Dollars and Sense: Boiler Tuning as a Best Management Practice

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Abstract

The Industrial, Commercial, and Institutional (ICI) Heater and Boiler Maximum Achievable Control Technology (MACT) Rule 40 CFR 63 Subpart DDDD (MACT DDDDD) requires that affected facilities conduct combustion tune-ups on applicable heater and boilers to improve emission performance. Heater and boiler tuning has been described as the application of science and engineering to optimize the equipment operational characteristics within the constraints of process operations. For the practice to be sound, it must be based on accurate and representative flue gas measurement.

Results derived from tuning combustion units at numerous facilities demonstrate that there are cost savings from the tune-ups routinely exceeding the cost of performing the annual, biennial, and 5-year tune-ups. For example, improved combustion efficiency in units rated between 150 and 200 MMBtu/Hr have realized an average annual fuel savings of around $57,950 from the MACT DDDDD compliance demonstration. Even more promising are the findings relative to the potential cost savings associated with full optimization of the combustion settings for a heater or boiler. For combustion sources with room for further improvement beyond MACT DDDDD compliance, unrealized fuel cost savings may be as high as $110,000 annually per source. The purpose of this paper is to highlight the benefits boiler tuning as a best management practice, while at the same time optimizing combustion efficiency mandated in the MACT DDDDD tune-ups.

Introduction

The Environmental protection Agency (EPA) was founded in 1970 to set and enforce rules that protect the environment and control pollution. Since then, industry has spent billions of dollars annually to reduce the overall impact of their operations on the environment. Companies have committed to sound environmental stewardship practices and shown a willingness to comply with an expanding list of regulatory requirements (e.g. Maximum Achievable Control Technology (MACT), Generally Achievable Control Technology (GACT), New Source Review (NSR), Benzene Waste Operations NESHAP (BWON), etc.) at federal, state, and local levels of government. There are four interrelated combustion source rules that have the potential to be triggered by industrial combustion sources, including:

- 40 CFR 241 - Solid Wastes Used as Fuel or Ingredients in Combustion Rule;
- 40 CFR 60, Subparts CCCC and DDDD – Commercial and Industrial Solid Waste Incineration (CISWI) Rule;
- 40 CFR 63 Subpart JJJJJ – Area Source Heater and Boiler GACT Rule; and
- 40 CFR 63 Subpart DDDDD – Major Source Heater and Boiler MACT Rule.

Under federal rules, a major source facility under the MACT DDDDD rules is defined as a facility that emits greater than 10 tons/year of a single hazardous air pollutant (HAP), or 25 tons/year of total HAPs. Combustion units at these facilities are those that have a (1) heat input capacity greater than 10 MMBtu/Hr, (2) do not implement an oxygen trim system, and (3) are not permitted for limited use (annual operation <876 hours) are subject to annually recurring tune-ups.

The focus of this paper relates to the tune-up work practice standard under MACT DDDDD, which requires routine tune-ups for affected major source facilities that includes gas-fired heaters and boilers, and specifically Gas 1-fired sources (natural gas, refinery fuel gas, etc.). Significant operational information has been collected for a variety of process heaters, hot water boilers, and steam generating boilers. Nearly four years of data from tune-ups conducted on 583 combustion sources of various makes, models, and sizes have been used to evaluate cost savings (actual and potential) that combustion tuning and optimization provide relative to fuel consumption. Although there are data available for solid- and liquid-fueled boilers to substantiate the monetary value of the tune ups, the focus for this study is on Gas 1-fired combustion sources.

While MACT DDDDD is designed to reduce emissions, this paper focuses on economic value of boiler tune-ups. Here, we find a rare circumstance in which implementing a regulatory requirement can provide a significant payback due to annualized energy cost savings while also resulting in a reduction a facility’s environmental footprint.
Conducting the MACT DDDDD Tune-Up

The MACT DDDDD Rule applies only to combustion sources that meet the definition of a boiler or process heater. In the Rule a boiler is defined as “an enclosed combustion device, using controlled flame combustion and having the primary purpose of recovering thermal energy in the form of steam or hot water” and a process heater is defined as “a combustion device in which combustion fuels do not directly contact the process materials, or process gas in the combustion chamber (i.e. indirect fired).” While the initial tune-ups were required to be completed before January 31, 2016, recurring tune-ups must be completed on the following schedule:

- Annually (within 13 months) thereafter for units >10 MMBtu/Hr
- Biennially (within 25 months) for units >5 MMBtu/Hr and <10 MMBtu/Hr
- Every 5 years (within 61 months) for units <5 MMBtu/Hr, OR meet the definition of limited use, OR meet the criteria set forth for an O2 trim system.

The EPA defines a tune-up as “the act of reestablishing the air-to-fuel mixture for the operating range of the heater or boiler. Oxygen and unburned fuel (carbon monoxide is usually the indicative measurement) are balanced to provide safe and efficient combustion. The primary goal of a combustion tune-up is to improve combustion efficiency” (EPA Boiler Tune-Up Guide). For the purpose of MACT DDDDD, EPA has established basic tune-up requirements for any combustion source, which are as follows:

- Visual inspection of the burner and burner assembly, including burner flames, tips, tiles, and pilots; if the visual inspection of the burner indicates plugged tips, or burner wear causing inefficiency, those deficiencies are to be noted and subsequently repaired;
- Visual inspection of the air registers and louvres to ensure that the air intakes are free of debris and obstruction and that the louvres are functional;
- Inspection of the main fuel control valve and header;
- Prior to tuning, measure the flue gas temperature, O2, CO, and NOx emissions at boiler or heater at high fire, or typical operating load;
- At the same load conditions, adjust the primary air register louvres to obtain the lowest practical flue gas O2, CO, and NOx, or otherwise re-establish the combustion conditions recommended by the burner manufacturer without significant impact to heater or boiler draft pressure (Note: Where heaters or boilers have multiple burners, each burner must be evaluated, adjusted, or tuned).

These basic tune-up requirements provide the basis for combustion unit tune-ups, but there are other important activities integral to the compliance demonstration that increase the value of the tune-up. These activities include a preliminary review of piping and instrumentation diagrams and manufacturer engineering specifications, which is important to understanding equipment and process configurations. Communication and coordination with operations staff ensures a clear understanding of the heater or boiler operating characteristics based on actual process needs and use. This active communication ensures that both safe boiler operation and required heat-rate production are not negatively impacted by the tune-up. Operations staff also assist by conducting a pre-tuning inspection of the unit to verify an appropriate sample port exists in an optimal location and to determine if burner air registers, louvres, stack dampers, and fans are functioning properly. Therefore, operators provide invaluable field support and operational information during the tune-up activities.

Although many facilities believe their boilers are operating optimally, extensive tuning efforts performed under the Boiler MACT work practice standard have revealed this is not always the case. For example, we find that many units are operated under high excess O2 firing conditions or utilize low-NOx burners. The design of these burners can potentially create high (and sometimes unmanageable) CO emissions when the operator attempts to lower the excess O2. We have frequently observed...
that air control systems (combustion air dampers, air louvres, and primary air registers in burners) or induced-draft fans are inoperable. As a result, the boiler tune-up is difficult and, in extreme cases, not possible. In other cases, a facility's process control system has logic setpoints that preclude true optimization of a heater or boiler.

Ensuring an accurate and representative measurement of flue gas is most critical to the tune-up process for the purposes of the compliance demonstration and calculating efficiency improvements between pre- and post-tuning conditions. Locating or installing a dedicated sample port above the breeching but below the stack damper ensures flue gas analysis is representative of both stack emissions and combustion characteristics in the radiant and convection sections of the heater or boiler. Another important aspect of flue gas measurement is being able to verify that data collected with the flue gas analyzer is accurate.

While each portable combustion analyzer is calibrated prior to use and can be recalibrated in the field with a zero check, it is also important to use a common-sense verification process in the field to identify any sensor discrepancies. This typically begins with a comparison of the $O_2$ readings of the flue gas analyzed relative to the $O_2$ readings at the local stack meter (see note below). If the unit has an $O_2$ CEMS, it can provide a good crosscheck that the combustion analyzer is functioning properly, since the CEMS requires regular and frequent calibration. Comparing temperature data between the combustion analyzer and the in-line stack monitor is also relevant because the combustion analyzer uses temperature to estimate efficiency.

Finally, flue gas data collected during the preliminary run can be used to manually calculate combustion efficiency. If data are not comparable between the combustion analyzer and the manual efficiency calculations, it may indicate a problem with the testing equipment and the need to resample.

Other common discrepancies can occur due to the location of the sample port relative to the $O_2$ meter, or failed seals on the ductwork introducing dilution air into the system in cases where fans or an economizer is utilized. This simply affirms that the location of the $O_2$ measurement during a test is important.

Note: The portable combustion analyzer uses a condensate trap to obtain $O_2$ measurements on a dry basis, whereas the local stack $O_2$ meter measures on a wet basis. Here an interpolation table, based on the stoichiometric properties of the fuel type (e.g. methane is used for the interpolation of natural gas), is necessary to verify accuracy on the wet-to-dry basis.

### Boiler Tuning as a Best Management Practice

As stated above, the MACT DDDDD tune-up focuses on improving the combustion efficiency of the boiler or process heater. Therefore, true burner optimization, based on actual operating loads, conditions, and process variability is overshadowed by the goal of the compliance demonstration. This point is important to understanding the cost savings data gathered for this evaluation. In most cases, actual tune-up results do not represent maximum optimization of the combustion source that was tested, but are simply a demonstration that tuning effectively improved efficiency and reduced CO emissions by making minor adjustments to the air-to-fuel ratio. Because of this, potential cost savings from tuning as well as truly optimized boiler operation have also been evaluated in this study.

### Calculating Actual and Potential Cost Savings

Tune-up data used to calculate actual and potential cost savings from the MACT DDDDD compliance demonstration has been compiled over the course of nearly four years from 583 Gas-1 type combustion sources located at almost 50 facilities nationwide. It should be noted that this study is specifically focused on highlighting cost savings related to combustion efficiency only. Therefore, thermal efficiency, radiant heat loss, or steam leaks (for example), while all valid considerations for
evaluating overall system efficiency, have been excluded from these results.

**Calculating Cost Savings from Actual Tuning Adjustments**

To calculate actual savings generated after a tune-up, the following equation was used:

\[
\text{Savings After Tuning} \left( \frac{\$}{\text{yr}} \right) = (\text{Final Efficiency (\%)} - \text{Initial Efficiency (\%)}) \times \text{Natural Gas Price} \left( \frac{\$}{\text{MMBtu}} \right) \times \text{Source Heat Rate} \left( \frac{\text{MMBtu}}{\text{hr}} \right) \times \left( \frac{\text{hr}}{\text{day}} \right) \times \left( \frac{\text{day}}{\text{yr}} \right)
\]

The results of this equation yield a total dollars/year ($/Yr) savings that is dependent on the price of natural gas. This equation can similarly be applied to other fuels using the known costs for the specific fuel.

**Potential Savings from Additional Tuning to Optimal Excess O_2 Range**

While actual savings are calculated using real data from a tune-up, potential savings are calculated using some general assumptions. The goal of conducting the MACT DD/DDDD tune-up is to minimize CO emissions by improving the operational efficiency of the combustion source. For the purposes of evaluating potential savings, a range of 3-5% excess O_2 (dry basis) is assumed as the optimal range for safe, practical, and efficient combustion. While this range is considered optimal, it is recognized that several factors may limit a specific combustion source to attain such a range, including: operational and process constraints, age of the combustion source, and variable quality of the fuel (e.g. refinery fuel gas). Because MACT DD/DDDD only requires that an improvement be made, excess O_2 is not always reduced to the ideal range during the tune-up. For some units, this means there are still potential fuel savings to be gained by additional tuning adjustments.

To calculate values for potential savings, the previously mentioned optimal range of 3-5% O_2 was used as the target level in the assumptions. If units were tuned to an excess O_2 level >5% during the actual MACT DD/DDDD tune-up, potential savings were calculated using a scenario where the source could be tuned down to 5% excess O_2 (the high end of the optimal range). If the unit was tuned to within the optimal 3-5% range during the actual tune-up, potential savings were calculated using the assumption that the source could be tuned further, down to 3% O_2.

To estimate potential improvements to combustion efficiency via additional tuning, linear extrapolations were made, based on the observed relationship between O_2 and efficiency. For example, the baseline O_2 reading for a specific unit was 7.09%, with a combustion efficiency reading (on the portable combustion analyzer) of 55.0% and it was tuned to a 6.53% O_2 reading, with a combustion efficiency reading of 56.0%. To estimate the potential savings from tuning further, down to 5.00% (since the O_2% is >5%) from the post-tuning result of 6.53% O_2, the following calculation was used:

\[
\frac{56.0\% - 55.0\%}{6.53\% - 7.09\%} \times (5.00\% - 6.53\%) + 56.0\% = 58.7\%
\]

Using the potential efficiency at assumed maximum optimization, the total potential savings can then be calculated as follows:
Total Potential Savings at Full Optimization \( \left( \frac{\$}{Yr} \right) \)

\[
\text{Total Potential Savings} = \frac{\text{Potential Efficiency} \ (\%) - \text{Baseline Efficiency} \ (\%)}{100\%} \times \text{Price of Natural Gas} \left( \frac{\$}{\text{MMBtu}} \right) \times \text{Fired Capacity of Source} \left( \frac{\text{MMBtu}}{\text{Hr}} \right) \times \left( \frac{\text{Hrs}}{\text{Day}} \right) \times \left( \frac{\text{Days}}{\text{Yr}} \right)
\]

Cost Savings Results

Cost savings from actual MACT DDDD tune-ups range from $4,191/Yr for Gas 1 sources rated less than 10 MMBtu/Hr up to $57,950/Yr for sources rated between 100-150 MMBtu/Hr. Total potential savings per unit (post-tuning), which represent the sum of the actual savings plus potential additional savings by tuning to the optimized range of 3-5% O\(_2\) indicate a savings from $16,798/Yr for sources rated less than 10MMBtu/Hr up to $107,159/Yr for sources rated between 100-150 MMBtu/Hr. Table 1 provides a summary of actual and total potential savings by source size.

Table 1: MACT DDDD Tune Ups- Actual and Potential Annual Cost Savings

<table>
<thead>
<tr>
<th>Rated Firing Capacity of Source</th>
<th>Number of Units Tuned</th>
<th>Cost Savings from Actual Tuning per Unit ($/Unit-Yr)</th>
<th>Total Potential Savings per Unit ($/Unit-Yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10</td>
<td>45</td>
<td>$4,191</td>
<td>$16,978</td>
</tr>
<tr>
<td>10 &lt; x &lt; 25</td>
<td>85</td>
<td>$7,055</td>
<td>$44,262</td>
</tr>
<tr>
<td>25 &lt; x &lt; 40</td>
<td>73</td>
<td>$12,365</td>
<td>$36,437</td>
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<tr>
<td>40 &lt; x &lt; 80</td>
<td>138</td>
<td>$14,085</td>
<td>$55,598</td>
</tr>
<tr>
<td>80 &lt; x &lt; 100</td>
<td>54</td>
<td>$15,933</td>
<td>$71,053</td>
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<tr>
<td>100 &lt; x &lt; 150</td>
<td>55</td>
<td>$12,229</td>
<td>$25,834</td>
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<tr>
<td>150 &lt; x &lt; 200</td>
<td>28</td>
<td>$57,950</td>
<td>$107,159</td>
</tr>
<tr>
<td>&gt; 200</td>
<td>105</td>
<td>$27,429</td>
<td>$109,733</td>
</tr>
</tbody>
</table>

Simple Payback of the MACT DDDD Tune Ups

While the actual and potential savings observed in Table 1 are averages from all 583 combustion sources tuned over the past 4 years, actual data from two sites is being used to show the simple payback period on the MACT DDDD tune-ups in the case studies below. In these examples, the facility and combustion source information has been anonymized, but realized savings and simple payback (in months) for individual units and the facility are provided.

Case Study 1

A fertilizer plant utilizes two (2) steam boilers and one (1) process heater in their manufacturing process. Each of these combustion sources meets the criteria to be tuned annually based on their size per the provisions in the MACT DDDD Rule. In this case study we see a realized savings of $284,385 per year, with a simple payback period of 0.53 months.
**Table 2: Case Study 1**

<table>
<thead>
<tr>
<th>Unit ID</th>
<th>Rated Firing Capacity (MMBtu/Hr)</th>
<th>Actual Savings ($/year)</th>
<th>Simple Payback Period (Months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-01</td>
<td>227</td>
<td>$188,989</td>
<td>0.26</td>
</tr>
<tr>
<td>B-02</td>
<td>227</td>
<td>$78,745</td>
<td>0.63</td>
</tr>
<tr>
<td>PH-01</td>
<td>40</td>
<td>$16,651</td>
<td>2.99</td>
</tr>
<tr>
<td>Overall Savings &amp; Payback Period</td>
<td>--</td>
<td>$284,385(1)</td>
<td>0.53(2)</td>
</tr>
</tbody>
</table>

(1)—Total Savings; (2)—Average Payback Period

**Case Study 2**

A plastics material and resin manufacturing plant utilizes four (4) boilers in its manufacturing process. Each of these combustion sources meets the criteria to be tuned annually per the provisions of the MACT DDDDD Rule. In this case study we see a realized savings of $268,148 per year, with a simple payback period of 0.66 months.

**Table 3: Case Study 2**

<table>
<thead>
<tr>
<th>Unit ID</th>
<th>Rated Firing Capacity (MMBtu/Hr)</th>
<th>Actual Savings ($/year)</th>
<th>Simple Payback Period (Months)</th>
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<tr>
<td>B-01</td>
<td>417</td>
<td>$72,328</td>
<td>0.61</td>
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<tr>
<td>B-02</td>
<td>417</td>
<td>$101,259</td>
<td>0.44</td>
</tr>
<tr>
<td>B-03</td>
<td>1500</td>
<td>Already Optimized</td>
<td>--</td>
</tr>
<tr>
<td>B-04</td>
<td>1500</td>
<td>$94,561</td>
<td>0.47</td>
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<tr>
<td>Overall Savings &amp; Payback Period</td>
<td>--</td>
<td>$268,148(1)</td>
<td>0.66(2)</td>
</tr>
</tbody>
</table>

(1)—Total Savings; (2)—Average Payback Period

**Limitations of This Study**

It is important to discuss the limitations and other consideration relevant to this study. First, the study is focused on cost savings relative to natural gas use. While facilities with combustion sources firing other fuel types are also capable of gaining tangible energy and cost savings through tuning, additional considerations to calculate energy savings must be made. This is substantiated by Davis et al. who noted that in the mid-2000’s, when energy prices soared, refineries quickly learned that their ability to reduce energy consumption was limited by the amount of refinery fuel gas produced and used, relative to their gas imports.

Secondly, the fluctuating price of natural gas results in savings that are a function of fuel cost; higher savings result when fuel prices increase and savings are reduced at lower fuel cost. This observation can be deceptive, because if a facility is subject to higher natural gas rates, there are savings from improved combustion efficiency, but these are offset by higher natural gas.
costs. Savings estimates were generated using the 12-month rolling average price for natural gas ($3.96/MMBtu\(^5\)). Thirdly, adjustments to combustion air at the register of the fan will affect flue gas temperature, which will, in turn, affect combustion efficiency as calculated by the combustion analyzer.

With respect to data correlating efficiency and excess O\(_2\) for each individual unit, linear extrapolation of potential efficiency is limited at best, particularly where the changes in O\(_2\) are greatest. Efficiency and excess O\(_2\) correlations are not strictly linear, as multiple factors contribute to the combustion efficiency of a fired source, but can be approximated as linear when small adjustments are made. Large changes in the excess O\(_2\) of a heater or boiler will also significantly impact flue gas temperature and flow, as well as air flow at the burners, all of which contribute to unit efficiency, thus leading to non-linear behavior in the correlation.

Due to the complex nature of such large changes to the operational conditions of a heater or boiler, the study could benefit from actual tuning efforts that undergo such large changes and that reach the assumed targets for optimal efficiency, rather than just assuming these targets are the best conditions at which to run the combustion source. Furthermore, detailed efficiency studies on individual units can be used to improve the validity of the extrapolations, as will the growing body of data from the annually recurring MACT DDDDD tune-ups.

Additionally, the DDDDD Rule only requires that the tune-up be conducted at high-fire or typical operating load. If load varies over the course of a process run (to meet specific production needs, for example), the boiler may not operate at optimized conditions throughout the process cycle. In these cases, total potential savings could only be realized by establishing optimal operating parameters at multiple loads, so operators or control systems can adjust the air-to-fuel ratio accordingly.

Efforts to improve combustion source efficiency also require cultural buy-in at the plant management and operations levels to properly evaluate and implement the tune-ups as a Best Management Practice (BMP). Many facilities are already implementing programs to improve efficiency, many of which include combustion efficiency (see ISO 50001 requirements as an example). Inadequate equipment maintenance, production limitations (reduced boiler load), and other operational conditions may limit combustion source optimization, particularly when equipment is idled for periods between usage in a process. It is certainly true that tune-ups conducted as a BMP are more time-consuming and expensive than tune ups for MACT DDDDD compliance; payback from improved efficiency should be calculated based on cost savings relative to truly optimized conditions. Finally, as a true BMP, combustion source tuning should be conducted as part of a larger energy efficiency program that evaluates heat transfer, steam systems, implements routine maintenance (e.g. burners, boiler water systems, refractory, FD/ID fans, steam piping, and ductwork), develops metrics for tracking activities, calculating cost savings, and focuses on safety.

**Conclusions**

Implementation of the MACT DDDDD tune-ups has resulted in overall cost savings to many industrial facilities. A key takeaway from the data is that there are opportunities to improve combustion efficiency beyond the scope of MACT DDDDD, with significant cost savings and payback on tune-up services in months. This study supports the conclusion that even greater cost savings can be realized by implementing heater or boiler tuning at production facilities concurrently with other BMPs such as plant energy efficiency, emission reductions, and operator training. Implementing improved combustion efficiencies reduces a facility’s environmental footprint and aligns with a corporation’s environmental stewardship. Therefore, for corporations that operate multiple facilities in the U.S., or worldwide, implementing a company-wide routine tuning program for its combustion source is a common-sense and fiscally responsible approach.
References


