



SAMA Symbols White Paper #6 – Oxygen Trim

SAMA Symbols clearly communicate and document how a boiler oxygen trim control loop would work to save money.

Boiler fuel budgets can be reduced with an oxygen trim system. As shown in Figure 1, the economical amount of combustion air is found in a “green” zone between unburned fuel (CO) and excess air (O₂). Not only can operating in this “green” zone save money, it can also reduce smoke stack emissions.

SAMA stands for Scientific Apparatus Makers Association, the organization that came up with the symbolic language to represent the various pieces of control loop hardware and how they interact together to create a process control scheme.

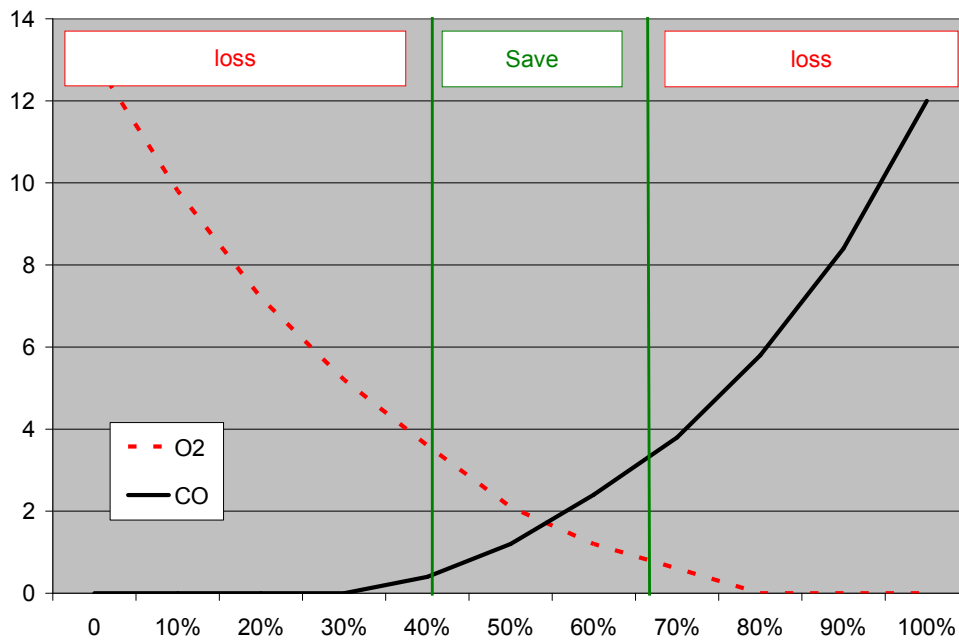


Figure 1

Oxygen losses decrease when less excess air is introduced, however unburned carbon in the form of CO increases with less excess air. There is green zone as shown in Figure 1 where the loss from both O₂ and CO is minimized.



It is important for the process control engineer to use a stack gas analyzer and collect the data for his specific boiler, burners, and fuel. Curves like Figures 1, 3, 4, and 5 need to be created at several steam load points throughout the firing range from minimum to maximum. The author recommends at least ten load points tested both going up in load and down in load. Testing should be done after several days of firing to ensure that the entire thermal mass of the boiler is up to operating temperature. Once the raw data is collected from the field test, the various curves can be plotted. The process control engineer can then illustrate the data and create equations. He can also develop the boiler oxygen trim control loop by using SAMA symbols and fill in the various blocks with the equations.

An oxygen trim system can measure, control, and regulate the amount of combustion air to achieve this green optimized firing zone that saves fuel, emissions and money. Excess combustion air as measured by excess oxygen can waste fuel and money by carrying heat up the stack. Recall that air is 78% nitrogen and that it simply flows through the boiler; first being heated up by an expensive fuel, and then flowing out the stack as wasted Btus. While a certain amount of excess air is necessary, because of equipment mixing limitations and turndown limits, it is important to reduce this to the minimum acceptable level.

Let's look at the full metered, parallel, cross limited boiler firing rate control scheme developed in the previous article. Recall that a full metered system measures both combustion air flow and oil flow. A parallel control scheme is one in which independent controllers regulate the oil and combustion air flow. A cross limited scheme means that the actual oil flow set point and combustion air flow set point are tied together in a safe and conservative ratio with feedback from the opposite measurement. And finally, these controllers are driven by a boiler pressure master that regulates more or less firing.



The boiler firing rate control scheme would look as follows in SAMA symbols in Figure 2.

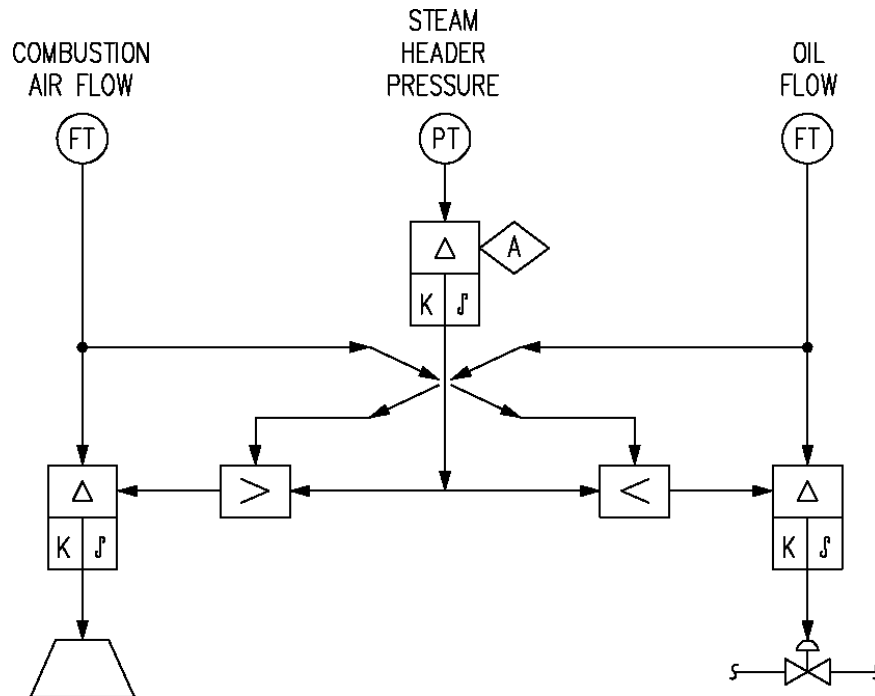


Figure 2

Here we see that the combustion air flow is measured, controlled, and modulated. The air flow signal is also used in a cross limited scheme to constrain the amount of oil that can be burned to the amount of combustion air available. This type of control results in a safe and limited amount of excess air.



Figure 3 shows the fuel flow and combustion air flow that result from this control scheme as a function of percent (%) boiler load.

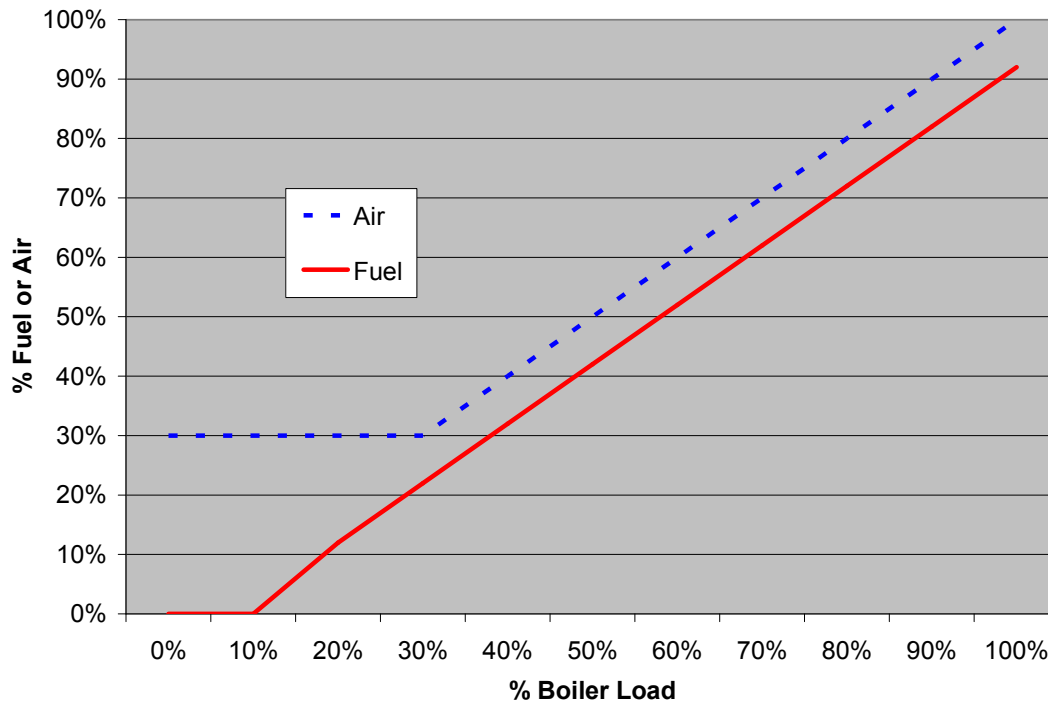


Figure 3

Notice that the combustion air has a fixed minimum flow point and that it is in excess throughout the boiler load range from 10% through 100% resulting in safe operation.

The amount of excess oxygen, and by proxy excess air, is a function of boiler load. The higher the load the more combustion air is required; however the amount of “excess” air is lower because the burner has sufficient flows and velocities to allow for proper mixing. At low loads and low air flow velocities, the fuel and air cannot be mixed fully which is why excess air is required.



The following is a typical chart showing how excess oxygen and hence excess air is diminished as boiler load increases. The blue line of Figure 4 shows oxygen dropping from 5% to 1% as boiler load increases.

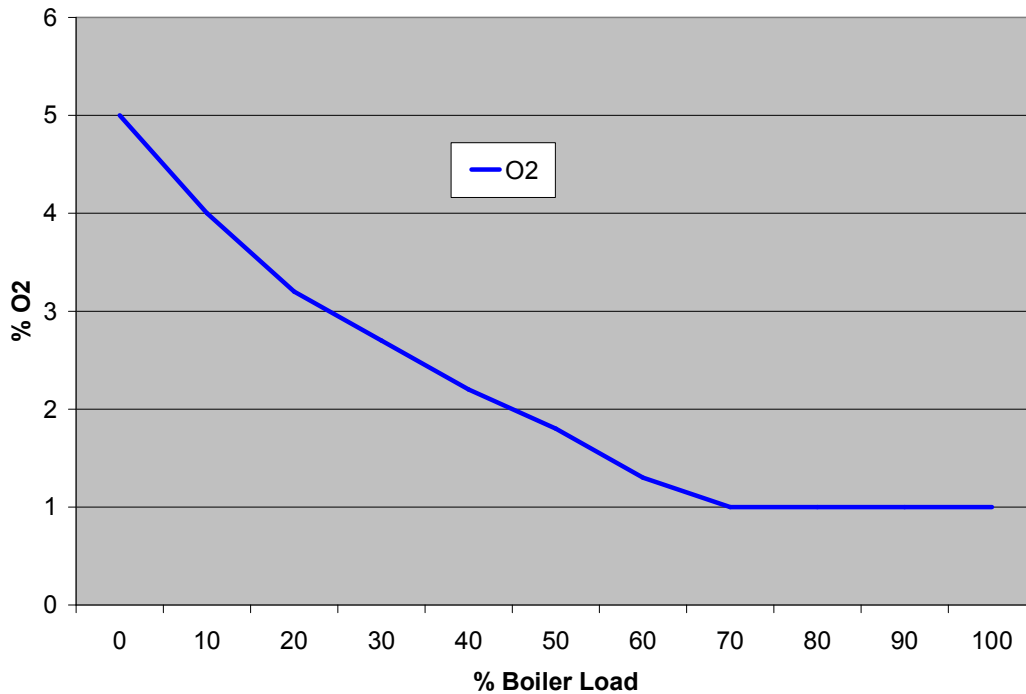


Figure 4

An oxygen control system uses this steam load and boiler load information to trim the amount of combustion air in the upper range.



The following chart in Figure 5 shows the fixed air flow of the combustion control scheme and how oxygen trim can be used to tighten the excess oxygen margin at higher boiler loads.

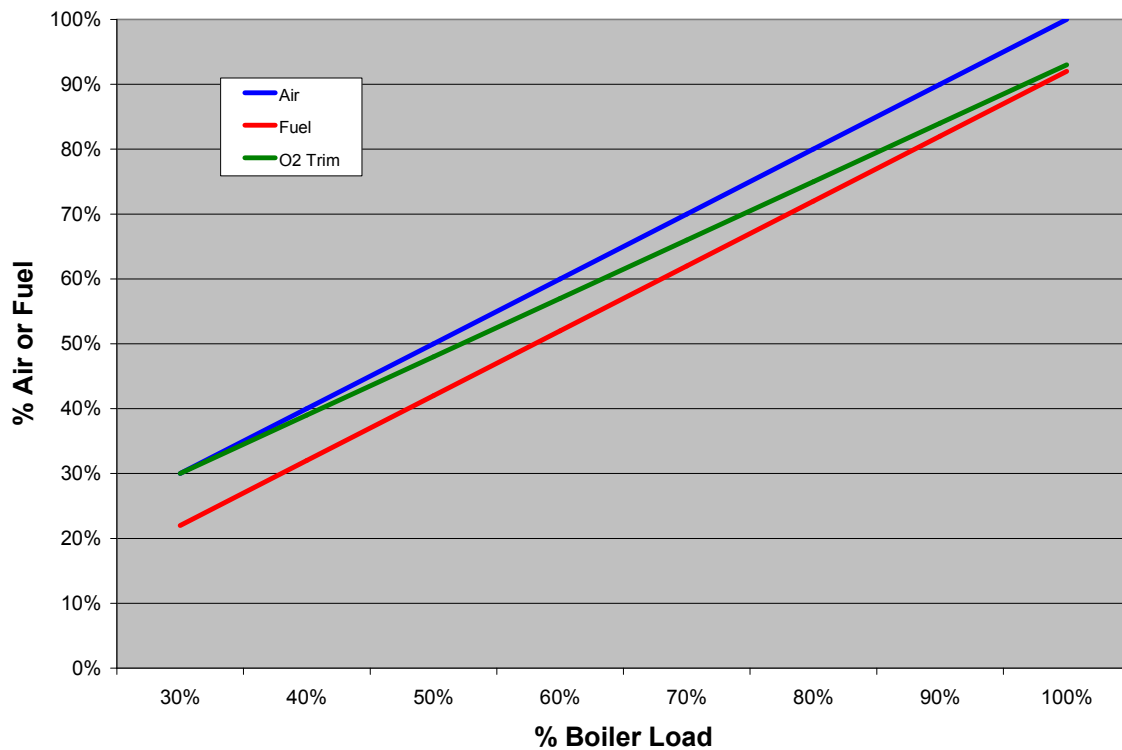


Figure 5

The blue line is the air flow as programmed in the basic control system. The red line is the fuel flow and is always below the air to ensure safe operation. The green line represents the reduction that can be achieved with an oxygen trim system.



Now that we know what needs to be controlled, let's return to the SAMA drawing and insert the necessary oxygen trim controls into the basic firing rate controls.

Referring to Figure 6 below we see that the boiler load will be taken from the steam flow signal used in the feedwater control scheme. This load information will be passed through an $f(x)$ function to generate the oxygen set point shown in Figure 4 above and in more detail in Figure 5 above. An oxygen sensor mounted in the stack will record the actual process variable and send this as a feedback signal to the oxygen controller. The oxygen controller output has high and low limits before the signal is combined with the actual combustion air flow signal. The following SAMA drawing depicted in Figure 6 shows this oxygen control scheme.

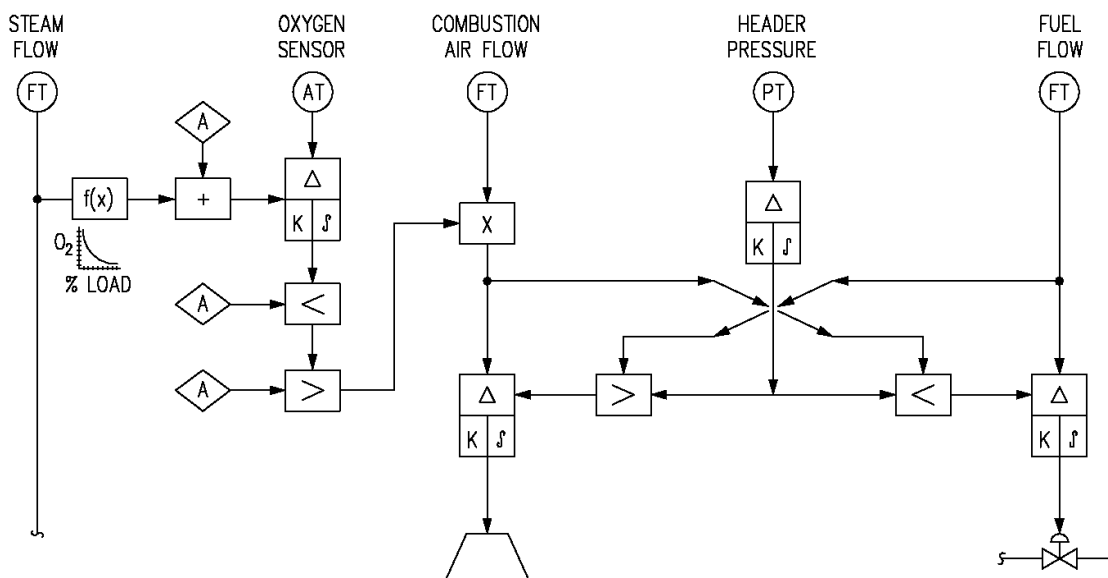


Figure 6

The equation in the multiplication block of the combustion air feedback signal is the green line shown in Figure 5 above. As the boiler load increases, the green line trims off some of the combustion air flow by adding in a false increase signal.

Assume that the boiler is at 75% load and that all control signals are at 75%. The oxygen trim system is turned on and the oxygen controller seeks to decrease the excess oxygen by sending out an increase (reverse acting controller) signal. This signal goes to the multiplication block and actually increases the output signal to 76%. The combustion air flow controller nudges the damper closed and the real air flow signal drops to 74% but the output of the multiplication block is 75% and the system is balanced again.



Field work by the process control engineer is necessary to actually set up and tune the oxygen trim system for proper operation. Manual control of the boiler at various load points along with backup stack gas monitoring will provide all the data necessary to set the curves and equations discussed above.

In the next article on SAMA symbols we'll learn about SAMA legends and how you can customize them to fit your process needs.

This article on SAMA symbols was written to convey the power, elegance, and ease of designing complex control schemes. This article is not a full, complete, or correct design of any control system. The reader shall retain the services of a licensed professional engineer with extensive process control experience. The professional engineer must first analyze the specific process in question. As my college professor used to say, "You can't design a control system until you understand the process."

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