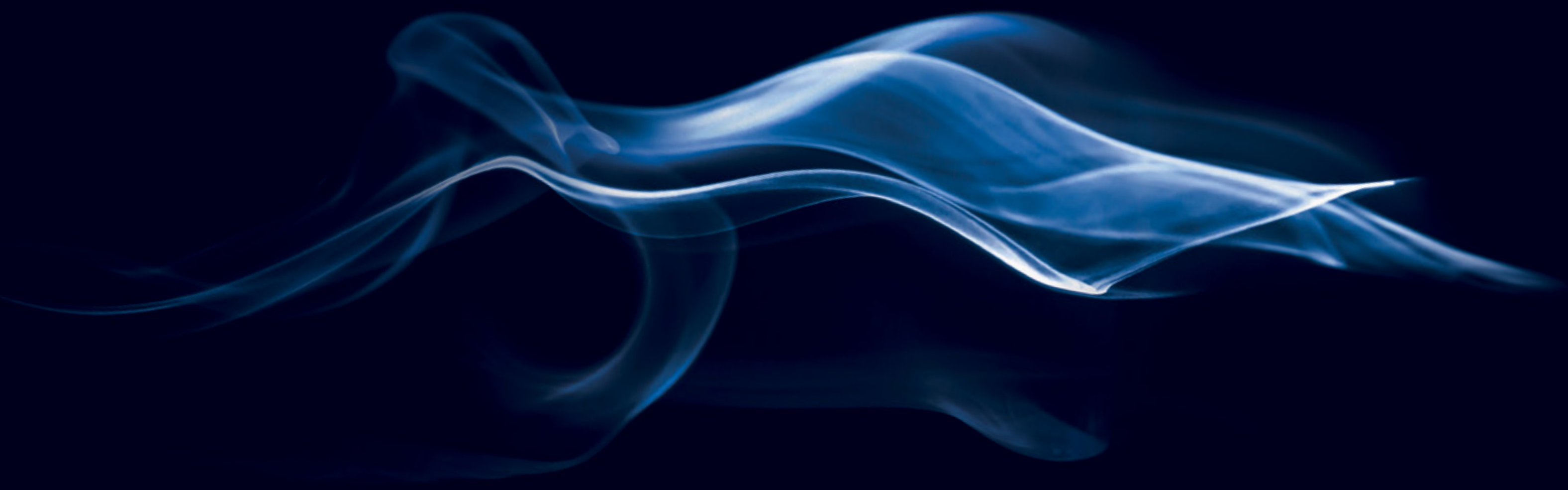
WHITE PAPER:

Achieving Perfect Combustion

A review of oxygen trim and negative pressure gas valve technology



Abstract: This white paper explores the key tasks that need to occur to properly combust natural gas. Both the base formula is discussed as well as the two leading technologies that ensure combustion is performed efficiently. This knowledge is key to understanding why the products in the heating industry exist with the components that they have, and why some perform this more efficiently than others.

WEIL-McLAIN®

Achieving Perfect Combustion

WEIL-McLAIN®

Achieving Perfect Combustion: A deep review of oxygen trim and negative pressure gas valve technology

Efficiency is the main driver for building design today. In hot water systems, condensing heat exchanger technology is the new standard in facility installations. Much is known about the importance of reclaiming condensing flue gas heat before it is exhausted from the appliance, but how does the exchanger control the combustion to ensure the unit is condensing at an efficient rate? How does the unit know what is the correct mixing ratio to make the most efficient package? What controls need to be put in place to analyze the combustion so that the equipment can dynamically adjust to varying load conditions?

The truth is, there is no one answer to these questions, but many variables in technology leading to the same solution. The key is to ensure that the appliance can maintain its air/fuel balance, without introducing an excess of one or the other for the entire range of appliance turndown. This can be done in one of two general ways, mechanically or electronically. Each has their advantages, but it is important to understand the differences and ensure when approaching the equation differently, you are balancing it to achieve the same result.

This white paper is going to explore two different types of controls and how they connect to their respective appliance, and with what additional components; bringing the same answer to the challenge of efficiency in today's ever-green world.

We start with the basics. What is the best ratio to operate an appliance?

The three elements essential to combustion control are air, fuel, and heat. Combustion is the rapid chemical reaction between oxygen and a combustible material that releases heat and light. In our case, the combustible material is a fuel in the form of a hydrocarbon. Air supplies the oxygen (O_2) for combustion, and heat is the byproduct of this combination. Perfect combustion is when the proper mixture of fuel and oxygen under precise conditions are consumed completely in the process. This precise amount is called the stoichiometric point of the fuel.

With hydrocarbons, the perfect mix of air and fuel results in two main byproducts, Carbon Dioxide (CO_2) and Water (H_2O). Carbon combines to form CO2, and the Hydrogen creates the H_2O. Combustion that is not complete leaves partially unburned fuel in the form of waste. Carbon Monoxide (CO) and Hydrogen are two common waste products. Natural Gas, the most common combustible in Weil-McLain equipment is made up of predominantly Methane (CH_4). Its byproducts are CO_2 and H_2O. The balanced equation for this process is below:

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

This stoichiometry is common for all hydrocarbons. Air, the other main ingredient of the equation, consists of approximately 78% Nitrogen (N_2), 21% Oxygen (O_2), and 1% Argon (Ar). Due to this makeup, the theoretical air/fuel ratio that is needed for the complete combustion of Carbon and Hydrogen is 9.53:1. This means you would need 9.53 cu ft. of Air to combust 1 cu ft. of Methane efficiently. The resulting heat that is released is known as the heat of combustion.

How does the appliance maintain that ratio?

It has been long recognized that controlling excess air in the combustion process is vital to the safe and efficient conversion of fuels to useful energy. The earliest iterations of this were purely mechanical metering of fuel and air. As technology progressed more complex controls were devised. This first better linkage system was developed with cam adjustment to tune the process from point to point across the operating range. An improvement to this style of control would require 2 major components, a sensing element, and a simple control element to adjust what is being sensed. These can be done either before the air/fuel is mixed (pre-combustion control), or afterward (post-combustion control).

Post-Combustion Controls Systems

Today with the reduced cost and increased computing power of microprocessor controls, technologies with servo-driven linkage-less combustion are being applied to boilers as small as 1,000,000 BTU input. Many of these systems are adding oxygen monitoring of the exhaust gases to measure Oxygen and provide either an alarm or readjust the fuel and air mixture to correct for deviation from the set oxygen level of the flue gas for the boiler. This process is also called oxygen trimming (O2 Trim).

While these systems are an improvement over previous non-electronic controls they only correct for errors after they have occurred. This is especially true any time the firing rate changes because these systems operate in the post-combustion environment. There is a delay before an alarm is displayed or correction can be applied to the operation. The delays occur as the firing rate changes, combustion changes based upon the rate change, the oxygen sensor absorbs the exhaust gas, and analyses the oxygen level and sends the signal to the controller which responds by repositioning the actuators. The process is continually repeated.

The downside to this process is now there a sensor that relies on its high sensitivity to accurately control the process makes your appliance efficient. In many cases, this sensor needs to be replaced as part of the annual maintenance required with each unit to maintain the optimum level of efficiency. This sensor then must be calibrated each heating cycle to ensure that the appliance is operating at peak efficiency. This can be a costly and time-consuming process if done every year. If it is not done every year, any benefits of having the technology are lost. Also, there is a complication if multiple motors are utilized to regulate this control. These too must be calibrated and adjusted in conjunction with the sensor and could result in additional downtime while maintenance occurs.

Pre-Combustion Control

Many boiler systems have been developed to include pre-combustion controls by adding metering of fuel and air. Pre-combustion is superior to post-combustion control because errors are eliminated before they occur. This type of control is all called a feed-forward appliance operation.

When Weil-McLain introduced condensing appliances in 2003, they recognized that precise excess air control was essential to building the most efficient boilers available. What developed is a simple venturi-based system utilizing readily available zero-governed gas valves for pre-combustion fuel-air control that maintains oxygen levels +/- .05% of the target 5% oxygen across the complete firing. The system operates without any moving parts. The venturi is used to normalize the pressure drop as airflow with load demand and air density changes due to temperature and barometric pressure changes. The zero-regulated gas valve responds to this normalized air pressure at a 1:1 ratio and can precisely meter fuel to the combustion process before combustion occurs. The precision of this combustion control method ensures that Weil-McLain maintains consistently low oxygen levels and reliably high exhaust gas dew points compared to typical condensing boilers available today. This translates to more hours of condensing operation when applied to comfort heating and hot water systems. This is coupled with low, dry stack temperature loss when an operation is outside of the condensing range as compared to other condensing boiler methods.

This ratio control, unlike what an O_2 trim system would require, is done without multiple motors or linkage. There are fewer moving parts overall minimizing burner system maintenance while maintaining efficient, reliable, and repeatable combustion. With new developments in orifice configuration, in conjunction with this method, a mechanical variable orifice design has been created to not only maintain reliable pressure-balancing but increase turndown capabilities allowing for consistent pressure-guided combustion. This is what refers to as mechanical turndown. This ensures the same efficient regulation of air and fuel as expected from Weil-McLain equipment at a much greater mechanically turned-down range on every appliance installed upon. Additionally, setup and maintenance time on the equipment is significantly less, ensuring your system is up and running efficiently.

Summary

It is the goal of the boiler and water heater industry to build safe and efficient boiler systems. Combustion control is vital to this goal and much development has taken place. When considering any boiler system, it is important to review the manufacturers' operation and maintenance manuals to identify what type of system is being employed, the effectiveness of the system, the operation, and maintenance requirements, and what impact these requirements have on your operations.

Both control systems differ in how they operate. Each has its own way to make sure that the appliance is operating to the correct level of oxygen required for efficient equipment combustion. Pre-combustion control requires less additional parts and overall maintenance, making it not only more reliable, but a more economical choice as well. Setup can be optimized and control can be immediate, but items like calibration of components on an initial or yearly basis need to be considered. The amount of efficiency concerning turndown can be varied if any of these items are neglected so being able to easily operate and observe all of the components would also need to be kept in mind. Without being aware of any of these items would be to the detriment of your building system.

Weil-McLain prides itself on providing consistent, efficient and reliable equipment and will continue to serve our customers with the same quality output into the future. As these innovations continue to evolve, Weil-McLain will continue to keep the industry informed and strive to provide the best equipment for your heating and hot water application.

Post Combustion and Pre Combustion Comparison

Post-Combustion Control	Pre-Combustion Control
Added Hardware	
Dedicated Combustion Controller	None
Servos	None
Actuators	None
Valves and Dampers	None
Oxygen Sensor	None
Set Up	
Multi-Point Numerous Steps	Two Steps
Sensor Calibration	No Calibration Required
Actuator Calibration	No Calibration Required
Maintenance Components:	
Wear Components	**Wear Components**
Actuators	No Additional Actuation
Valves	No Additional Valves
Dampers	No Additional Dampers
Renewal of Oxygen Sensor	Not Required
Combustion Precision	
Constant Deviation	Minimal Deviation
+/- 2%	+/- .05%
Component Source	
Third-party controllers, actuators and sensors	Standard Production Gas Valve