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New Configuration May Make it Harder to Say No to Thermal Regeneration

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Thermal regeneration is a proven technology that is generally accepted as the most efficient means of heating an industrial furnace. But regenerative systems, though commonplace, are far from the norm in the industry. This is largely because regenerative systems are substantially more expensive than cold-air systems (Fig. 1) due to the costs of the regenerators themselves and the required specialized, paired burners.

Standard regenerative systems fire in a one-off/one-on cycle with each burner tied directly to its own regenerator box. A new patent-pending system developed by Olson Industries of Burgettstown, Pa., requires no specialized burners and eliminates cycling from one burner to another. The new system also eliminates the one-to-one burner/regenerator box configuration and allows for spatial flexibility because regenerator boxes can be placed anywhere space allows.

History of Thermal Regeneration in the Steel Industry

Thermal regeneration is the capturing of heat from exhaust gases and using it to preheat combustion air. Given the enormous quantity of fuel necessary for any type of heat processing, it is likely that some thought was given to recapturing waste heat beginning with man's earliest attempts at heat treatment. In fact, there were some attempts at thermal regeneration in the ancient world with some marked success by ancient Chinese and Korean pottery makers. However, the concept of using waste heat to preheat combustion air remained largely undeveloped until the time of the industrial revolution.

Regenerative Technology Gave Birth to the Open-Hearth Steelmaking Era

During the 1830s, Carl Wilhelm Siemens, a young German engineer living in England, began studying the earlier work of Robert Stirling, a Scottish minister who patented a power system that became known as the "Stirling Engine" in 1816. The Stirling Engine is a closed engine system containing a fixed amount of gas that, when subjected to external heat, cycles back and forth between a hot end and a cold end. The expansion of the gas when heated, followed by the compression of the gas when cooled, activates pistons attached to a fly wheel that can perform work. Stirling placed a simple heat-retaining media in the midpoint of the system that absorbed heat from the hot portion of the engine as the gas passed to the cold side and released the heat to the cooled gas as it returned to the ho t side.

While the Stirling Engine itself is still recognized for its simple ingenuity, its impact has been relatively small due to the success of the later-developed internal-combustion engine and electric motor. However, Robert Stirling's idea of cycling hot and cold air over a heat-retaining media fostered a revolution in steelmaking.

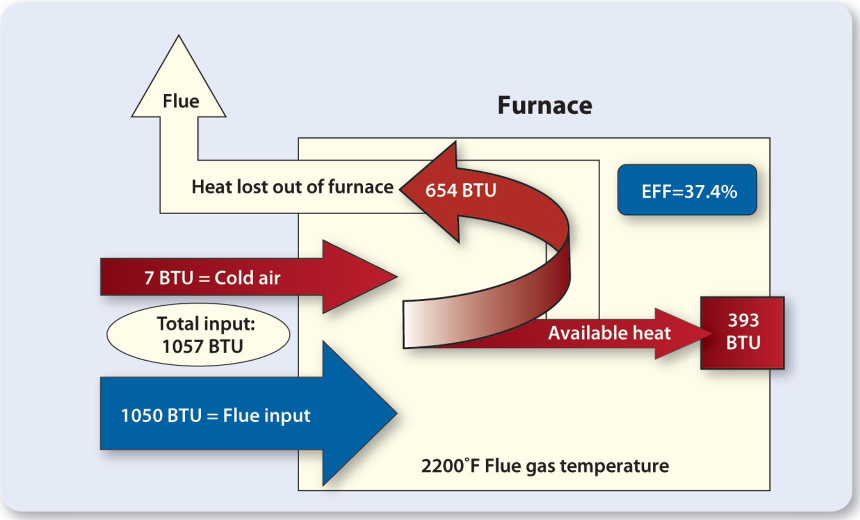

Fig. 1. Cold-air combustion system

Siemens became fascinated with heat regeneration and spent years trying and failing to apply Stirling's regeneration idea to improve steam-powered mechanical functions. Siemens finally found success after he realized that the regeneration concept was easier applied to large-scale industrial processes. In 1861, Siemens secured a patent for a regenerative industrial furnace. Shortly thereafter, he installed regenerators containing brick checker-work media on a glass furnace near Birmingham, England. The furnace exhausted gases through two heat-absorbing chambers made of brick that operated cyclically, with one serving as an exhaust flue and the other as a combustion draw. Cycling exhaust and combustion functions back and forth between the two chambers provided a continuous supply of preheated combustion air and vastly increased efficiency.

Siemens licensed the technology to Pierre Emile Martin who built a regenerative open-hearth furnace sitting atop two regenerator chambers containing the Siemens-devised brick checker-work media in 1865. While the idea of an open hearth was not new, melting ore and scrap in an open hearth was not previously economical because of the enormous amount of fuel needed to maintain the required temperatures.

The regenerative open hearth, or "Siemens–Martin process" as it came to be known, was cost-competitive with the Bessemer steelmaking process of decarburizing pig iron by forcing high-pressure air through the molten mix. The open hearth allowed for a more controlled and refined process of steelmaking, resulting in substantially superior and more consistent grades of steel. Ironically, after it appeared that the regenerative open hearth would render the Bessemer process completely obsolete, a variation of the Bessemer process, the basic oxygen process, appeared. Employing almost pure oxygen, the basic oxygen process produced higher-quality steel in one-tenth of the time needed in the open hearth. Not surprisingly, open hearths began to disappear, and by the late 1980s few could be found in the U.S.

Small-Scale Regenerative Systems are Born

The demise of the open-hearth furnace was not the end of thermal regeneration in the steel industry. The same concept of thermal regeneration employed in the gargantuan open-hearth furnaces was scaled down by industrial burner manufacturers and applied to heat-treating applications. Hotworks Combustion Technology Ltd. of Yorkshire, England, claims credit for devising the first compact regenerative systems in 1982. The credit appears deserved, but it also appears true that others in Germany, Japan and the U.S. were pursuing the idea at the same time. By the mid-1990s, thermal-regeneration systems became widely available, and since that time more and more have been included in new furnaces and retrofits (Fig. 2).

The drawback to these systems is the need for increased burner capacity in order to maintain a desired furnace temperature. Standard systems include paired regenerative burners that are directly connected one-to-one with a regenerator with the furnace waste gases exhausted through the burner itself to the regenerator box dedicated to that burner. Because burners cannot fire when in the exhaust mode, each burner fires only half of the time. Thus, maintaining the desired heat capacity requires additional burner capacity. Moreover, each additional burner requires its own dedicated regenerator, which can often be problematic due to space availability.

How Does It Work?

The new system allows all burners to fire continuously and eliminates both specialized regenerative burners and the one-to-one pairing of burners and regenerator boxes.

Because the burners are not part of the new system's exhaust process, they need not cycle on and off, and with all burners continuously

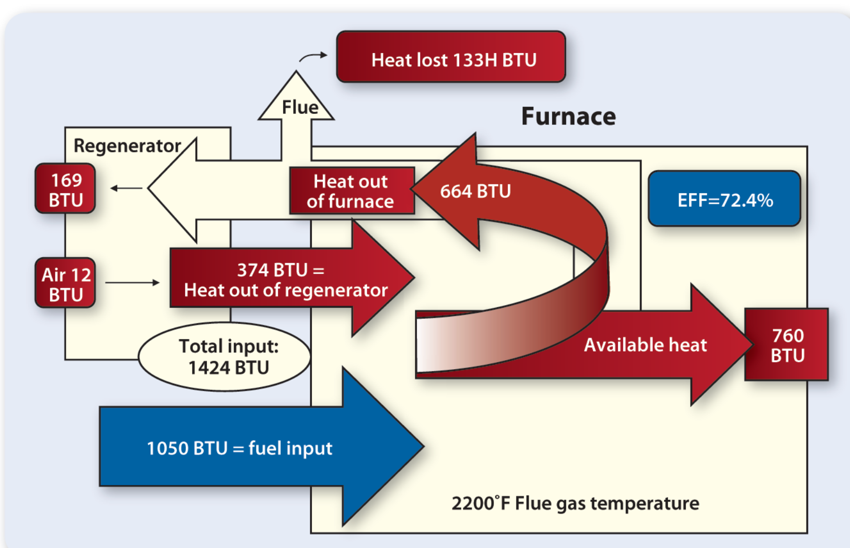

Fig. 2. Regenerative combustion system

available, less total burner capacity is required to maintain the desired heat. Also, without need for exhaust-function capability, burners can be selected based solely upon performance and suitability for the particular application. The need for intricate and complicated specialized regenerative burners is completely eliminated while all the fuel savings are retained.

Just as is done in standard regeneration systems, the new system directs the hot furnace exhaust through a media such as tabular alumina spheres located within the regenerator box. And just as in standard systems, there is a cycling from one regenerator box to another (Fig. 3). But, because nothing exhausts through the burners, the burners can fire continuously and need not cycle. The furnace gases instead pass from a port in the furnace wall to the regenerator box, where the media becomes charged with heat. A valve in the exhaust line positioned between the furnace port and the regenerator box controls the flow of the hot exhaust into the regenerator. The system recovers the hot furnace gases to such an extent that the temperature of the exhaust is less than 200°F after being pulled through the regenerative media. There are no furnace flues used in the system, and no stack is required. All exhaust gases coming out of the regenerators are handled through a fan, allowing the exhaust to be easily routed to a safe location.

When the charging of a regenerator is completed, the furnace-port valve closes, stopping the flow of the furnace exhaust gases into the regenerator. An ambient-air valve then opens, allowing the flow of ambient air through the now-heated media. The ambient air absorbs the heat charge from the media and passes the now-superheated air to the burners for combustion. At the same time, a separate port connected to a separate regenerator opens, causing the exhaust gas to begin charging that regenerator. The number of regenerators used is dependent on the capacity of the furnace. Whatever the arrangement, there are always some regenerators charging and some discharging at any given time, enabling the burners to fire continuously.

A Common Combustion Air Supply

The key aspect of this system is the incorporation of a common combustion air supply that receives all of the preheated air from all of the regenerators and feeds it to all of the burners uniformly and simultaneously. This is accomplished via a system of piping, valves and fans. Each regenerator box has four separate piped connections controlled by separate valves as follows:

- A furnace exhaust line connects the furnace port to the regenerator.
- A regenerator exhaust line powered by a fan forcibly draws the furnace exhaust through the media with the small amount of heat not absorbed by the media exhausted to the atmosphere.
- An ambient-air supply line is powered by a fan, which pushes cold ambient air through the media during discharge.
- A heat discharge line transports the superheated ambient air from the regenerator to the common combustion-air supply which feeds the burners.

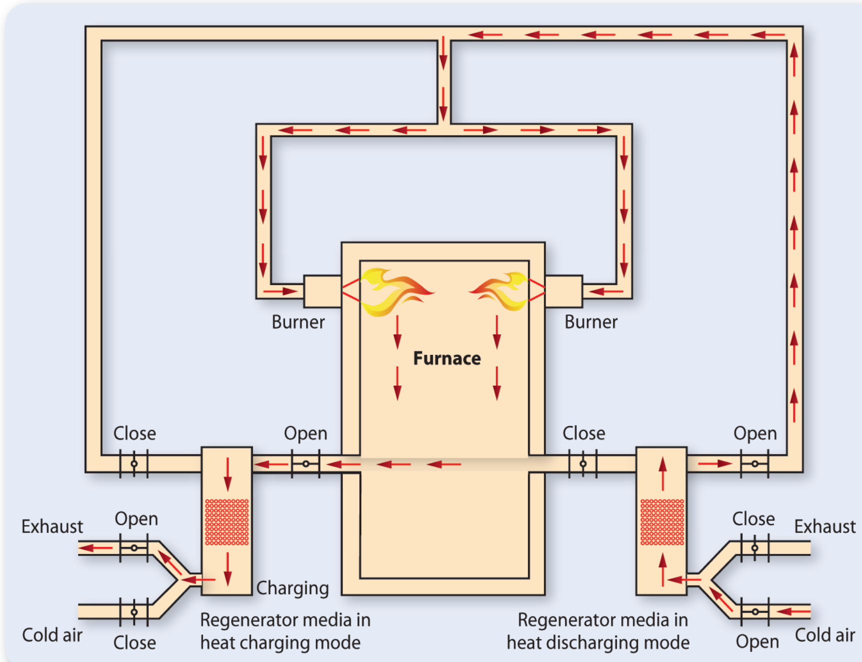

Fig. 3. Airflow diagram for new system

Sequence of Valve Movements

1. Regenerator is charging
   - The furnace exhaust line and the regenerator exhaust line are open such that the furnace exhaust flows in and through the media.
   - The ambient-air line and the heat-discharge line are closed.
2. Regenerator is discharging (the valves are reversed)
   - The furnace exhaust line and the regenerator exhaust line are closed.
   - The ambient-air supply line and the heat-discharge line are open. Ambient air is forcibly pushed across and through the media and out to the common combustion air supply and finally to the burners.

Fully Automated

Throughout operations, the regenerators run in a timed sequence of charging and discharging, which provides a constant supply of heated combustion air that is directed from the common combustion air supply to each burner. The system is fully automated, and the valve sequencing is pre-programmed to optimize efficiency. The timing will be variable, depending on the application. This cycle of transferring waste furnace heat to a common combustion air supply continues until the combustion air reaches a pre-programmed maximum allowable temperature. Once this occurs, a thermocouple feedback control mechanism will cause additional unheated ambient air to mix with the common combustion-air supply and dilute the superheated combustion air.

Benefits

The new system provides fuel savings comparable with standard regeneration systems. However, the elimination of redundant burners, regenerators and specialized burners significantly reduce the up-front costs. A more uniform heat is also possible because the common combustion-air supply allows all of the burners to continuously fire or pulse. The steady supply of preheated combustion air to all burners also provides more precise temperature control and is thus adaptable for use in applications that require multiple or rapid temperature changes. The new system works across any temperature ranges and allows operators the option of using a number of small firing burners to maximize control over furnace heat uniformity.

The new system also makes lower-temperature regeneration economical. In the past, regeneration below a 1200°F furnace temperature required very expensive self-regenerative burners with the heat-storage media contained within the burner itself. Self-regenerative burners can fire continuously, just as is the case with the new system. However, the up-front cost of self-regenerative burners can be daunting. Also, because the burners themselves contain the media, they are large and intrude into the heating chamber. With the new system, smaller and substantially less-expensive burners can be used, causing minimal intrusion.

Perhaps most important is the spatial flexibility created by the decoupling of the regenerators and burners. The system decreases the physical area needed for installation of a regenerative system and makes the efficiency of regeneration available in furnace locations where it was previously considered to be unworkable. With the direct connection between the regenerator boxes and the burners eliminated and with a reduction in the number of burners required, the placement of the boxes is unrestricted. The boxes can be stacked in one place, grouped on just one side of the furnace, installed above the roof or located in reasonable proximity to the furnace. Adding to the system's spatial flexibility is the low-temperature exhaust, which eliminates the need for a raised stack.

Controlling NOx with the Olson System

NOx is formed from thermal oxidation of nitrogen in the ambient air. The amount of oxygen, the flame temperature and the duration of the thermal process are the factors affecting the formation of NOx. Because the length of any given thermal process is typically fixed, NOx controls depend on reducing peak flame temperature and limiting the concentrations of the reactants O2 and N2. Any currently available NOx-reduction techniques are compatible with the new system. The system will work with low-NOx burners and air staging, and catalytic processes can also be easily incorporated into the system depending on the level of NOx reduction sought by the operator. IH