VOC. Minor reorganizations were made within the Agency in 1976 to provide the budget and labor for developing appropriate VOC-limiting regulations.

Those charged with limiting VOC emissions found that gas-fired thermal oxidizers easily destroy 95% and more of the VOC delivered to them. They require little labor and can be monitored for compliance simply and cheaply. Those charged with reducing VOC emissions quickly accepted thermal oxidizers as the best means for control. The simple and relatively inexpensive compliance monitoring procedure (maintain a minimum firebox temperature) endeared them to State enforcement officials and helped gain their acceptance by the user.

In those early days of environmental concern, the Nation's bountiful supply of clean-burning natural gas was viewed as the solution to a number of environmental problems. In addition to its reputation as the pinnacle control technology for reducing VOC emissions, power plants were urged to convert both oil and coal-fired boilers to a "dual-fuel" capability that would allow firing with natural gas to reduce the nitrogen and sulfur oxide emissions characteristic of the heavier fuels. Natural gas was also considered by many as a practical replacement for gasoline as a motor fuel. The enormous quantity of natural gas that would be required to serve either the power industry or as the motor fuel is testimony that future shortages were then unimaginable.

In developing a rule for an industry, the EPA examines "regulatory alternatives," or optional technologies for reducing emissions of the targeted pollutant. The control system that provides the greatest reduction becomes the basis for a rule unless its cost-effectiveness ratio (\$ per ton of emission reduction) exceeded some previously determined value. Thermal oxidizers met the cost-effectiveness ratio partially because the prevailing low cost of natural gas reflected its seemingly inexhaustible supply. As a result, the Agency crafted a number of regulations for which thermal oxidizers were (and are) the only means for achieving the high destruction efficiency demanded by the rules. With time, they became the near-universal basis for a variety of regulations for VOC (or its subset of hazardous air pollutants, HAP) including those intended to achieve "best available control technology" (BACT), "lowest achievable emission rate" (LAER), "maximum available control technology" (MACT), and "prevention of significant deterioration" (PSD).

This fixation on high destruction efficiency by those responsible for reducing emissions of VOC and HAP, coupled with the complexity of quantifying adverse environmental effects, limited any interest or ability in contrasting the pros and cons associated with proliferating thermal oxidizers. In hindsight, by assigning responsibilities on a pollutant-by-pollutant basis, the Agency appears to have unintentionally blinded the environmental community to any disadvantages associated with their use. This is reflected in the near absence of speciated data on emissions from thermal oxidizers. Inquiries to three State agencies revealed surprisingly little emission data beyond the initial performance test of VOC destruction efficiency required shortly after startup. It seems rather remarkable that so little information is available on emissions from this mainstay of air pollution control technology.

Today, almost thirty years since VOC reduction programs began, it is still unclear that the Agency has developed a broader means for examining what might be referred to as the “benefit ratio” of regulatory alternatives. “What new pollution is introduced if a regulation requires a specific control technology be used?” “How will a regulatory alternative effect the total emissions of all air pollutants?” “What will be the effect on cross media pollution (air, water and solid waste)?” Admittedly, determining these would be difficult, but the approach would be a dramatic improvement over concluding the acceptability of a regulation based merely on the cost-benefit associated with the targeted pollutant. Regulatory alternatives should be compared by summing the post-control emissions from both the targeted source and each of the various control devices appropriate for the pollutant. It may well be that a less stringent standard that permits use of a cleaner control technology is overwhelmingly to the benefit of the environment. To continue to ignore the control device as a source of pollution perpetuates a false basis for evaluating the effectiveness or desirability of a regulation. At some point, an even more thorough examination of regulatory alternatives should quantify second-generation environmental abuse such as water consumption and contamination, consumption of non-renewable resources, and the environmental cost of exploring, drilling, refining and delivering fuel used by the control system.

During the three decades since the EPA was formed, more sophisticated tools for examining air pollution and its effects reveal the Nation’s air pollution problems are far more complex than initially envisioned. Contrary to earlier premises that the most economical means for reducing ambient ozone is to reduce the availability of VOC in the atmosphere, we now know that in many locales, background levels of VOC are so high that ambient ozone is more sensitive to changes in nitrogen oxide than VOC. John Bachmann, Associate Director for

Science, Policy and New Programs in EPA's Headquarters in North Carolina, wrote in the December, 2003 edition of EM Magazine that the Agency is "rethinking" conventional wisdom concerning ozone. He noted "The realization that natural sources (trees, plants, crops, etc) contribute significant amounts of volatile organic compounds on a regional scale meant that the focus of regional ozone control needed to be weighted heavily toward man-made sources of nitrogen oxides, and not "nonmethane hydrocarbons"" (intended as a synonym for VOC).

Yet, the Agency appears not to have taken that into consideration in a recent rule-making for ethanol manufacturers. Shortly after passage of the 2003 Agriculture Bill which requires doubling of the ethanol content of gasoline, EPA (reportedly spurred by the Sierra Club), imposed a regulation on ethanol plants that requires very high destruction efficiency of certain VOC that are hazardous air pollutants (HAP). Applicable to both new and existing plants, the level of control excludes all but thermal oxidizers as the control option.

Was mandating thermal oxidizers wise on the part of either the Agency or the Sierra Club? Requiring installation of thermal oxidizers was tantamount to requiring natural gas as a raw material for manufacturing ethanol. One major reason Congress mandated ethanol as a component of gasoline was to reduce the Nation's dependence on foreign oil since ethanol, made from corn, is a domestically renewable resource. As detailed below, requiring natural gas in the manufacture of ethanol may, at the very best, merely make our energy needs hostage to a different mix of foreign countries.

Further, since one would expect most ethanol plants to be located near cornfields, the source of their primary raw material, many are likely in rural regions where background levels of biogenic VOC are high. If true, the "man-made" nitrogen oxides released by the thermal oxidizers would tend to exacerbate ozone, exactly the circumstance described by Mr. Bachmann.

The Agency's science appears to be outpacing its application in practice. Many of the estimated 300 thermal oxidizers now in service are likely located in air basins where NOx emissions would increase ambient ozone.

It also could be easily argued that regulations that directly or indirectly demand installation of thermal oxidizers are inconsistent with the will of Congress. In Section 112 of the Clean Air Act Amendments of 1990, Congress instructed the Environmental Protection Agency to develop standards for hazardous air

pollutants that require “*the maximum degree of reduction in emissions of the hazardous air pollutants ... (including a prohibition on such emissions, where achievable) that the Administrator, taking into consideration the cost of achieving such emission reduction, and any non-air quality health and environmental impacts and energy requirements, determines is achievable for new or existing sources*”

Clearly, the Agency’s new-found concern over release of man-made NO_x in rural regions would suggest there are air quality health and environmental impacts associated with mandating use of thermal oxidizers in certain geographic areas. One could also conclude that Congress properly foresaw the Nation’s significant decline in domestic sources of fuel when it specified “energy requirements” and the “cost of achieving” as two of four considerations that would justify tempering the stringency of a standard. Today, it is now clear that both the cost and availability of natural gas should be considered before promulgating a standard that requires thermal oxidizers. Further, it would appear in the Nation’s best interest to revisit past regulatory decisions to quantify their present cost-effectiveness ratios, energy requirements, adverse environmental impact and low-energy alternatives as detailed below.

Fuel Cost, Consumption, and Availability

At a typical historical price for natural gas of \$3.00 per thousand cubic feet, a thermal oxidizer treating 50,000 cfm of contaminated air at very high thermal efficiency burned about a quarter of a million dollars worth of natural gas annually. In the last two years, the price of gas climbed to \$6, peaked briefly at \$10, returned to the \$6 level but was projected to be up again to \$7.50 this winter^{[1][1]}. These higher costs were not used in calculating the Agency’s original cost-effectiveness ratios. At these higher prices, the fuel required for the 50,000 cfm thermal oxidizer would cost from \$500,000 to \$850,000 annually.

As serious as is the increase in fuel cost, that consideration pales when one looks at America’s current energy challenges. Just as 40 years ago the United States grew dependent on foreign sources of oil, we now are on the threshold of dependency on foreign gas. In testimony before Congress in June, 2003^{[2][2]}, Alan Greenspan, Chair of the Federal Reserve, in noting the decline in domestic and Canadian production, warned that manufacturing plants and other businesses dependent on gas could close because of tight supplies and price increases. Some already have, he observed.

In November 2003, Knight Ridder Newspapers reported that the US is approaching the end of an era in its ability to produce natural gas. According to the article^{[3][3]}, the US has turned to the Republics of Trinidad and Tobago as potential suppliers of liquefied natural gas, explaining that during the last several months, most shipments of LNG destined for Spain were rerouted to the US. Spain is 16 days away by tanker, the US, only 8. “Shipments to the US also command a higher price,” according to the article. Earlier in 2004, Knight Ridder Newspapers^{[4][4]}, reported a revolt in late 2003 against the Bolivian government’s plans to export natural gas to the United States resulted in almost 60 deaths and removal of the President.

To economically transport natural gas by sea it first must be liquefied by cooling to less than minus 170 F. The tankers must be able to maintain the cryogenic temperature and special offloading facilities are required that can gasify the cryogenic liquid. Greenspan warned that the infrastructure necessary to import liquefied natural gas in quantity do not now exist and construction should be started on all three coasts. Clearly, the cost of gas will increase as we turn to offshore sources. The only question is, how much?

Perhaps more to the point, how much longer can the U.S. with less than five percent of the world’s population continue to outbid the energy needs of rest of the world? How much longer will less-developed countries permit us to bid when over 20 percent of the world’s population has no access to the energy services that modern society takes for granted^{[5][5]}?

Since a typical thermal oxidizer is reported to burn enough gas to heat almost 1500 homes and the equivalent of about 300 such systems are now operating, their total fuel demand would heat a city with a population of over one million. With availability decreasing (and price already increasing, as homeowners experienced last winter), it would seem prudent to harbor remaining domestic supplies for use in homes across the Nation.

Still another reason to question the use of thermal oxidizers is the increasing world-wide concern about global warming that has focused attention on carbon dioxide, a greenhouse gas whose atmospheric concentration set records during the winter of 2003^{[6][6]}. Fascination with the extremely high destruction efficiency of thermal oxidizers fades even more when one realizes their efficiency in reducing VOC is almost overshadowed by their efficiency in producing carbon dioxide. About 80 percent of the carbon dioxide released by a thermal oxidizer is a product of fuel combustion (more than four times that created by oxidation of the pollutant), almost two tons of CO₂ per ton of natural gas burned.

A Low-Energy Alternative

The confounding realities detailed above provide multiple reasons for air pollution control agencies to revisit past perceptions that thermal oxidizers are the ideal VOC (or HAP) control system. This is especially true as the pollution-control community, slowly, it seems, gains increasing confidence in an alternative oxidation technology. Depending on the organic pollutant, biological oxidation can sometimes compete with thermal oxidizers in VOC destruction efficiency, yet place no direct demand on the Nation's reserve of fossil fuel. These air pollution control systems use microbial populations indigenous to backyard compost piles to catalyze the oxidation of VOC. Although often somewhat less efficient than a thermal oxidizer (especially in treating the larger and more complex organic molecules), the tradeoff is significant in that they operate almost energy free, requiring only enough heat to raise inlet gas temperatures to a typical summer temperature of about 85F. Because of the low operating temperature, there are no nitrogen oxide byproducts, CO₂ emissions are a small fraction, perhaps 20% of that from a thermal oxidizer, and their meager energy requirements both save fuel and fuel costs but also avoid the environmental costs associated with producing, refining and delivering the fuel required by a thermal oxidizer.

Biological processes (used since biblical times for fermentation and leavening) have been used for over half a century to reduce odors, often VOC air pollutants that can be objectionable at concentrations of a few parts per billion. Over the last couple of decades, pharmaceutical and chemical industries have begun using microbes to catalyze chemical reactions. Over the same period, a number of companies have explored the use of microbes to meet VOC regulations. The results of that pioneering work are slowly making inroads into the market for VOC control devices through the efforts of a small number of manufacturers of "biological oxidizers." The following table describes several such installations.

1	2	3	4	5	6
7	8				

1. Screen Printing 1996 37,700 134 ppm TGNMO
alcohols, glycol ethers, acetone, aromatics, aliphatics 97%
2. Wood Products 2001 400,000 54 lbs/hr formaldehyde 97%
35 lbs/hr methanol >90%
3. Lens Coating 1997 3,000 120 ppm proprietary alcohols >90%
4. Press Emissions, Oriented Strand Board
May, 2004 200,000 30 – 75PPM * 42 to 75+%**
*** 0****

1. Application
2. Date of Installation
3. Inlet Flow, ft³/scfm
4. Inlet Concentration, PPM
5. Pollutant Species
6. Control Efficiency
7. Energy Consumption
8. NOX and CO₂ Contribution

*For unknown reasons, this new OSB plant continuous press has had less than half the methanol, formaldehyde and total VOC emissions typical of the industry (or for which the bio-reactor was designed. Emissions are a function of the wood (pine or aspen/popular) and which type and amount of resin used for binding the board; conventional liquid phenyl- formaldehyde (P-F), a newer melamine-urea-phenol-formaldehyde (MUPF) resin or medium density isocyanate (MDI), which shows the lowest emissions.

** Operating in compliance with all numeric (PPM and lb/hr) emission limits.

*** Power to operate pumps only.

**** The CO₂ value is not absolute, but rather above stoichiometric with the inlet VOC due to biological oxidation. Values are generally a fraction of the CO₂ emissions from thermal oxidizers because of the CO₂ formed from the fuel required to raise the emission stream to 1500 F. Low quantities of NO_x in the press exhaust are actually reduced by about 50% by the bio-reactor.

For the host of reasons described above, both government and industry, mindful that environmental challenges will demand resources for the foreseeable future (20, 50 or 200 years, depending on one's personal perspective), should join forces to fully exploit Nature's natural renewable oxidizers. Biological oxidizers are most efficient and can compete with thermal oxidizers in destroying water-soluble, low molecular weight organics such as the formaldehyde, methanol, ethanol and acetaldehydes released by ethanol plants). Under worst-case conditions where the inlet VOC consists of a few hundreds of parts per million of predominantly large, complex, water resistant compounds such as naphthalenes, the destruction efficiency could average as little as 80 to 85 percent. Efficiencies also decline when inlet concentrations are low as shown in the chart above. Yet, a look at what a biological oxidizer brings to the union of industry and government is instructive! No direct fossil fuel is necessary, the inlet gas need be warmed (or cooled) to only about 85 F, the carbon dioxide formed is minimal (essentially stoichiometric with the inlet VOC), and the reaction temperature is too low to produce NO_x

A serious investigation of the performance of biological oxidizers might persuade that the reduction in destruction efficiency of a few percent is more than offset when viewed in combination with emissions (or lack thereof) from the control device. Biological oxidation is especially suited for destruction of water soluble, low molecular weight compounds such as those emitted by the ethanol industry.

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[1][1] The Associated Press as published in the Raleigh News and Observer in the Summer and Winter of 2003 (June 11 and December 13) and Spring of 2004.

[2][2] The Associated Press as published on June 11, 2003 in the Raleigh News and Observer.

[3][3] Knight Ridder Newspapers as published in the Raleigh News and Observer on November 3, 2003.

[4][4] Knight Riddre Newspapers as published in the Raleigh News and Observer on February 6, 2004.

[5][5] ExxonMobil's magazine, The Lamp.

[6][6] The Associated Press as reported in the Raleigh News and Observer, March 21, 2004