To get the best efficiency, productivity, and quality from your furnace, it is essential to understand the different types of combustion control systems, how they work, and what has to be done to keep them in peak tune.

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• Fuel/air ratio control
• Safety control
• Furnace pressure control

The first three are in almost every furnace; pressure controls are found mostly on large furnaces, such as aluminum melters or steel reheating furnaces.

Although each of these control systems is an independent entity, it does not operate in complete isolation from the others. By opening or closing an air or fuel control valve, the temperature control system tells the combustion system it needs more or less heat. The ratio control system sees to it that the air and fuel flows are properly matched as the firing rate changes.

The safety system watches over the furnace, ensuring that all the vital signs are correct before it allows fuel to the burners, and it stands ready to shut off the burners if any of those vital signs go out of limits during operation. If the furnace has pressure control, that system is constantly adjusting to accommodate firing rate changes.

**Ratio control requirements**

The heating requirements of the process determine the most suitable way to control burner ratios. The selection of a ratio control system is based on several factors. In rough order of priority, they are:

- **Turndown ratio:** This is the maximum heat requirement divided by the minimum heat requirement. For example, if a process requires 1,000,000 Btu/hr heat input at full production capacity and 50,000 Btu/hr under minimum load conditions, its turn-down is 20 to 1 (1,000,000 ÷ 50,000).

The combustion system has to be capable of matching this turn-down ratio. Otherwise it will be either short on firepower at high fire, or will produce too much heat at low, causing temperature overshoot problems.

- **Temperature uniformity:** The temperature throughout any process chamber will vary somewhat from location to location. Just how much variation can be tolerated depends on the product and customer specifications. As a general rule, the greater the required temperature uniformity, the greater the required flow of hot combustion products or heated air through the chamber.

- **Temperature sensitivity:** This refers to how finely the output temperature of the heating system can be adjusted. In other words, does a given change in fuel input cause a small or large change in temperature?

**Energy efficiency:** How much fuel is required to heat the process?

**Ratio control methods**

Basically, ratios are controlled in two ways, on-ratio and excess air.

With on-ratio control, the burner is held at or near correct ratio at all firing rates (Fig. 1). The temperature of the combustion products is always high, but their volume varies directly with the firing rate. Burner system turn-down rarely exceeds ten to one, and is sometimes less than that. For any fixed set of operating conditions, on-ratio operation produces the highest fuel efficiency.

With excess air control, the burner operates at or near correct ratio at high fire (Fig. 2). As the process requires less heat, the burner ratio is shifted to more and more excess air. It can be done by either holding the combustion air flow fixed and controlling only the fuel; or by reducing the air flow as the burner goes to low fire (like an on-ratio system), but reducing the fuel flow more rapidly.

Excess air operation is less fuel-efficient because some of the fuel is expended to heat the excess air, and this is later discarded out the exhaust. However, it has some important advantages, especially in lower-temperature applications such as tempering or aluminum aging.

First, the excess air helps control temperatures with greater sensitivity. Second, the excess air adds to the volume of the combustion gases at low firing rates, and this promotes better temperature uniformity throughout the furnace (Fig. 3). And third, excess air increases the turn-down range of the burner, giving it the ability to respond to a wider range of process loading conditions. With excess air control, burner system turn-downs of 50 to 1 or higher are not unusual.

**Ratio control systems**

If we look at the fundamentals of operation, burner ratio control systems include only five or six different types — two types are for premix burners, and the rest are for nozzle mix burners.

- **Premix control systems:** By their nature, most premix burners are not stable with more than a small amount of excess air, so premix control systems operate essentially on-ratio over their entire firing range.

- **Injectors, inspirators, and atmospheric mixers:** These mixers are venturi tubes in which the energy from a jet of gas entrains combustion air, so that no combustion air blower is needed. The correct air/gas ratio is set by manually adjusting an air shutter. Because the turndown capability of these systems is very limited, most of them are simply operated on-off. These systems have been popular for years because their initial cost is low — they do not need a combustion air blower. Unfortunately, they cannot compensate for even the smallest changes in atmospheric conditions or combustion chamber pressure or draft. This means that their performance is more likely to fluctuate than any other combustion control system. Unless the process varies is not critical, they should be candidates for replacement with a more modern, adaptable combustion system.

- **Air-aspirated systems:** These are based on venturi tubes called aspirators or proportional mixers. The systems have combustion air blowers, and the energy of the moving air is
used to pull gas into the mixer and push the gas/air mixture to the burner (Fig. 4). Because the air provides more energy, these systems can be operated over a turndown range of at least five to one, and sometimes as much as ten to one.

The system is controlled by a motor-driven valve in the air line to the mixer. As the air-flow through the mixer rises and falls, the suction generated in the venturi throat also rises and falls, and along with it, the amount of gas drawn into the venturi. These air-aspirated systems are far superior to injector systems for consistency and repeatability.

**Nozzle mix control systems:** In nozzle mix burners, the air and fuel do not meet until they are ready to be ignited at the front of the burner. Consequently, they can be mixed in stages, producing a burner that can operate with excess air as well as on-ratio. It’s worth pointing out here that the control system selection and setup will determine which way the burner actually operates.

**Proportioning valve systems:**
These were among the earliest types of control systems, and they are still widely used today. They consist of two valves, one in the combustion air line and one in the fuel line. The two valve arms are linked to each other and to a drive motor that takes its commands from a temperature controller. As one valve opens or closes, the other follows. One advantage of this system is that operators can see the valves working together, and that is a confidence builder. However, it does have several shortcomings that must be recognized:

- **Port valves of different sizes:** First, it is nearly impossible to find two fixed port valves of different sizes, handling different fluids (air and fuel), with flow curves that match. By setting the connecting linkage carefully, it is possible to get the ratios you want at high fire and low fire, but the mismatch in the flow curves will probably cause the burner to be off-ratio at some firing rates in between. If the temperature control system is in high-low operation, it’s no big deal; the burner will be off ratio only for the short time the valves are passing between high and low. The way to deal with the problem is to set the linkages to operate the system on excess air at low fire, so that matching the valve curves is not critical.

On a fully proportioning control system, valve-curve mismatch can be dealt with by including at least one adjustable-characteristic valve. One of these valves, which contain adjustable ports or cam-position compensators, can be tuned to closely match the flow characteristic of the other valve.

- **Ratio control accuracy:** The second limitation of proportioning valves is that ratio control accuracy depends on constant air and gas pressures entering the valves, and in many cases, on constant pressure in the combustion chamber. If any of these pressures changes unexpectedly, the fuel/air ratio can be upset, even when adjustable characteristic valves are used.

- **No feedback:** Third, this type of ratio control is an open loop system. If the two valves get out of synchronization due to a slipping linkage or other mechanical problem, no direct feedback signal will call anyone’s attention to the situation, let alone correct it.

**Pressure-balanced systems**
Pressure-balanced systems, better known as ratio, cross-connected, or proportioning regulator systems, use a pneumatic linkage between the air and fuel-control valves (Fig. 6). Air flow is handled by a conventional motor-driven valve, but fuel flow is governed by a diaphragm regulator whose vent is connected to the controlled air line. This loading line, or cross-connection line, is the linkage between the two valves. As the air valve opens, the pressure in the downstream air line increases, and this higher pressure is transmitted to the regulator diaphragm. This forces the regulator valve farther open, and fuel flow rises in proportion to air pressure.

![Fig. 4 — Air aspirator mixer and burner system.](image)

![Fig. 5 — Proportioning valve control system.](image)

![Fig. 6 — Pressure-balanced control system.](image)
flow. This arrangement can hold air/fuel ratios fairly closely over a wide range of flows, and is less time-consuming to set up than an adjustable characteristic valve.

Like mechanically linked valves, pressure-balanced systems operate on an open loop and can not automatically correct off-ratio conditions due to misadjustment. However, they will compensate for fluctuating supply and combustion chamber pressures. Unlike proportioning valve systems, if the burner filter gets plugged or the air valve malfunctions and fails to open, air starvation will not cause the system to go rich. Because it depends on air pressure to open, the gas ratio regulator will also remain partially closed. At worst, the result is a loss of firing capacity.

Although pressure-balanced systems are usually considered on-ratio systems only, they can be used where moderate amounts of excess air are needed at low fire. The gas regulator can be “biased” lean by adjusting its spring. The amount of excess air gained this way is not as high as with a fixed air control setup, but it is sufficient for many applications, and it produces somewhat better fuel economy.

**Pressure-balanced systems with bleeders:** Because pressure-balanced systems work by matching the regulator’s outlet gas pressure to the air-loading pressure, the gas pressure entering the ratio regulator must be higher than the combustion air-loading pressure. If not, a straight cross-connection setup will not work, because the air signal has to be reduced to a level equal to or lower than the outlet gas pressure. This is done with a bleeder, which is essentially a pipe tee in the loading line, with one connection open to the atmosphere. A small orifice in that connection allows some of the loading air to escape, or “bleed,” reducing the pressure of the air signal reaching the regulator. This arrangement allows a fixed percentage reduction in the loading pressure at all firing rates, and permits the gas flow to track with the air flow.

Bleeders are often also placed on radiant tube burner systems in which recuperators preheat the combustion air. Because of the pressure resistance of the recuperator, higher-than-usual combustion air pressures are required. Even if the gas supply pressure is sufficient to match these higher air pressures, the ratio regulator may not control properly. The bleeder brings the air-loading pressures back down into a range that permits good regulator tracking characteristics. However, the small bleed orifices are susceptible to plugging, so they must be periodically checked and cleaned to avoid the burners accidentally going fuel-rich.

**Fuel-only control system:** Excess air can be controlled with a proportioning valve or pressure-balanced system, but some applications call for more excess air at low fire than either of these systems can provide. Many of these applications use the fuel-only control system, in which the combustion air flow is fixed at all firing rates and a single valve regulates the fuel flow (Fig. 7). This is the simplest system to set up and permits the highest turndown ratios and greatest temperature control sensitivity. However, it is also the least fuel-efficient. It is also best suited to single-burner installations.

**Throttled bleed system:** Multiple burners running off a common control valve can be difficult to balance, and that has led to the use of the throttled bleed system. Although this resembles a pressure-balanced system, there are some key differences. The combustion air valve is locked in the full open position, and the air loading pressure to the regulator is varied by bleeding some of it off through a control valve. This tricks the regulator into opening and closing, even though the combustion air flow is unchanged.

Throttled bleed setups are sometimes combined with a straight on-ratio control system so that the furnace operating mode can be converted from excess air on-ratio to the flick of a switch. This is very convenient where the furnace has to handle a wide variety of temperature cycles.

**Metered ratio systems:** A true closed-loop fuel/air ratio control system requires measuring the flow of air and fuel and then comparing those measurements (Fig. 8). Over the years, this has been done with pneumatic, hydraulic and electrical controllers, but electronic systems are now almost universal.

The idea is fairly straightforward — either air or gas is designated the primary fluid, and its flow is controlled by a valve driven by the temperature controller. A meter in that line monitors flow and sends a signal to the ratio controller. The controller compares that signal to one it receives from the flow meter in the other line.

If the signals are equal, the system is on correct ratio.

If they are out of balance, the ratio controller sends a compensating signal to a slave valve in the second line, increasing or decreasing its flow to restore the ratio balance. Early controllers were limited to constant-ratio operation, but today’s electronic systems can be programmed to handle excess-air operation.

Although this is basically a proportioning valve system, the feedback loop addresses many of the problems with mechanically linked proportioning valves. It will correct for fluctuating inlet and back pressures, and the valves do not require matched curves — the controller will compensate for that.

**Ratio systems with flue gas feedback:** It has long been argued that the most important indicator of good fuel/air ratio control is the result of combustion, not the relative amounts of ingredients going in. That logic led to the use of flue gas analysis as a feedback signal in a closed-loop fuel/air ratio control system. Most of these systems measure excess oxygen in the flue gases, because excess oxygen is directly related to fuel/air ratio.

Although it is possible to run the system strictly off the oxygen signal, most system designers have shied away from doing it for fear that an
An oxygen sensor or controller malfunction will cause the combustion system to go completely out of control.

The preferred approach is O₂ trim, which superimposes a flue gas feedback signal on a standard open-loop proportioning valve, pressure balanced, or metered flow system. The O₂ trim loop is allowed to make small adjustments to the ratio to maintain peak combustion efficiency, but is not allowed to take over full control of the system.

These systems are best on applications that normally run close to correct air/fuel ratio, have only one zone of control in the combustion chamber, and show little likelihood of air leakage from the outside. Boilers are the best example of this type of application, but many process furnaces also fill the bill.

Interaction between control systems

As we said at the beginning, none of the control systems on an oven or furnace operates in complete isolation. They are always interacting, we hope with good results. However, from time to time, something will go wrong, and because of this interaction, the symptom of the problem may be far removed from the cause.

For example, a malfunctioning fuel/air ratio controller can cause a burner to operate with excess fuel, lowering the process temperature. The temperature controller could perceive this as a load increase and respond by increasing the air and fuel flows. This, in turn, could aggravate the off-ratio condition, setting in motion a spiral that leads to burner instability and flame failure. To someone arriving on the scene a few minutes later, a defective burner or loss of a limit switch might be the apparent culprit.

The more complex the systems, the greater the chance of such scenarios. This requires the people responsible for the operation and maintenance of combustion control systems to be thoroughly familiar with their operation and to keep them in good adjustment and working order. This is especially true of the safety system, which is the first line of defense against accidents.

Which ratio control system is best?

Earlier, we said four performance factors govern the choice of a ratio control system — turndown ratio, temperature uniformity, temperature sensitivity, and fuel efficiency.

The turndown ratio will be dictated by heat balance calculations on the process oven or furnace. If its turndown works out to 3 to 1, almost any control system will do; however, if you come up with a 30 to 1 turndown, plan on some type of excess air system, or perhaps a pulse system.

Pulse systems are a special type of computer-controlled high-low input control system. They are normally only for direct-fired furnaces, and they probably will not be cost-effective unless the furnace has several burners.

On recirculating air systems such as draw furnaces and nonferrous solution heat-treating and aging ovens, excess air controls are usually needed. If the oven operates with large amounts of makeup air, a fixed-air, fuel-only control system is probably the best choice. It is the least expensive and has the highest turndown and greatest temperature sensitivity. If the amount of makeup air can be restricted in the interest of fuel economy, then it is preferable to use an excess-air control system where the combustion air is also turned down.

The decision to choose closed loop (metered fuel or flue gas feedback) systems versus open loop systems is usually an economic one. Closed loop systems cost more to install, and this has to be weighed against their ability to maintain a high degree of control repeatability with less maintenance.

Electronic ratio controls

Computers and microprocessors have been so widely accepted for controlling industrial equipment that we may overlook some of the limitations inherent in the complete system. This certainly seems to be true with combustion controls. For example, many combustion control panels carry meters that read air or gas "valve posi-
tion,” and people will quote those meter readouts as the absolute truth. Actually, most of these meters simply indicate the position of a slidewire in the valve drive motor. If two valve linkages are set up differently, matching meter readings are no assurance of proportional air and gas flows. In fact, they are no guarantee the valves are even hooked up to the motors!

The important point to remember is that the high-tech microprocessor is not talking directly to the heating system. The message has to be passed through some relatively low-tech control equipment. Butterfly valves were probably designed a couple of hundred years ago. Zero governor premix systems date back to at least the 1920s, and even those sophisticated metered flow and flue gas feedback ratio systems have roots going back 50 or 60 years.

The equipment is not inferior in any way — it’s tough and reliable — but we have to keep in mind that the amount of information it can transmit is limited in both directions. The presence of a panel full of meters and lights does not change that, and this fact has some powerful implications for maintenance practices.

Keep them running right

Typically, furnaces and combustion systems get less maintenance attention than they deserve. This is often due to the assumption that if we have a sophisticated controller running everything, all is well.

A more important reason, however, seems to be associated with how combustion equipment and controls fail. Some equipment screams for immediate attention when it gets sick, while other equipment suffers in silence. This is because equipment operates in one of two common modes — Binary and Gray-Area.

In Binary operation, there is no such thing as an out-of-tolerance or less-than-ideal condition. The equipment either runs perfectly, or it does not run at all. A lot of solid state electronics fit into this category — fine one minute, dead as a doornail the next.

On the other hand, most combustion equipment follows the Gray-Area or analog mode of operation. On the day it is first started or tuned up, it runs perfectly, but on Day Two, dirt, heat, vibration and neglect start it on a long, slow, almost unnoticeable downhill slide. Unlike Binary equipment, combustion and process heating equipment can run hurt, and it will keep plugging along as well as it can, operating less efficiently and productively, compromising product quality and pumping out more and more emissions. Eventually, it gets so bad it quits. Finally it will get maintenance attention, but by then, the harm has been done.

The old adage, “If it ain’t broke, don’t fix it,” is applied to a lot of furnaces and combustion systems. This will no longer do if we are to enjoy world-class performance from process heating equipment. It is no longer acceptable to let furnaces and ovens spiral downhill until they can no longer be ignored.

We have to become skilled at tuning and maintaining them and then put them on the same sort of strict preventive maintenance schedule we use on machine tools. If we are serious about competing in a world market, we cannot afford to do any less.

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