Johnston Boiler Company Technical Brief

Efficiency Comparison: 4:1 Turndown & 10:1 Turndown

Burner/Boiler turndown has always been a topic of discussion when analyzing boiler loads, operating cycles, and overall boiler efficiencies. As a manufacturer of boilers and burners, Johnston has addressed this issue many times. The purpose of this technical brief is to document a comparison energy loss and the resulting impact on boiler efficiency between a boiler operating at a 4:1 turndown compared to a 10:1 turndown.

Energy Production

This energy analysis will focus on the boiler energy input and losses. A control volume will be used that includes the burner and boiler through the stack. This analysis will not include the electrical and other non-thermodynamic system losses but will focus on only the boiler heat transfer and stack gas losses.

The time frame that we will focus on is 1 hour to 8 hours where the required boiler load is equal to a 10:1 turndown. This means that the energy output required to the system is $1/10^{th}$ of the normal full load demand requirements.

$$\text{Boiler load} = \frac{\text{Boiler full Rate}}{10}$$

The required energy output forms the basis of our analysis. As an example, if the boiler for our analysis were a 1000 hp boiler then possibly, the night time energy requirements would be equivalent to a 100 hp boiler load. If the burner were operated with a 10:1 turndown, it would be able to run all night without being required to shut down. It then follows that for a boiler operating at a 4:1 turndown would have to run for a significantly shorter amount of time to produce the same amount of energy in steam or hot water to the system. The actual time that it would have to operate can be simply calculated by:

$$1hr * \frac{\text{Fullload}\,Btu/hr}{10} = t_{4:1} * \frac{\text{Fullload}\,Btu/hr}{4}$$

Therefore:

$$t_{4:1} = \frac{4*1hr}{10} = .4hr \text{ or } 24\text{min}$$

This means that in order to have the same energy output as the 10:1, the 4:1 boiler setting must operate for 24 minutes out of every hour.

For this analysis, the effects of convection and radiation have been neglected because they will be constant for each boiler. Assuming that the boiler operation requires a specified outlet temperature for the water (or steam) the boiler shell temperature would be constant and the resulting energy loss equal over for this comparison.

Stack Gas Analysis

A Stack gas analysis will be used to evaluate the energy lost during operation for both the 4:1 and the 10:1 operational modes. In the ASME PTC-4 code, the methodology for obtaining the Higher Heating Value (HHV), the combustion products at various O_2 levels, and the enthalpy of the mixtures. The enthalpy is calculated for the mixtures using the JANAF tables. The enthalpy is the basis for this evaluation. By knowing how much enthalpy (or internal energy of a gas mixture), a calculation can be done to evaluate how much energy was put left in the flue gas as it left the boiler. This is done with the following simple equation:

$$\text{Stack Losses} = \dot{m}(h_{out} - h_{in})$$

When operating the boiler at any load, the unrecovered energy can be calculated through this equation.

Prior to starting the burner, the pre-purge cycle requires the fan to push at a minimum 4 air changes through the furnace. During this time there is no heat being added to the system. However, as the air travels through the pressure vessel, it picks up heat from the boiler and energy is removed from the system. With the use of the JANAF tables and the above equation, that amount of energy lost can be calculated.

Similarly, the post purge cycle also forces air through the pressure vessel and this energy loss can be calculated in the same manner.

Operational Differences

An important difference to note between firing at a 10:1 turndown vs. a 4:1 turndown is that the amount of excess air typically used increases dramatically at higher turndown ratios. This is done to maintain good mixing at the burner front and to keep the firing head equipment cool. Flue gas O_2 concentrations used in this analysis were 9% and 5% for the 10:1 and 4:1 turndown cases. It should be noted that often the boilers can be set up for lower O_2 levels, especially at 4:1 and if this is done the resulting energy savings can be even more pronounced.

Study Case

For this paper, we chose a 750 hp firetube water heater firing natural gas. The water heater represents a best case scenario for the heat loss analysis because the stack temperatures for typical operation are much lower than for steam boiler applications. Steam boiler applications will produce an even greater difference between 4:1 operation and 10:1 operation because of the higher stack temperatures.

The water heater outlet temperature was set at 220 °F and the corresponding stack gas outlet temperature is approximately 251 °F at high fire. To calculate exit gas temperatures at the 10:1 turndown, 4:1 turndown, pre-purge and post-purge cases, Johnston Boiler Company's proprietary heat transfer programs were used.

Key Parameters

Purge times:

Pre- Purge	1 Minute
Post-Purge	15 Seconds

Exit Gas Temperature During Purge Times	220 °F
Exit Gas Temperature 4:1	230 °F
Exit Gas Temperature 10:1	224 °F

% Excess Air Levels

High Fire	15%
4:1	28%
10:1	70%

Results

The results are shown in the following Figures

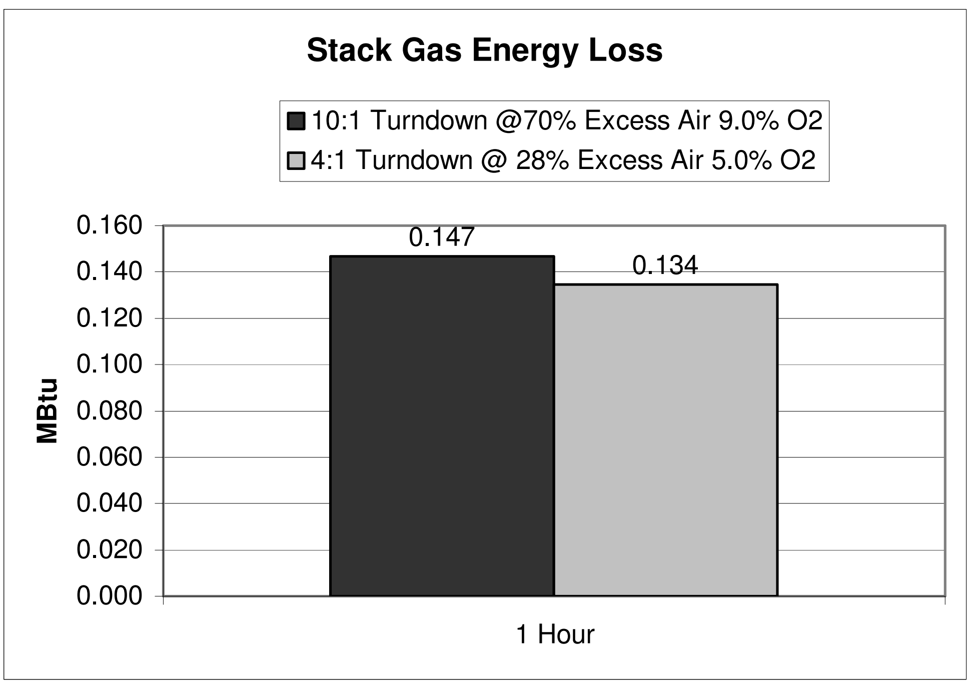
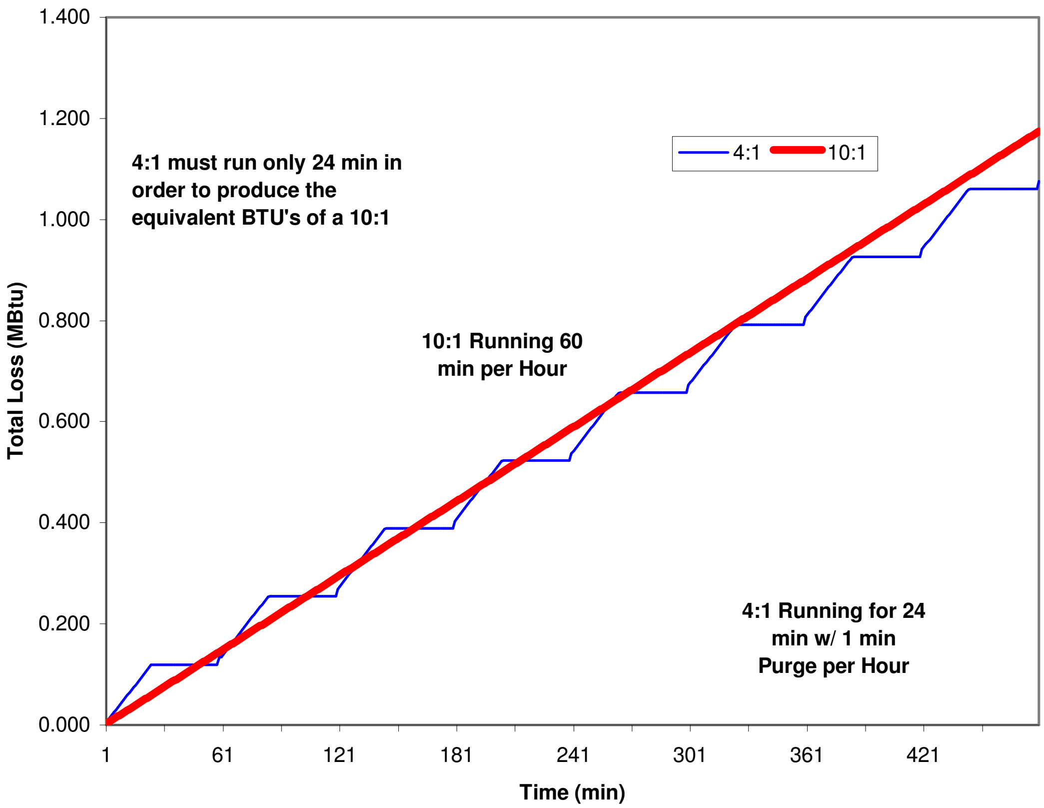


Figure 1 Stack Gas Energy Loss Over a One Hour Time Period

The one hour time comparison between the 4:1 and the 10:1 show that the energy wasted out the stack is higher for the 10:1 case. During the 10:1 turndown operation, hot stack gases are being emitted to the atmosphere for 60 minutes every hour. The 4:1 burner operation allows the boiler to be shut down for 36 minutes every hour. The energy wasted during startup and shutdown have been included in Figure 1 and they do not significantly change the results.

A cumulative analysis of the energy loss over an eight hour period produces some interesting insight into this comparison. Figure 2 shows that for the first hour, the 4:1 looses much more heat than the 10:1 in the beginning. However, as the hour goes on, the 4:1 is turned off and the energy loss is stopped.



Summary The analysis shows, from an energy balance, that the stack gas losses are higher over a period of time for a boiler operated at 10:1 as compared to a boiler operating at a 4:1 turndown ratio.

If the desire is to operate a boiler as efficiently as possible, then there is no advantage to operating to a 10:1 vs. a 4:1 boiler turndown.