



Waste Heat Reduction and Recovery for Industrial Furnaces

An Online Continuing Education Course for Engineers

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Credit: 1 Hour / 1 PDH / 1 CPD

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Introduction

Thermal efficiency of process heating equipment, such as furnaces, ovens, melters, heaters, and kilns is the ratio of heat delivered to a material and heat supplied to the heating equipment. For most heating equipment, a large amount of the heat supplied is wasted in the form of exhaust or flue gases. These losses depend on various factors associated with the design and operation of the heating equipment. This course will provide guidance on reducing waste heat losses associated with the heating equipment.

Heat Losses from Fuel-Fired Heating Equipment.

Waste-gas heat losses are unavoidable in the operation of all fuel-fired furnaces, kilns, boilers, ovens, and dryers. Air and fuel are mixed and burned to generate heat, and a portion of this heat is transferred to the heating device and its load. When the energy transfer reaches its practical limit, the spent combustion gases are removed (exhausted) from the furnace via a flue or stack to make room for a fresh charge of combustion gases. At this point, the exhaust flue gases still hold considerable thermal energy, often more than what was left behind in the process. In many fuel-fired heating systems, this waste heat is the greatest source of heat loss in the process, often greater than all the other losses combined.

Reducing these losses should be a high priority for anyone interested in improving the energy efficiency of furnaces and other process heating equipment.

The first step in reducing waste heat in flue gases requires close attention and proper measures to reduce all heat losses associated with the furnace. Any reduction in furnace heat losses will be multiplied by the overall available heat factor. This could result in much higher energy savings. The multiplier effect and available heat factor are explained in greater detail in the following sections.

These furnace losses include:

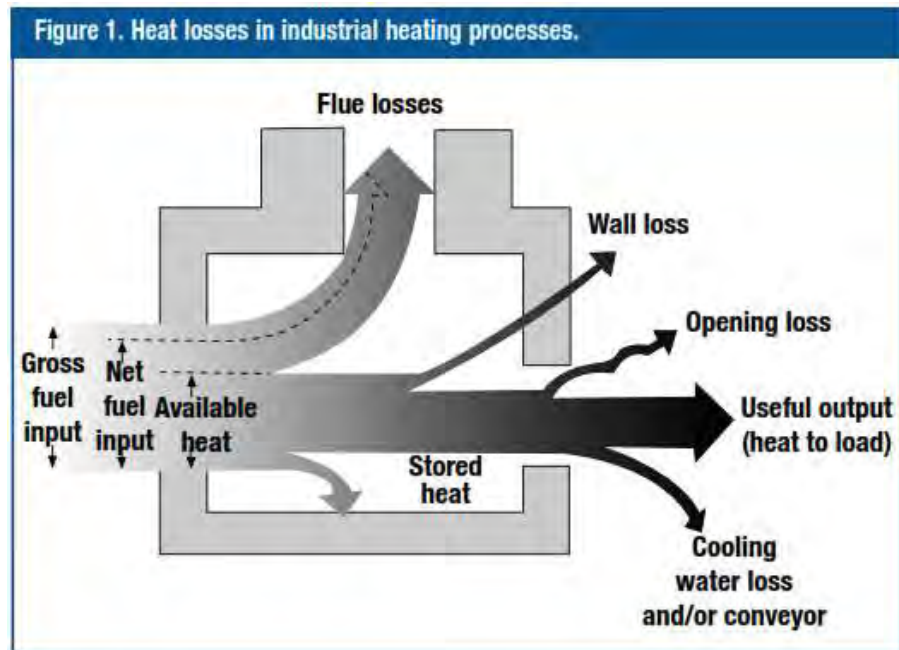
- Heat storage in the furnace structure
- Losses from the furnace outside walls or structure
- Heat transported out of the furnace by the load conveyors, fixtures, trays, etc.
- Radiation losses from openings, hot exposed parts, etc.
- Heat carried by the cold air infiltration into the furnace
- Heat carried by the excess air used in the burners.

Reducing waste heat losses brings additional benefits, among them:

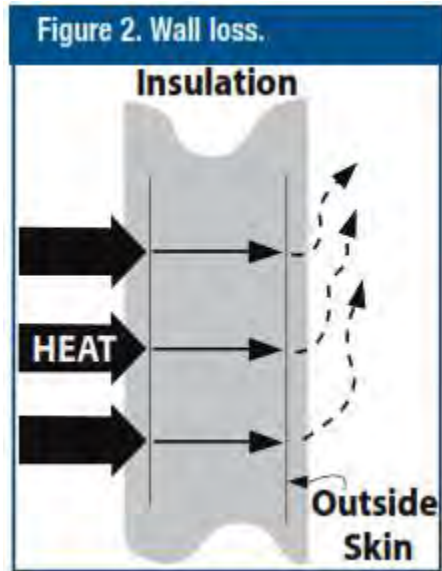
- Lower energy component of product costs
- Improved furnace productivity
- Lower emissions of carbon monoxide (CO), nitrogen oxides (NO_x) and unburned hydrocarbons (UHCs)
- May contribute to more consistent product quality and better equipment reliability.

What Determines Waste-Gas Losses?

To answer this, the flow of heat in a furnace, boiler, or oven must be understood. The purpose of a heating process is to introduce a certain amount of thermal energy into a product, raising it to a certain temperature to prepare it for additional processing, change its properties, or some other purpose. To carry this out, the product is heated in a furnace or oven. As shown in Figure 1, this results in energy losses in different areas and forms.



First, the metal structure and insulation of the furnace must be heated so their interior surfaces are about the same temperature as the product they contain. This stored heat is held in the structure until the furnace shuts down, then it leaks out into the surrounding area. The more frequently the furnace is cycled from cold to hot and back to cold again, the more frequently this stored heat must be replaced. In addition, because the furnace cannot run production until it has reached the proper operating temperature, the process of storing heat in it causes lost production time. Fuel is consumed with no useful output.



Wall losses.

Additional heat losses take place while the furnace is in production. Wall or transmission losses are caused by the conduction of heat through the walls, roof, and floor of the heating device, as shown in Figure 2. Once that heat reaches the outer skin of the furnace and radiates to the surrounding area or is carried away by air currents, it must be replaced by an equal amount taken from the combustion gases. This process continues as long as the furnace is at an elevated temperature.

Material handling losses.

Many furnaces use equipment to convey the work into and out of the heating chamber, and this can also lead to heat losses. Conveyor belts or product hangers that enter the heating chamber cold and leave it at higher temperatures drain energy from the combustion gases. In car bottom furnaces, the hot car structure gives off heat to the room each time it rolls out of the furnace to load or remove work. This lost energy must be replaced when the car is returned to the furnace.

Cooling media losses.

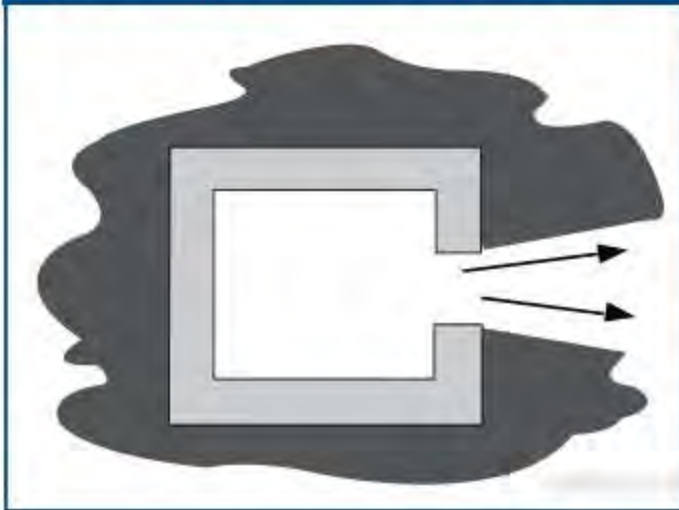
Water or air cooling protects rolls, bearings, and doors in hot furnace environments, but at the cost of lost energy. These components and their cooling media (water, air, etc.) become the conduit for additional heat losses from the furnace. Maintaining an adequate flow of cooling media is essential, but it might be possible to insulate the furnace and load from some of these losses.

Radiation (opening) losses.

Furnaces and ovens operating at temperatures above 1,000°F might have significant radiation losses, as shown in Figure 3. Hot surfaces radiate energy to nearby colder surfaces, and the rate of heat transfer increases with the fourth power of the surface's absolute temperature. Anyone who has ever stood in front of the open door of a high-temperature furnace can attest to the huge amount of thermal energy beamed into the room.

Anywhere or anytime there is an opening in the furnace enclosure, heat is lost by radiation, often at a rapid rate. These openings include the furnace flues and stacks themselves, as well as doors left partially open to accommodate oversized work in the furnace.

Figure 3. Radiation loss from heated to colder surface.



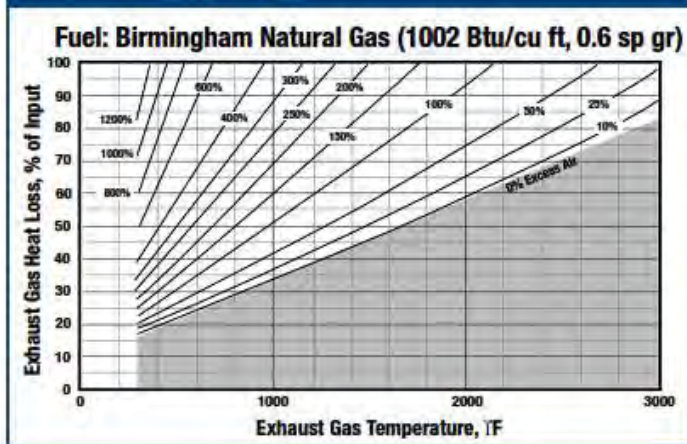
Waste-gas losses.

All the losses mentioned above – heat storage, wall transmission, conveyor and radiation – compete with the workload for the energy released by the burning fuel-air mixture. However, these losses could be dwarfed by the most significant source of all, which is waste-gas loss.

Waste-gas loss, also known as flue gas or stack loss, is made up of the heat that cannot be removed because heat flows from the higher temperature source to the lower temperature heat receiver.

In effect, the heat stream has hit bottom. If, for example, a furnace heats products to 1,500°F, the combustion gases cannot be cooled below this temperature without using design or equipment that can recover heat from the combustion gases. Once the combustion products reach the same temperature as the furnace and load, they cannot give up any more energy to the load or furnace, so they have to be discarded. At 1,500°F temperature, the combustion products still contain about half the thermal energy put into them, so the waste-gas loss is close to 50% (Figure 4). The other 50%, which remains in the furnace, is

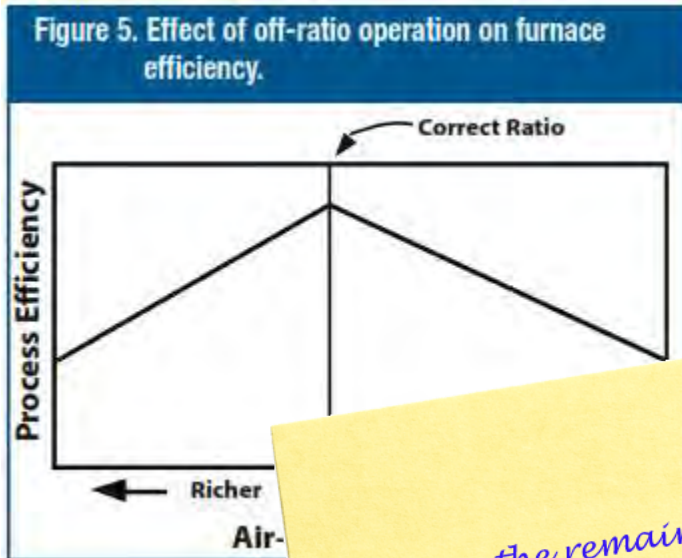
Figure 4. Exhaust gas heat losses vs. exhaust gas temperature and air-gas ratio.



called available heat. The load receives heat that is available after storage in furnace walls, and losses from furnace walls, load conveyors, cooling media and radiation have occurred.

This makes it obvious that the temperature of a process, or more correctly, of its exhaust gases, is a major factor in its energy efficiency. The higher that temperature, the lower the efficiency.

Another factor that has a powerful effect is the fuel-air ratio of the burner system.



Fuel-air ratios.

For every fuel, there is a chemically correct, or stoichiometric, amount of air required to burn it. One cubic foot of natural gas, for example, requires about 10 cubic feet of combustion air. Stoichiometric, or on-ratio combustion will produce the highest flame temperature and thermal efficiencies.

of adjustment. The ratio is either rich (excess fuel) or lean (excess air). Either way, the combustion is inefficient, operating at a lower efficiency than stoichiometric combustion, operating at the correct ratio. The excess fuel is discarded with some of the heat, and the excess air (CO) and unburned hydrocarbons are also discarded.

At first glance, operating at a rich ratio seems like all the fuel is being consumed. Indeed, a lean ratio is not a rich ratio, but it does waste energy. First, it lowers the flame temperature, which is like adding cold water added to hot pot of water. The hot combustion gases are cooled, and the heat is lost. More damaging, however, is the fact that the products of stoichiometric combustion and the excess air become one more competitor for the energy demand in the process. Because this is part of the combustion process, excess air goes to the head of the line, taking its share of the heat before the furnace and its contents.

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Combustion systems can be operated at rich or lean ratios. Sometimes, this is done to obtain certain characteristics, but often, it happens because the burner system is out of adjustment (excess fuel or insufficient air) or because the fuel is not rich enough for complete combustion. The result is a loss of efficiency by allowing it to be carried away by the products of carbon monoxide and unburned hydrocarbons. In a process operating at 2,000°F, available heat at stoichiometric ratio is about 45% (55% goes out the stack). Allowing just 20% excess air into the process (roughly a 12-to-1 ratio for natural gas) reduces the available heat to 38%. Now, 62% of the total heat input goes out the stack, the difference being carried away by that relatively small amount of excess air. To maintain the same temperatures and production rates in the furnace, 18% more fuel must be burned.

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