Energy Saving Methods

Furnace Load
Fixture Losses
Water Cooling Losses
Wall Losses
Opening Losses
Other Losses
Heat Storage
Flue Gas Losses

Energy Reduction and Recovery Strategy

Additional information on each topic is available on the web sites or on the PHAST CD as a separate folder.

Furnace Load

Description:
Heat supplied to the load or material being processed in a furnace is used to raise its temperature, to melt it or for a chemical reaction. In a few cases the chemical reaction will generate heat and will reduce the heat taken from the furnace. The heat used for processing (heating, melting etc.) can be calculated by using its specific heat, heat of phase change (melting or vaporizing) and heat of reaction. PHAST program provides the necessary parameters for most commonly processed materials. In cases where such information is not included in the database it is necessary to provide the information to estimate actual heat requirement for the load. The heat supplied to the load is what is left after heat storage, wall, water, fixture, and opening losses take what they need, anything left over is absorbed by the load.

A commonly overlooked factor in energy efficiency is scheduling and loading of the furnace. “Loading” refers to the amount of material processed through the furnace or oven in a given period of time. It can have significant effect on the furnace’s energy consumption when measured as energy used per unit of production. Total energy consumption per unit of production will follow the curve i.e. lowest at 100% of furnace capacity and progressively higher the farther throughputs deviate from 100%. Furnace efficiency varies inversely with the total energy consumption. The lesson to be learned here is that furnace operating schedules and load sizes should be chosen to keep the furnace operating as near to 100% capacity as much as possible. Idle and partially loaded furnaces are less efficient.

Energy Saving Methods:
- Review the downstream process requirements and possibilities of lowering the final product temperature
- Investigate possibilities of preheating the charge or incoming load entering the furnace
- Pre-drying to reduce moisture content of the load entering the furnace
- Maintain-clean heat transfer surfaces such as tubes, muffle, radiant tubes, and electrical heating elements.
- Consider use of high convection burners or recirculating fans to increase heat transfer to the load
- Schedule the furnace operations with full load as much as possible.
- For more information visit [http://www.oit.doe.gov/bestpractices/process_heat/](http://www.oit.doe.gov/bestpractices/process_heat/)
Fixtures Losses

Description:
Many furnaces have material handling equipment to convey the work into and out of the heating chamber. Heating and cooling of the material handling parts can lead to heat losses, too. 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's rolled out of the furnace to load or remove work. This lost energy has to be replaced when the car is returned to the furnace.

Energy Saving Methods:
- Review design of fixtures or baskets or other material handling to reduce weight
- Investigate alternate high strength material to reduce weight of the fixtures etc.
- Where possible reduce cooling of conveyors, belts, fixtures baskets etc. during their return from unloading to loading station.
- Use full loading of baskets, trays etc. to avoid multiple heating and cooling of material handling parts.
- For more information visit [http://www.oit.doe.gov/bestpractices/process_heat/](http://www.oit.doe.gov/bestpractices/process_heat/)

Water-cooling Losses

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

Energy Saving Methods:
- Insulate water or air cooled parts to reduce heat losses.
- Look for cracks, breaks and erosion of insulation on water-cooled parts. Repair and maintain the insulation.
- Reduce or eliminate use of water-cooled components by using high temperature materials for the components where possible.
- For more information visit [http://www.oit.doe.gov/bestpractices/process_heat/](http://www.oit.doe.gov/bestpractices/process_heat/)

Wall Losses

Description:
The furnace wall 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. Once that heat reaches the outer skin of the furnace and radiates to the surrounding area or is carried away by air currents, it has to be replaced by an equal amount taken from the combustion gases. This process will continue as long as the furnace is at an elevated temperature.

Energy Saving Methods:
- Look for cracks, breaks and erosion of insulation. Repair and maintain furnace insulation.
• Use proper insulation and thickness to reduce furnace casing or surface temperature while rebuilding the furnace.
• Consider use of low weight, fiber insulation when appropriate.
• Account for process atmosphere composition (i.e. presence of hydrogen) in the furnace while selecting and sizing the insulation.
• Reduce or eliminate external wall cooling if used.
• For more information visit http://www.oit.doe.gov/bestpractices/process_heat/

Opening Losses

Description:
Furnaces and ovens operating at temperatures above 1000°F may have significant opening losses hot surfaces radiate energy to colder surfaces in their line of sight, and the rate of heat transfer increases with the fourth power of the surface's absolute temperature. Anywhere or anytime there is an opening in the furnace enclosure, heat is being lost, often at a rapid rate. These openings include the furnace flues and stacks themselves, as well as doors left partly open to accommodate oversize work in the furnace.

Energy Saving Methods:
• Use and maintain proper seals to eliminate or reduce size of openings.
• Watch for proper closing and seals for doors, openings at moving or rotating parts such as rolls, conveyors, rotary kilns etc. Provide and maintain seals.
• Look for cracks or breaks in seals for components (burners, feed pipes, cooling tubes) attached to the furnace. Repair and maintain the seals.
• Consider use of "radiation shields" or sight glasses with covers to reduce radiation heat losses.
• For more information visit http://www.oit.doe.gov/bestpractices/process_heat/

Other Losses

Description:
There are a number of other losses such as exposed hot parts. Hot waste material (loose material or scale coming off the load) that can result in heat loss from the furnaces. These losses can be prevented by proper material handling, taking care in loading of the furnaces, process control to avoid discharge of hot materials etc. The operators should watch for such losses during normal

Energy Saving Methods:
• Eliminate reduce exposure of hot parts. Where possible, insulate hot parts (such as rolls, shafts, sticking, support components) that are sticking out of the furnace.
• Maintain process conditions to eliminate or reduce scaling or discharge of hot materials form the heating system.
• For more information visit http://www.oit.doe.gov/bestpractices/process_heat/

Heat Storage
**Description:**
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 Heat Storage will be held in the structure until the furnace is shut down. Then it will leak out into the surrounding area. The more frequently the furnace is cycled from cold to hot and back to cold again, the more times this stored heat will have to be replaced. In addition, because the furnace can't run production until it has reached the proper operating temperature the process of storing heat in it entails lost production time — fuel is being consumed with no useful output.

**Energy Saving Methods:**
- Schedule production and use of the furnace to avoid repeated heating and cooling.
- Where possible keep the furnace in "banking condition" to retain heat in the furnace when it is not in use.
- Use low density refractory material for furnace insulation and structural parts.
- Minimize the furnace openings during the non-operating periods. Keep the doors closed.
- Minimize air entrainment in the furnace during cooling periods. Where possible, minimize the stack opening by covering it with only a small gap.
- For more information visit [http://www.oit.doe.gov/bestpractices/process_heat/](http://www.oit.doe.gov/bestpractices/process_heat/)

**Flue Gas Losses**

**Description:**
This is the biggest loss of all. Flue Gas Loss also known as Waste gas loss or stack loss is made up of the heat that can't be removed from the combustion gases inside the furnace. There's a reason for this: heat, like water, flows downhill, and once there is no temperature difference between the heat source and the load, all heat transfer stops. In effect, the heat stream has hit bottom. If, for example, a furnace is heating products to 1500°F the combustion gases cannot be cooled below this temperature. Once they reach the same temperature as the furnace and load, they can't give up any more energy to them, so they have to be discarded. At this temperature, they still contain about half the thermal energy put into them, so the waste gas loss is close to 50%. The other half, which stayed in the furnace, is called available heat. After heat storage and wall, conveyor, cooling media and radiation losses take what they need; the load absorbs anything left over.

From this, it's 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.

**Energy Saving Methods:**
- Maintain appropriate level of oxygen in flue gases by controlling air-fuel ratio for the burners.
- Maintain and control burner operations to eliminate formation of soot or combustible gases such as carbon monoxide and hydrogen in flue gases.
- Eliminate or reduce air leakage in the furnace. See "Opening Losses” and “Flue Gas Loss” sections.
- Consider use of heat recovery from flue gases. Review various methods described in "Waste heat Recovery” section above.
- Where appropriate, consider use of oxygen enrichment of combustion air to reduce mass of flue gases.
Specific Steps to Increasing Energy Efficiency Through Reduction in Exhaust Gas Heat Losses

The exhaust gas heat losses can be calculated by the equation:

\[
\text{Furnace exhaust heat losses} = W \times Cp \times (T_{\text{exhaust}} - T_{\text{ambient}})
\]

Where
- \( W \) = Mass of the exhaust gases.
- \( Cp \) = Specific heat of the exhaust gases
- \( T_{\text{exhaust}} \) = Flue gas temperature entering the furnace exhaust system (stack)
- \( T_{\text{ambient}} \) = Ambient temperature (usually assumed 60 deg. F.)

The highest priority is to minimize exhaust gas temperature and mass or volume of exhaust gases.

- The furnace exhaust gas temperature depends on many factors associated with the furnace operation and heat losses discussed above. It can be measured directly or can be assumed to 100 F. to 200 F. above the control temperature from the furnace zone where the flue gases are exhausted.

- The exhaust mass flow depends on the combustion airflow, fuel flow and the air leakage into the furnace. Measurement of fuel flow together with the oxygen (or Carbon Dioxide – CO2) percentage in the flue gases can be used to estimate mass or volume of exhaust gases.

- The flue gas specific heat \( Cp \) for most gaseous fuel fired furnaces can be assumed to be 0.25 Btu/(Lb. Deg. F.) or 0.02 Btu/(std. Cu/ft. deg. F.) for a reasonably accurate estimate of flue gas heat losses.

Minimize Exhaust Gas Temperatures. Excessive exhaust gas temperatures can be the result of poor heat transfer in the furnace. If the combustion gases are unable to liberate the maximum possible heat to the furnace and its contents, they will leave the furnace at higher temperatures than necessary. Optimizing heat transfer within the furnace requires different methods for different situations. The Tip Sheet on Furnace Heat Transfer provides greater insight into how transfer takes place and what can be done to improve it.

Overloading a furnace can also lead to excessive stack temperatures. To get the proper rate of heat transfer, combustion gases must spend a certain amount of time in the heating chamber. The natural tendency of an overloaded furnace is to run colder than it should – unless the temperature is set artificially high. This causes the burners to operate at higher-than-normal rates, with an accompanying increase in combustion gas volumes. The higher gas flow rates, the shorter their residence times in the furnace and the poorer the heat transfer. Increased volumes of hotter flue gases lead to sharply increasing heat losses. Over ambitious production goals may be met, but at the cost of excessive fuel consumption.

Minimize Exhaust Gas Volumes. Avoiding overloading and optimizing heat transfer are two ways to lower waste gas flows, but there are others. The most potent one is exercising close control of fuel-air ratios. By operating the furnace close to the optimum ratio for the process, fuel consumption is closely controlled. This best part of this is that it can usually be done with the existing control equipment – all that's required is a little maintenance attention. The "Check Burner Air-Fuel Ratios" Tip Sheet provides a useful chart for figuring exhaust gas losses and shows how to figure the efficiency improvements that
can come from controlling ratios more closely.

Some reduction in exhaust volumes will be the indirect result of efficiencies applied elsewhere. As pointed out earlier, flue gas losses are a fixed percentage of the total heat input to the furnace, so any reduction in heat storage, wall, conveyor or radiation losses will be multiplied by the available heat factor.

For example, on a furnace operating at 50% available heat (50% exhaust gas loss), lowering wall losses by 100,000 Btu/hr will permit a firing rate reduction of 200,000 Btu/hr – 100,000 for the wall loss and 100,000 for the accompanying exhaust gas loss.

**Maintain 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 temperatures and thermal efficiencies.

Combustion systems can be operated at other ratios, however. Sometimes it’s done deliberately to obtain certain operating benefits, but often, it happens simply because the burner system has been allowed to get out of adjustment.

The ratio can go either rich (excess fuel or insufficient air) or lean (excess air). Either way, it wastes fuel. Because there’s not enough air for complete combustion, operating rich wastes fuel by allowing it to be discarded with some of its energy unused. It also causes the generation of large amounts of CO and UHCs.

At first glance, operating lean might seem to be a better proposition because all the fuel is consumed. Indeed, lean operation doesn’t produce the flammable, toxic by-products of rich combustion, but it does waste energy.

Excess air has two effects on the combustion process. First, it lowers the flame temperature by diluting the combustion gases, in much the same way cold water added to hot will produce warm water. This lowers the temperature differential between the hot combustion gases and the furnace and load they’re heating, and this makes heat transfer less efficient. More damaging, however, is the increased volume of gases to be exhausted from the process – the products of stoichiometric combustion, plus the excess air, and they’re all at the same temperature. The excess air becomes one more competitor for the energy released in the process. Because it’s 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 get theirs. The results can be dramatic – in a process operating at 2000°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) will knock the available heat down 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 will have to be burned.

**Reduce Air Infiltration.** Excess air doesn’t necessarily have to enter the furnace as part of the combustion air supply – it can also infiltrate from the surrounding room if there’s a negative pressure in the furnace. Because of the draft effect of hot furnace stacks, negative pressures are fairly common, and cold air will slip past leaky door seals and other openings in the furnace. Once in the furnace, it absorbs precious heat from the combustion system and carries it out the stack, lowering the furnace efficiency. A furnace pressure control system may be an effective way to deal with this – see the “Air Infiltration” Tip Sheet for guidelines on estimating infiltration losses.

The bottom line is that to get the best possible energy efficiency from furnaces and ovens, reduce the amount of energy carried out by the exhaust and lost to heat storage, wall conduction, conveying and cooling systems and radiation.

**Waste Heat Recovery:**
Reducing exhaust losses should always be the first step in a well-planned energy conservation program. Once that goal has been met, it’s time to consider moving to the next level – waste heat recovery.

Waste heat recovery elevates furnace efficiency to higher levels, because it extracts energy from the exhaust gases and recycles it to the process. Significant efficiency improvements can be made even on furnaces that are operating with properly tuned ratio and temperature controls. There are four widely used methods:

1. If exhaust gases leaving the high temperature portion of the process can be brought into contact with a relatively cool incoming load, energy will be transferred to the load, preheating it and reducing the energy that finally escapes with the exhaust. This is the most efficient use of waste heat in the exhaust, but it requires a continuous process. More often, heat is transferred to a surrogate medium, like combustion air to the burner system. This reduces the amount of purchased fuel required to sustain the process. This requires the use of a recuperator, regenerator or waste heat boiler.

2. A Recuperator is a gas-to-gas heat exchanger placed on the stack of the furnace. There are numerous designs, but all rely on tubes or plates to transfer heat from the outgoing exhaust gas to the incoming combustion air, while keeping the two streams from mixing. They are the most widely used heat recovery devices.

3. Regenerators are basically rechargeable storage batteries for heat. A regenerator is an insulated container filled with metal or ceramic shapes capable of absorbing and storing relatively large amounts of thermal energy. During part of the operating cycle, process exhaust gases flow through the regenerator, heating the storage medium. After a while, the medium becomes fully charged, so the exhaust flow is shut off and cold combustion air is admitted to the unit. As it passes through, the air extracts heat from the storage medium, increasing in temperature before it enters the burners. Eventually, the heat stored in the medium is drawn down to the point where it’s necessary to recharge the regenerator. At that point, the combustion airflow is shut off and the exhaust gases return to the unit. This cycle repeats as long as the process continues to operate. Obviously, if the process is to operate without interruption, at least two regenerators and their associated burners are required – one to provide energy to the combustion air while the other is recharging. In this sense, it’s much like a using a cordless power tool – to use it continuously; you must have at least two batteries to swap out between the tool and the recharger.

4. Waste Heat Boilers are an option for plants needing a source of steam or hot water. They are similar to conventional boilers with one exception – the exhaust gas stream from a process furnace instead of their own burners heats them. Waste heat boilers may be the answer for plants seeking added steam capacity, but remember that the boiler generates steam only when the process is running. Not all processes are candidates for waste heat recovery. Exhaust volumes and temperatures may be too low to provide financial justification, but if the exhaust temperature is above 1000°F, waste heat recovery is worth looking into. For guidance on how to estimate the efficiency and economic benefits of preheating combustion air, refer to the “Preheated Combustion Air” Tip Sheet.
Energy Reduction and Recovery Strategy

A comprehensive program for reducing furnace energy consumption involves two sets of activities. The first set deals with getting the best possible performance out of the existing equipment. Equipment modifications, if required, are relatively modest. The second involves major equipment modifications and upgrades that can make substantial reductions in energy consumption. These techniques and their benefits are summarized in the table below.

Area of Potential Improvement

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<thead>
<tr>
<th>Energy Conservation Technique</th>
<th>Heat Transfer To Load</th>
<th>Reduction of Exhaust Gas Mass</th>
<th>Temperature Uniformity</th>
<th>Productivity</th>
<th>Refer to Tip Sheet Number</th>
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*Tip Sheet Numbers refer to specific guidelines for each technique.*