Of the various available options for increasing the energy efficiency in industrial furnaces, preheating the combustion air offers the most effective way to increase efficiency in most furnaces.

Joachim G. Wünning
WS Inc., Elyria, Ohio

Energy efficiency is a top priority in the steelmaking and heat treating industries. Because hot exhaust gases represent the largest source for losses in most industrial furnaces, preheating the combustion air provides the highest potential for energy savings. This article discusses the advantages of different strategies to boost energy efficiency and factors that must be considered when evaluating their suitability for the application.

Energy Efficiency Related to Flue Gas Losses

Efficiency is usually defined as:

\[
\text{Efficiency} = \frac{\text{benefit}}{\text{expenditure}}
\]

Regarding firing systems for industrial furnaces, efficiency or available heat, is defined as:

\[
\text{Efficiency} = \frac{\text{fuel input} - \text{exhaust gas losses}}{\text{fuel input}} = 1 - \left(\frac{\text{fuel input} - \text{exhaust gas losses}}{\text{fuel input}}\right)
\]

Figure 1 shows efficiency as a function of exhaust gas, or process temperature. For a system without air preheat, efficiency decreases with rising exhaust gas temperature. At a process temperature of 1000°C (1830°F), about 50% of the fuel input will be lost as hot exhaust gas heat. To determine the usefulness of air preheat, the relative air preheat (\(\varepsilon\)) can be defined as:

\[
\varepsilon = \frac{\theta_{\text{preheat}} - \theta_{\text{air}}}{\theta_{\text{exhaust}} - \theta_{\text{air}}}
\]

where \(\theta_{\text{preheat}}\) is air preheat temperature, \(\theta_{\text{exhaust}}\) is hot exhaust temperature, and \(\theta_{\text{air}}\) is air inlet temperature.

The air preheat temperature is the temperature supplied to the burner. Energy losses between a central heat exchanger and the burner have to be considered. The hot exhaust temperature is the temperature of the exhaust gases leaving the furnace, which, in most cases, is close to the process temperature. In radiant tube heated furnaces, this temperature can be substantially higher than the furnace temperature. The air inlet temperature is usually ambient air, and, therefore, the relative air preheat can be expressed as the ratio of preheat temperature to hot exhaust temperature. The relative air preheat value

Fig. 1 — Efficiency as a function of exhaust gas of industrial furnace-firing systems.
is a good number to characterize a heat exchanger for air preheating.

Heat exchanger performance is evaluated using the NTU (number of transfer unit), which is proportional to the heat exchanger area and inversely proportional to the heat capacity flow through the heat exchanger.

\[ \text{NTU} = \frac{k \cdot A}{m \cdot c_p} \]

where \( A \) is heat exchanger surface area, \( k \) is heat transfer coefficient, \( m \) is mass flow, and \( c_p \) is specific heat. Figure 2 shows the relative air preheat in a simplified diagram for counterflow and coflow heat exchangers. The savings can be calculated as:

\[ \text{Savings} = 1 - \frac{\text{low efficiency}}{\text{high efficiency}} \]

which translates to savings of 20% if a system with 68% efficiency is upgraded to 85% efficiency.

**Continuous Direct-Fired Furnaces**

One option (Fig. 3) to lower the exhaust gas losses is to add an unheated section to the furnace where the incoming products are preheated. This is quite effective as long as the flue gas is hot, but very long preheat zones would be necessary to transfer a considerable amount of heat. This method to improve efficiency is common in tunnel furnaces in the ceramic industry.

Additional useful cooling of exhaust gases can be done in a central recuperator (Fig. 4). The limitation stems from the recuperator design and size, as well as the maximum temperature for the hot air control valves. Common air preheat temperatures are 300 to 500°C (570 to 930°F), and in some cases, as high as 600°C (1110°F).

Air-preheating limitations can be overcome using regenerative-burner systems for decentralized heat recovery (Fig. 5) or self-recuperative burners (Fig. 6). Every burner has its own heat exchanger, which is placed in the furnace wall or close to the burner. Combustion air-control valves are located on the cold side of the heat exchangers. In addition to providing higher efficiency, such a system provides more exact furnace temperature control because there is no interaction between furnace zones. The lack of the costly insulated hot air piping and a preheat zone usually offsets higher burner costs and the expense of the exhaust collection system. Energy savings of 10
to 30% compared with systems having central recuperators can be achieved.

Even higher air preheat temperatures, and, therefore, higher efficiency can be achieved using regenerative burners. For larger burner capacities, regenerative burner pairs are common (Fig. 7), where two burners are linked and fire alternately. Exhaust and combustion air are directed over the regenerators, which are made of ceramic balls or honeycombs. Relative air preheat values of 0.8 to 0.9 are achievable, making these systems very effective. Figure 8 shows a regenerative burner. The burner uses air staging as a NOx-reducing measure.

For smaller burner capacities, a self-regenerative burner allows the same high efficiency, but with the advantage of a single-burner solution. There is no need to switch from one burner to another; the one burner can fire continuously just like a recuperative burner. This is possible by integrating all switching valves and regenerators into one compact unit (Figs. 9 and 10).

Fuel savings compared with self-recuperators are in the range of 10 to 20%, and savings of 50% or greater have been achieved compared with cold air systems.

Fig. 5 — Limitations for air preheating can be overcome using regenerative burner systems for decentralized heat recovery, or using self-recuperative burners (see Fig. 6).

Fig. 6 — WS Inc. REKUMAT self-recuperative burner.

**Custom Heat Treating Furnaces**

- STC™ (Short Time Cycle)
- Continuous and Batch Roller Hearth
- Rotary Hearth
- Generators
- Mesh Belt
- Car Bottom
- Walking Hearth and Walking Beam
- Specialty Heat Treating Furnaces
- Technical Service and Revamps
- EnCORE™ Process Control and Automation

Core Furnace Systems designs and supplies a variety of high quality industrial furnaces for heat treating, reheating, carbon processing, melting and specialty applications.

Visit booth #1120
Radiant Tube-Fired Systems

For radiant tubes, decentralized heat recovery is preferable. Central heat exchangers, which are common for large direct-fired furnaces, are not practical for radiant tube fired systems because there is no central exhaust outlet of the furnace. Hot exhaust gases would have to be transported to the heat exchanger in costly insulated ducts, and then the hot air has to be distributed back to the individual radiant tubes. For radiant tube heating, a good heat recovery system is essential because exhaust temperatures are often substantially higher than the furnace temperature. It is particularly true for ceramic radiant tubes having high heat-release rates.

Different radiant tube designs (Fig. 11) require different strategies for heat recovery. Radiant tube designs (Fig. 11) require different strategies for heat recovery.
heat recovery. In straight-through tubes, heat recovery is very rare. For U- and W-tubes, the most common way to preheat the combustion air is to use a plug-in recuperator (Fig. 12). To enhance the air preheat, external recuperators are also possible. The limitation for air preheating stems from the necessity to guide the hot air from the exhaust leg to the burner and also from the coflow heat exchanger design.

Higher air preheat temperatures, and, thereby, higher efficiency can be achieved using regenerative burner systems in U-, W- and A-tubes. Two burners per tube alternate firing (Fig. 13). Regenerative systems allow air preheat temperatures close to the furnace temperature. Energy savings of more than 20% compared with systems using plug-in recuperators are typical. Besides energy savings, temperature uniformity of the tubes is much better due to the alternating flow direction in the tube. It is important to pay attention to NOx formation due to the high air preheat and system complexity (i.e., two burners per tube).

Single-ended P- and Double-P tubes are usually fired using self-recuperative burners. The counterflow heat exchanger, which is placed inside the furnace wall, allows high air preheat temperatures, and there is no hot air piping required outside the furnace. For high temperatures, self-recuperative burners with ceramic heat exchangers (see Fig. 6) are available. Air preheat temperatures in the range of 500 to 700°C (930 to 1290°F) are typical. Figure 14 and 15 show a double-P tube with a self-recuperative burner. High-velocity combustion provides good temperature uniformity, and internal recirculation allows the application of flameless oxidation, or FLOX, as an effective method to reduce thermal NOx formation. Self-recuperative burners are widely used because they combine good performance with a high efficiency.

A self-regenerative burner for radiant tubes was developed to combine the advantages of regenerative systems and self-recuperative burners (Fig. 16). Figure 17 shows a self-regenerative burner that could be...
used for direct firing and to heat recirculating radiant tubes. The self-regenerative burner is used in combination with a pulse-firing system; the burner is on/off controlled. All the logic for regenerative switching, flame safety, ignition, and valve operation is handled by a local burner-control unit, making installation, start up, and maintenance as easy as with self-recuperative burners. Tube temperature uniformity is excellent because of the internal recirculation, and NOx emissions are low due to flameless oxidation.

Larger diameter radiant tubes should be used to keep the number of radiant tubes and burners, and, thereby costs, at a minimum. Using double-P tubes, it is possible to heat a furnace using a fraction of the number of burners used in a system with small diameter straight tubes.

Conclusions
There are many options for increasing the energy efficiency, and preheating combustion air is the most effective way to increase efficiency in most furnaces. The challenges of rising energy costs and stricter environmental regulations can be met through close cooperation of the end user, the furnace builder, and the burner manufacturer to choose the best possible configuration with respect to performance, energy efficiency, low emissions, and low maintenance, while minimizing investments costs.

FLOX, REKUMAT, and REGEMAT are trademarks of WS Inc.

For more information: Dr. Joachim G. Wuenning is the president of WS Thermal Process Technology Inc., 719 Sugar Ln., Elyria, OH 44035; tel: 440-365-8029; fax: 440-365-9452; e-mail: j.g.wuenning@flox.com; Web site: www.flox.com.