4. Process Heating Systems

Nearly all process heat used in chemical manufacturing can be classified as batch/continuous processes with indirect/direct heating methods provided by fuel or steam energy sources. This chapter will identify best practices in process heating for the chemical industry as a whole. Use of these practices will provide the highest energy savings for the lowest initial capital investment.

4.1 Overview

Process heating is essential to the production of consumer and industrial goods. Industry-wide, it accounts for 5.2 quads, or nearly 17% of total industrial energy consumption in the U.S. [USDOE OIT, 2001].[17] Figure 2.1 illustrates the types of energy used in process heating applications. As the figure indicates, about 92% of process heat energy is directly provided by fossil fuel sources.

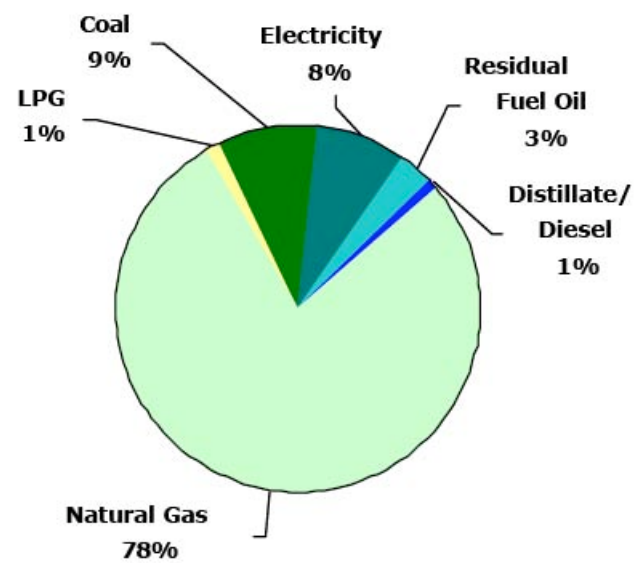

Figure 4.1 Types of Energy Used for Process Heating[18]

Energy efficiency gains have helped to alleviate the demand for energy in process heating applications, and they are expected to help alleviate future energy consumption. The expected increase in energy demand for process heating will not be offset by the current gains in energy efficiency, therefore resulting in an overall net increase in the demand for energy as the chemical industry grows. Figure 4.2 displays projected energy demand increases for process energy by the year 2015 for several important industry sectors.

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[17] U.S. Department of Energy: Office of Industrial Technologies, *Roadmap for Process Heating Technology*, March 2001.
[18] Energy Information Administration, *Manufacturing Consumption of Energy 1994*, Report Number DOE/EIA-0214, December 1997.

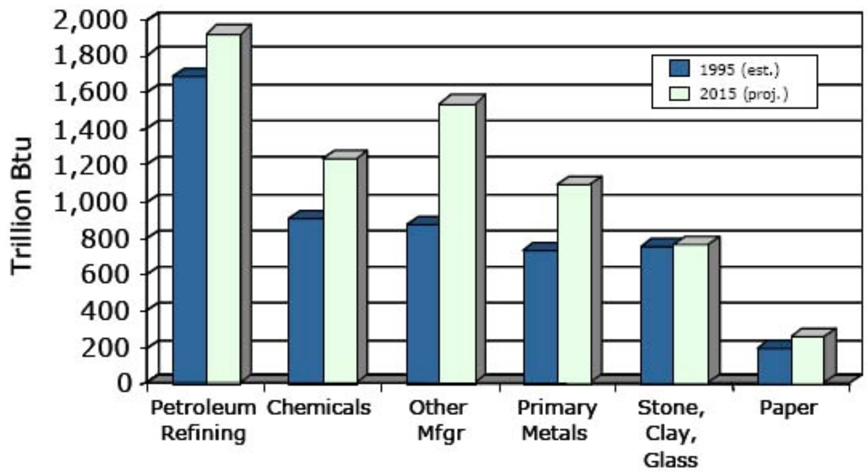

Figure 4.2 Projected Energy Demand for Process Heat[19]

Within the chemical industry, approximately 1.05 quads are consumed for process heating alone. This represents about 32% of the total energy consumption of the industry. According to the projections displayed in Figure 4.2, by the year 2015 consumption will jump by 20% to nearly 1.25 quads of energy consumption for process heat use. Since nearly 92% of this energy will come from the volatile fossil fuel industry, energy efficiency measures must be taken.

Due to low efficiency levels of equipment currently being used in the chemical industry, the opportunity for energy savings is limited. The most simplest, most significant opportunities for savings using currently installed equipment lie in the application of energy efficiency measures known as best practices. Further research and development will improve the energy efficiency of new equipment. With the concurrent use of advanced technologies, new operating practices, and implementation of best practices, reductions of 5 to 25% in energy consumption are possible over the next 10 years.[20]

The rest of this chapter will provide additional general information on process heating and its applications in the chemical industry. This information may be useful in indicating where best practices can be implemented.

4.2 Explanation of Use

Process heat is used to supply heat energy during the manufacture of basic materials and goods. Process heating is very energy intensive, accounting for a large percentage (10% to 15%) of total production costs. Typical process heating components used in the chemical industry are boilers, fired heaters, heated reactors, distillation columns, calciners, dryers, heat exchangers etc. Common to all chemical process heating applications is the transfer of heat energy to the product material being treated. Process heating systems typically include a heating device that generates and supplies heat, heat transfer devices for transferring heat energy from the sources to the product, a heat containment structure, and a heat recovery device (Figure 4.3).[21]

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[19] Gas Research Institute, *Industrial Trends Analysis 1997*, Report Number GRI-97/0016, January 1997.
[20] U.S. Department of Energy: Office of Industrial Technologies, *Roadmap for Process Heating Technology*, March 2001.
[21] U.S. Department of Energy: Office of Industrial Technologies, *Roadmap for Process Heating Technology*, March 2001.

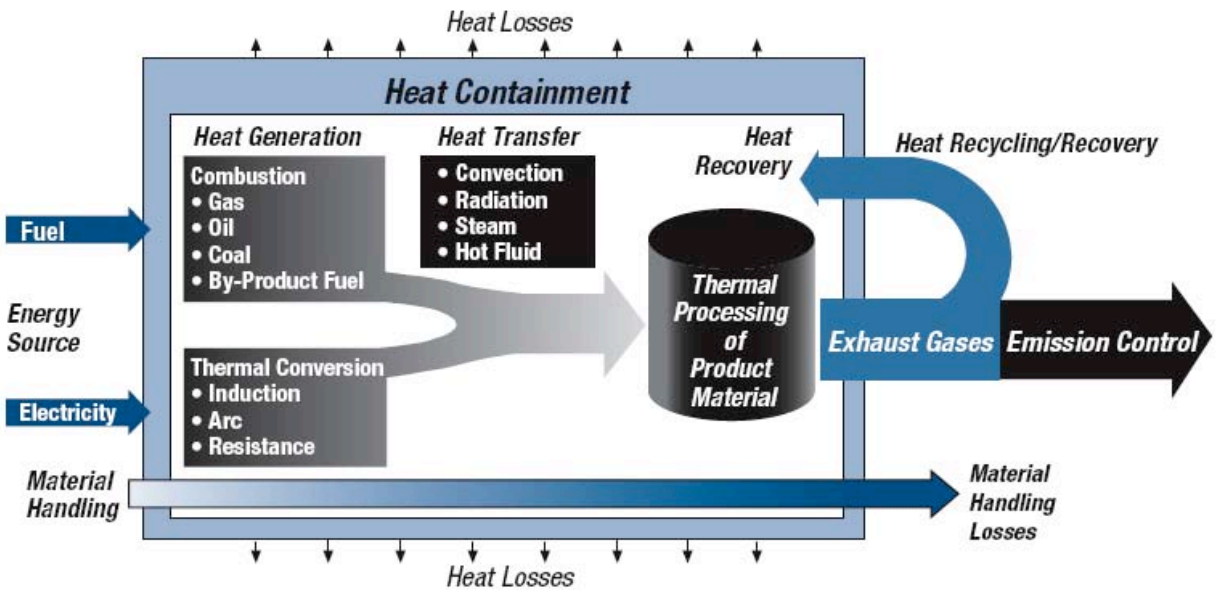

Figure 4.3 General Schematic of a Typical Process Heating System[22]

In addition, most operations have control systems that coordinate the process, its materials handling, atmospheric needs, and safety. The means in which process heat is applied and the temperature used are dependant on the industrial application in the chemical industry. Temperatures can range from less than 300ºF to more than 3,000ºF. Some process heating operations are continuous and heat several tons of material per hour, while other operations are slow, precise, and heat small batches according to very accurate time/temperature profiles.

In all instances, heat is transferred to the product directly from the heat source, indirectly through the heat containment vessel, or through other mechanisms such as jets or hot gas recirculation. Typically, the operation is conducted in some form of heat containment enclosure. Depending on design, anywhere from 10 to 25% of the heat supplied may be lost through the enclosure. In addition, the flue gas exiting the heating equipment may contain anywhere from 20-70% of the heat input, especially in combustion-based heating equipment. Most enclosures, especially those performing high-temperature operations, include some type of heat recovery device to recycle waste heat. Improper cooling of the enclosure combined with inadequate heat recovery can result in losses of 5-20% of heat input. Finally, most chemical operations also incorporate control systems to optimized the performance of the process heat application, which, in turn, can save anywhere from 5-30% in energy costs.[23] For these reasons, the implementation of energy-reducing best practices is ideal in the realm of process heating.

4.2.1 Generation

The first step in any chemical process system operation is generating heat for process heating. Although electricity can be used to generate the process heat being required, the chemical industry relies most heavily on the methods described below.

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[22] U.S. Department of Energy: Office of Energy Efficiency and Renewable Energy, *Improving Process Heating System Performance a Sourcebook for Industry*, 2001.

- Direct-fired burners or heat transfer devices—These devices are intended to supply either direct or indirect heat to process streams containing the reactants and products essential to the manufacture of chemical goods, and to provide heat energy to heat transfer fluids needed for process operations. The most common heat transfer fluid is steam produced by boilers using direct-fired burners powered by natural gas, by-product gases, fuel oils, coal, or other types of solid fuels. (The generation of process steam, while extremely important to the chemical industry, can be considered in the same way as process heat generation. Further explanation on the generation of steam for process steam systems is provided in Chapter 5.) Other heat transfer fluids used in industry include water, hot oil, liquids, air, and other gases. In most cases, these heat-transfer fluids are heated directly by fuel-fired processes or indirectly by steam.

- Cogeneration systems—A boiler is used to produce steam that, in turn, powers a steam turbine that creates electricity and heat for process heating. An alternate route is to use a gas turbine and heat recovery boiler.

Steam heating is used for heating fluids through heat exchangers, direct contact heating of fluids, and other heating such as tracing of utility or product distribution lines, vessels and reactors.

4.2.2 Process Uses

Although there is a very broad range of process uses and operations in the chemical industry, commonalities allow them to be grouped into the following categories:

- fluid heating
- calcining
- drying
- curing and forming
- other process heating operations

Table 4.1 provides a list of specific processes linked to the five generic process use operations presented in section 4.2.2.

Table 4.1 Typical Process Heating Applications Found in Industry[23]

Fluid Heating	Calcining	Drying	Curing and Forming	Other Heating
- Air Heating - Cat Reforming - Distillation - Fluid Cracking - Hydro-treating - Liquid Heating - Quenching Systems - Reforming - Visbreaking	- Cement - Coke - Calcining - Mineral - Calcining - Ore Calcining	- Crude Oil - Food and Kindred Products - Ladle and Vessel - Molds and Cores - Natural Gas - Powder (Metal and Non Metal) - Pulp and Paper - Resin	- Ceramics - Clay - Glass - Metal (Ferrous and Non-Ferrous) - Resin and Plastic - Heat Forming - Thermal Forming - Paint and Organic Coatings	- Atmosphere Systems - Gas Cleaning - Gasification - Pyrolysis - Waste Treatment - Incineration - Regenerative Chambers

Fluid Heating

Fluid heating is performed for a wide range of purposes in chemical industry operations. Using fuel-fired heaters, steam-heated chemical reactors, or heat exchangers, fluids (gases or liquids) are heated in both batch and continuous processes to induce or moderate a chemical reaction. Steam heating, perhaps the most common type of fluid heating used in the chemical industry, is used in heat exchangers, direct contact heating of fluids, and other methods such as tracing of utility or product distribution lines, vessels and reactors. More information on steam system specifics is provided in Chapter 5.

Calcining

Calcining is the removal of chemically bound water and/or gases, such as carbon dioxide, through direct or indirect heating. Calcining is common in the preparation of raw materials, as well as the production of intermediate or final products.

Drying

Drying is the removal of free water through direct or indirect heating. It is common in the chemical industry where the moisture content of raw materials such as clay or sand must be reduced. Drying is also key to removing water from Distillers Dried Grain Products common to the ethanol industry. There are several types of dryers, including but not limited to, conveyor, fluidized bed, rotary, and cabinet.

Curing and Forming

Heating material in a controlled manner to promote or control a chemical reaction is called curing. In chemical and plastics applications, curing is the cross-linking reaction of a polymer. Curing is common in the application of coatings to several products produced by the chemical industry. Forming operations, such as extrusion and molding, use process heating to improve the workability of rubber, dry substances such as powdered paints, and miscellaneous plastics.

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[23] U.S. Department of Energy: Office of Energy Efficiency and Renewable Energy, *Improving Process Heating System Performance a Sourcebook for Industry*, 2001.

Specific Heat Transfer Operations

Many process-heating applications do not fall into any of the above categories; however, they collectively account for a significant amount of industrial energy use. Common applications that use process heating include controlling a chemical reaction and establishing favorable physical or mechanical properties (e.g., plastics production). Some of the systems that fall under this classification are thermal oxidizers, high-temperature exothermic or endothermic processes using catalysts, thermal cleaners, flares etc.

Many previously mentioned processes use heat exchangers to transfer heat energy to the process stream. Freestanding heat exchangers are also used in the chemical industry, mostly in applications of heat recovery and further heating of process streams. Many different types and variations of heat transfer equipment can be applied to different applications. The major types are:

- plate coil
- plate-and-frame
- spiral heat exchanger
- bare tube
- finned tube
- shell-and-tube

Freestanding exchangers are the most common source of process heat exchange in the chemical industry. They serve many purposes ranging from complex temperature control of process streams in continuous flow operations to simple warming of batch processes. Two configurations are found— process streams on both sides and a process stream on one side with the heat transport medium on the other.[24] The heat transport medium is generally composed of steam, hot oil/gas/water, or another hot process stream.

Heat transfer units can be made of many different materials depending on the needs and requirements of the process. Each type of unit has criteria for proper application and design. In the selection process it is not only important to understand the advantages of each type of heat transfer unit, but it is equally important to understand the disadvantages. One type of heat transfer unit will work extremely well in one application, but may perform poorly in another.

The construction materials used in heat exchangers depend on the fluids, vapors, temperatures, and pressures in the system. To determine the most cost-effective unit for an application, initial costs must be measured against the expected lifecycle and maintenance requirements. The entire unit as well as any of its components can be made of stainless steel, copper-nickel, copper, Alloy 20, or other special alloys. Selection of materials involves careful consideration of these factors:

- initial cost
- longevity

[24] U.S. Department of Energy: Industrial Technologies Program, *Chemical Bandwidth Study*, December 2004.

- maintenance
- performance
- corrosion resistance

All units should be evaluated on a 10-year operation basis, including:

- initial cost
- maintenance cost
- down time losses, due to failure or performance loss
- replacement cost (if unit fails)
- heat transfer equipment can be made to last one year, five years, ten years or more, depending on the selection of materials and installation versus cost.

4.2 Process Heating Best Practices

Table 4.2 and Figure 4.4 are intended to be used as a quick reference to identify possible areas of improvement within a generic chemical process heating system, categorized by the type of process heating component being considered. The rest of the chapter provides more detailed information describing the best practices found in Table 4.2 and elaborates on additional energy efficiency measures that may be taken to ensure an efficiently operating process heating system.

Table 4.2 General Process Heating Best Practice Information[25]

Process Heating Component	Energy Saving Method	Energy Saving Potential (% of current use)	Typical Implementation Period	Typical Payback	Example Activities
1. Heating Generation	Efficient combustion (burners) and operation of other heat generating equipment	5%-25%	1 week to 2 months	1 to 6 months	Maintain minimum required free oxygen (typically 1%-3%) in combustion products from burners for fuel-fired process heating equipment Control air-fuel ration to eliminate formation of excess carbon monoxide (CO), typically more than 30-50 ppm, or unburned hydrocarbons. Eliminate or minimize air leakage into the direct-fired furnaces or ovens.
2. Heat Transfer	Design, operation, and maintenance of furnaces and heating systems to increase heat transfer from heat source to process or load	5%-15%	3 months to 1 year	6 months to 1 year	Select burners and design furnaces that allow use of high convection or radiation in processes and loads. Clean heat transfer surfaces frequently in indirectly heated systems, such as steam coils, radiant tubes, and electrical elements. Replace indirectly heated systems, such as radiant tubes, and enclosed electrical heating elements, where possible.
3. Heat Containment	Reduction of heat losses	2%-15%	4 week to 3 months	3 months to 1 year	Use adequate and optimum insulation for the equipment. Conduct regular repair and maintenance of insulation.
4. Heat Recovery	Flue gas heat recovery	10%-25%	3to 6 months	6 months to 2 year	Preheat combustion air. Preheat and/or dry the charge load. Cascade heat from exhaust gases to the lower temperature process heating equipment.
5. Sensors and Controls	Improved process measurements, controls, and process equipment	5%-10%	1 to 10 week	1 to 6 months	Develop procedures for regular operations, calibration, and maintenance of process sensors (i.e. pressure, temperature, and flow) and controllers
6. Process Models and Tools	Process models and design simulation to optimize equipment design and operations	5%-10%	2 weeks to 6 months	1 months to 2 year	Set appropriate operating temperatures for part load operations to avoid long "soak" or overheating.
7. Advance Materials	Reduction of nonproductive loads	10%-25%	2 weeks to 3 months	3 months to 2 year	Use improved materials, design, and applications of load support (fixtures, trays, baskets, ect.) and other material systems.

[25] U.S. Department of Energy: Office of Industrial Technologies, *Roadmap for Process Heating Technology*, March 2001.

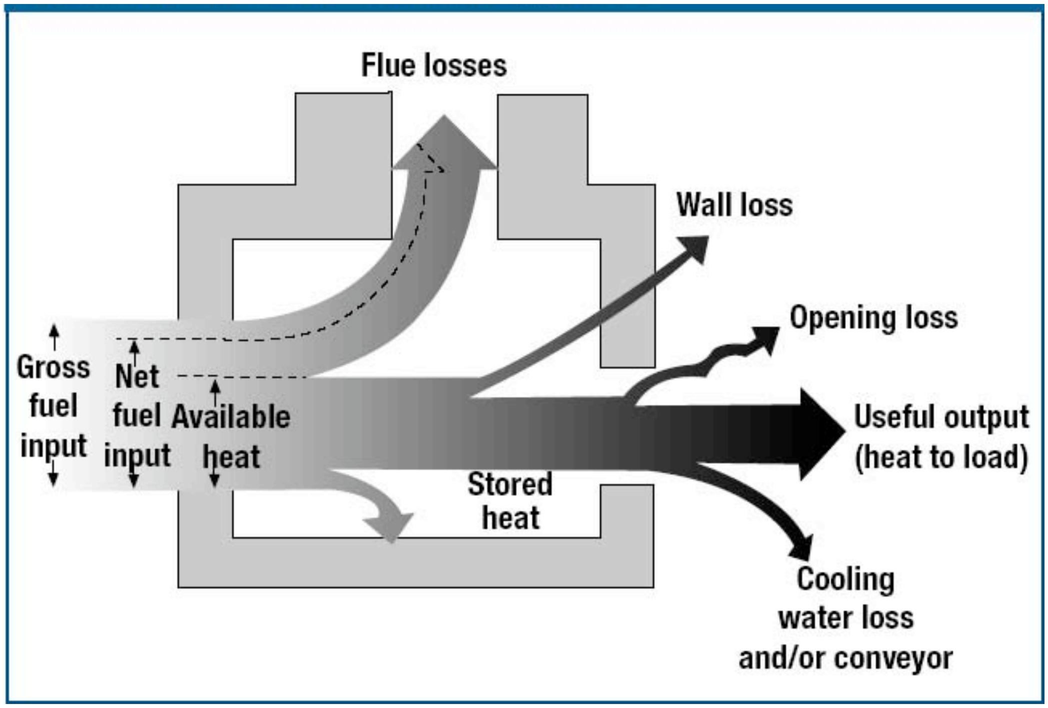

Figure 4.4 Schematic Indicating Heat Losses in a Generic Process Heating Application[26]

4.4 Heat Generation Best Practices

The best practices described in this section are applicable to all fired systems, including boilers and fired heaters. A single term—"process furnace" or just "furnace"— is used here to describe both of these fired systems. No matter their purpose, process furnaces typically are large sources of energy loss due to inefficient combustion, improper operation, and poor maintenance. Figure 4.4 provides a schematic of a generic process furnace; implementing best practices can minimize many of the energy losses noted in the diagram.

4.4.1 Reduce Flue Gas Losses

Exhaust gas is the most significant form of heat loss in heat generation equipment. Commonly called flue gas or stack gas loss, it occurs when heat can't be transferred from the combustion products to the desired operation in the process furnace. The total amount of heat available minus losses through flue gases is known as the available heat. This is the heat that stays in the system and can be used for process heating. Figure 4.5 displays the percentage of total heat input that is lost through the stack vs. exhaust gas temperature. The chart clearly indicates that the temperature of the process or, more correctly, the temperature of the exhaust gases is a major factor in the energy efficiency of the furnace. The higher the temperature, the lower the efficiency. The chart also indicates that the percentage of excess air is very influential to the final thermal efficiency of the furnace.

[26] U.S Department of Energy: Office of Energy Efficiency and Renewable Energy, *Waste Heat Reduction and Recovery for Improving Furnace Efficiency, Productivity and Emissions Performance*, 2003.

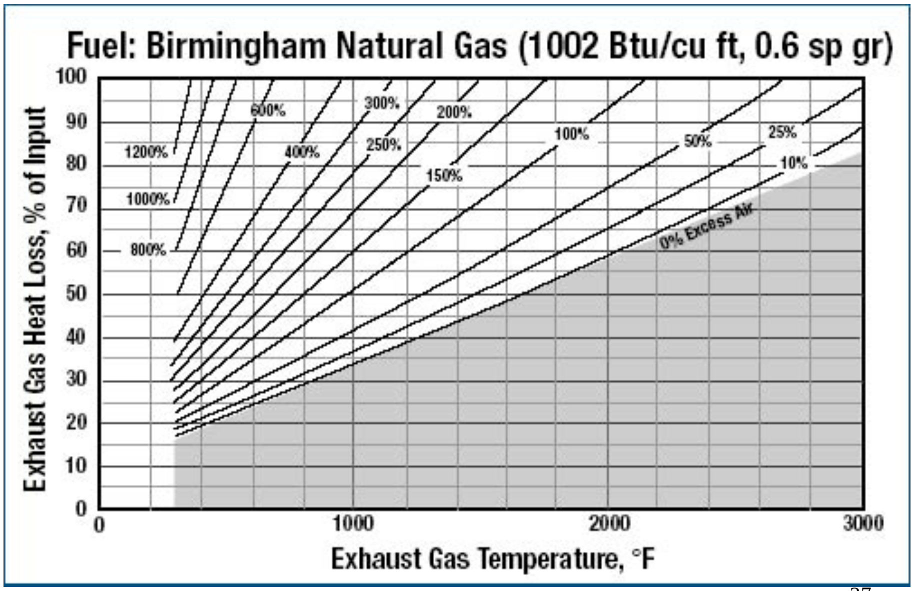

Figure 4.5 Exhaust Gas Heat Losses vs. Exhaust Gas Temperature[27]

Best Practices—Reducing Exhaust Gas Losses

- Monitor and maintain the proper level of O_2 concentration, 2-3%, by operating at the correct air/fuel ratio for the burner.
- Wherever possible, use heat recovery of flue gas to preheat incoming combustion air.
- Eliminate or reduce all sources of undesired air infiltration into the furnace.
- Perform proper maintenance on a regular schedule to reduce soot and other deposits on heat transfer surfaces, thus ensuring efficient transfer of heat to the process.

Best practices for exhaust heat loss reduction are quite extensive and within each practice, there are several options that are dependant on the equipment, and process parameters. A discussion of these options follows. .

Check Burner Air/Fuel Ratio

For every fuel used, an optimum or stoichiometric amount of air is required to produce the most efficient, highest temperature flame with the least amount of emissions. As indicated in Figures 4.5 and 4.6, process heating efficiency is considerably reduced if the air supply is significantly higher or lower than the required stoichiometric amount of air.[28] Most high-temperature, direct-fired furnaces, heaters, and boilers operate with about 10-20% excess combustion air at high fire to prevent the formation of dangerous carbon monoxide and soot deposits on heat transfer surfaces and inside radiant tubes.

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[27] U.S Department of Energy: Office of Energy Efficiency and Renewable Energy, *Waste Heat Reduction and Recovery for Improving Furnace Efficiency, Productivity and Emissions Performance*, 2003.

[28] U.S Department of Energy, Process Heat Tip Sheet Number 2, *Check Burner Air to Fuel Ratios*, May 2002.

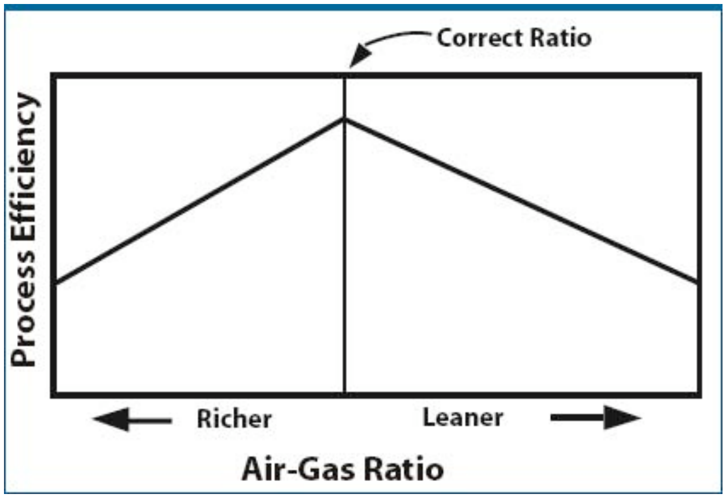

Figure 4.6 Effect of Air/Fuel Ratio on Efficiency [USDOE EERE, 2003]

Air-gas ratios can be determined by flow metering, flue gas analysis, or, occasionally, a combination of both methods. Figure 4.5 indicates that the larger the percentage of excess air used while operating at a set exhaust gas temperature, the larger the amount heat lost through flue gas exiting the stack, and, therefore, the smaller amount of available heat for the process. Although this chart was developed for natural gas fuel, it can be used to approximate air-fuel fuels for propane, fuel oils, coal etc. It is not applicable for byproducts fuels containing large amount of H2, CO or noncombustible gases such as N2, CO2, etc.

Best Practices—Check Burner Air/Fuel Ratio

- Regularly monitor airflow rate or exhaust gas composition.
- Determine the optimum level of excess air for operating your equipment.
- Set combustion ratio controls to maintain that amount of excess air.
- Maintain excess air in the 10-20% range.
- Maintain a 2-3% O_2 concentration in exhaust gas.
- Maintain a CO concentration of no more than 350 ppm.

Preheating of Combustion Air

Waste heat recovery elevates furnace thermal efficiency because it extracts energy from the exhaust gases and recycles it to the chemical process. Significant improvements in efficiency can be achieved even on furnaces that are operating with improperly tuned burners. One of the most effective ways to recover waste heat from the exhaust gas is by using it to preheat incoming combustion air. A heat exchanger, placed in the exhaust stack or ductwork, can extract a large portion of the thermal energy in the flue gases and transfer it to the incoming combustion air. Recycling heat this way will reduce the amount of the purchased fuel needed by the furnace. Table 4.3 indicates the possible decrease in fuel energy input that can be obtained by preheating incoming combustion air.

Table 4.3 Fuel Savings % from Using Preheated Combustion Air[29]

Furnace Exhaust Temperature, °F	Preheated Air Temperature, °F					
	600	800	1,000	1,200	1,400	1,600
1,000	13	18	—	—	—	—
1,200	14	19	23	—	—	—
1,400	15	20	24	28	—	—
1,600	17	22	26	30	34	—
1,800	18	24	28	33	37	40
2,000	20	26	31	35	39	43
2,200	23	29	34	39	43	47
2,400	26	32	38	43	47	51

Combustion air can be preheated with recuperators, which are gas-to-gas heat exchangers placed on the furnace stack. Internal tubes or plates transfer heat from the outgoing exhaust gas to the incoming combustion air, while keeping the two streams from mixing. They are available in a wide variety of styles, flow capacities, and temperature ranges. A typical installation used in chemical industry is shown in Figure 4.7. In this case, combustion air supplied by a forced draft (FD) air fan is preheated by using flue gases before using it in burners.

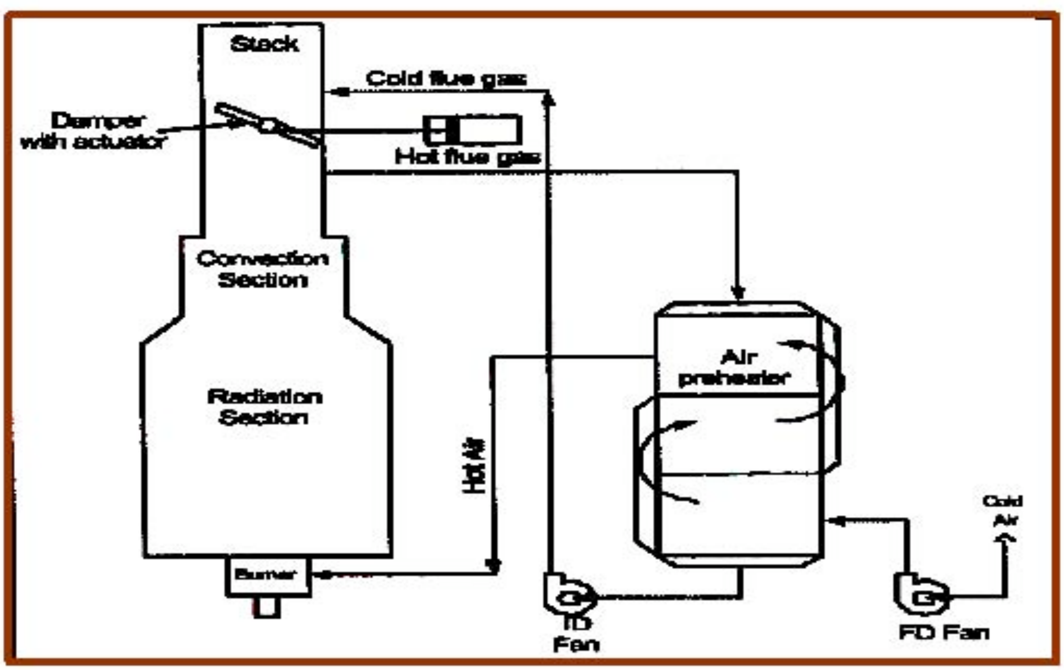

Figure 4.7 Typical Recuperator Installations

[29] U.S. Department of Energy, Process Heat Tip Sheet Number 1, *Preheated Combustion Air*, May 2002.

Best Practices—Preheating of Combustion Air

- Consider various options for recovering heat from flue gases.
- Rule of thumb for beginning analysis: Processes operating at or above 1600ºF are good candidates for air preheating, while process operating near or below 1000ºF may not be justified. Those operating within the range of 1000 to 1600º may still be good candidates but should be considered on a case-by-case basis.[30]

Reducing Air Infiltration into Furnace

Excess air can enter the furnace by other means than combustion air. Air infiltration due to negative pressure and improper seals has the same effect on furnace efficiency as excess combustion air. The infiltrated air has to be heated to the flue gas temperature before it leaves the furnace through the stack, resulting in loss of energy and reduction in efficiency.

Furnace draft, or negative pressure, occurs in fuel-fired furnaces when high-temperature gases are discharged from the system at a level higher than the location of the furnace openings. This is commonly known as the "chimney effect." In a furnace operating at a fixed temperature, the negative pressure, or draft, changes with the heat input rate or mass flow of flue gases going through the stack.

Furnace pressure controllers regulate and stabilize the pressure in the working chamber of process-heating equipment. Typically, a pressure gauge in the furnace chamber or duct regulates the airflow to maintain a slightly positive pressure (a few one-hundredths of an inch of water gauge) in the furnace chamber. Airflow can be regulated by varying the speed of draft fans or by changing damper settings for the incoming combustion air or the exiting flue gas. Four different types of draft systems can be found in industrial furnaces used in the chemical industry.

- Natural (uses the *chimney effect*)—Gases inside the stack are less dense and will rise, creating a vacuum that draws air into the furnace.
- Induced—A fan draws air from the furnace into the stack.
- Forced—A fan pushes air into the furnace.
- Balanced—Both induced- and forced-draft fans are used.

Pressure controllers can be manual or automatic. An equipment operator, typically using a dial on a control panel, sets the pressure in manual systems. Automatic systems have a feedback loop and continuously monitor and regulate the pressure through an electronic control system.

Many process furnaces used in chemical industry employ a natural draft system to supply combustion air to the burners. In these instances, it’s neither possible nor easy to control negative pressure in the furnace. In such cases, the only option is to take steps to eliminate or reduce the openings through which cold air enters the furnace, such as:

- Areas around the heater tubes, commonly known as heater penetration area
- Bolted casings that may have a small gap between the furnace casing and the bolted

[30] U.S. Department of Energy, Process Heat Tip Sheet Number 1, *Preheated Combustion Air*, May 2002.

component (i.e. access doors etc.)

- Old, cracked or damaged gaskets used for seals or other areas
- Explosion doors that are not properly fitted

Best Practices—Reducing Air Infiltration into Furnace

- Use a draft (pressure) control system where possible to maintain a slightly positive pressure. The furnace pressure can be controlled using a damper on the combustion air blower or by installing a damper in the furnace exhaust stack.
- Minimize the draft (negative pressure) in an induced-draft system by reducing the openings through which cold air enters the furnace.
- Specify and use a forced-draft system with pressure control in future rebuilds or for new heaters.
- Check seals for leaks using a “smoke” device. Damaged seals will all air to leak into the furnace and therefore, must be repaired or replaced.
- Perform regular inspections. Bi-annual checks are recommended.

4.3.2 Proper Furnace Maintenance

Proper maintenance should always be performed on the process furnace at scheduled intervals. Scheduled maintenance ensures long-term efficient operation. The key is proactive maintenance, not reactive repairs.

Best Practices—Performing Proper Furnace Maintenance

- Keep heat transfer surfaces on indirect heat generation furnaces clean and free of deposits and soot.
- Ensure burner is operating properly and most efficiently within the limits set by controls and operators.
- Continuously inspect the furnace enclosure for any forms of deterioration or safety issues.

4.4 Heat Transfer Best Practices

While the most significant source of heat loss is exhaust, other heat loss areas are evident as well. Using best practices to increase the efficiency of heat transfer to process streams and other heat transfer mediums may also reduce energy consumption. Many of the best practices listed for heat transfer scenarios will be explained using steam as a heat transfer medium. Although it is not the only heat transfer medium used by industry, steam the most common. For additional information on steam as a heat transfer medium and its uses in industry, see Chapter 5.

4.4.1 Optimize Generation Heat Transfer

Best practices often fall into the category of “using the proper equipment for the job.” If economically feasible, one should always select equipment for a retrofit or new installation to perform at the optimum level. In the area of increased heat transfer to a process stream, this often means using burners and furnaces that effectively utilize convection and radiation. Eliminating indirect heat transfer, where possible, also enhances the efficiency of heat transfer equipment. The more effectively heat transfer to a process stream occurs, the less energy is loss and fuel costs are, in turn, reduced.

Best Practices—Optimize Generation Heat Transfer

- When economically feasible, select high-heat, transfer-rated equipment for retrofits and new installations.
- When contacting a vendor, select burners and/or have the vendor design furnaces that allow use of high convection or radiation in processes and loads.
- Replace indirectly heated systems and enclosed electrical heating elements where possible.

4.4.2 Optimize Heat Transfer Equipment Design

No matter the type of heat transfer equipment used—simple fin-tube heat exchanger or complex shell-and-tube heat exchanger—the design must be compatible with the desired operation. Thermal transfer can be increased by air elimination and proper space design. (Space design is equivalent to the surface area in direct contact with the steam or other heat transfer medium.) Optimum designs improve flow patterns and velocity over the heat transfer tube surfaces, fins, etc., which help scrub unwanted films away and account for the largest amount of heat transfer.

Best Practices—Optimize Heat Transfer Equipment Design

- When selecting new heat transfer equipment, make sure it's properly designed for the specific operation, employing the exact parameters inherent to the operation in order to eliminate trapped air and increase the heat transfer rate.
- Make sure all heat transfer units and equipment are installed and operating according to required TEMA (Tubular Exchanger Manufacturer Association) and ASME (American Society of Mechanical Engineers) designations, requirements, and codes. More information can be found at the respective websites, www.tema.org and www.asme.org.
- Air or non-condensable entrainment is very problematic to steam heat exchanger equipment. For more explanation and best practices for removal see Section 5.6.3.

4.4.3 Clean Heat Transfer Surfaces

Process heating systems in the chemical industry use a variety of methods to transfer heat to the load or material being processed. Heat transfer systems include direct heat transfer from flame or heated gases to the heater tubes and indirect heat transfer from radiant tubes, muffles, or heat exchangers. Indirect heating methods may use fuel firing, steam, or hot liquids to supply heat. In each of these cases, clean heat transfer surfaces can improve system efficiency. Deposits of soot, slag, and scale should be avoided.

Soot is a black substance formed by combustion that adheres to heat transfer surfaces. Slag is the residue formed by oxidation at the surface of molten metals; also it, too, can adhere to heat transfer surfaces. Soot and slag on heat transfer surfaces impedes the efficient transfer of heat and makes industrial heating systems less efficient. As shown in the Table 4.4, a layer of soot with a thickness of only 1/32-inch can reduce heat transfer by an estimated 2.5%.

Table 4.4 Table Indicating Effect of Soot on Heat Transfer

Soot Layer Thickness, Inches	1/32	1/16	1/8
Efficiency Reductions due to Soot Deposits*	2.50%	4.50%	8.50%

The extent to which the efficiency of heat transfer surfaces is impacted by dirt can be estimated from an increase in stack temperature relative to a "clean operation" or baseline condition. For every 40°F increase in stack temperature, efficiency is reduced by approximately 1%. Contamination of heat transfer surfaces due to soot or slag residue from combustion is typically the result of:

- low air-to-fuel ratios
- improper fuel preparation
- malfunctioning burner
- oxidation of heat transfer surfaces in high-temperature applications
- Corrosive gases or constituents in heating medium
- stagnant or low velocity areas in contact with heat transfer surfaces for hot liquid or gas heating systems
- special atmospheres (e.g., cracking furnaces or reformers) that can produce soot during the heating process
- particulates from the material being processed

Contamination from flue gas can also decrease equipment life and lead to maintenance problems that can cause downtime.

Problem areas for indirectly heated systems, where heating mediums such as steam, air, or hot liquids are used, include scale, dirt, oxide film, and/or fouling on the heat transfer surfaces that are in contact with the heating medium. Figure 4.8 shows typical resistant film buildup on a tube used in an indirect steam heat transfer system.

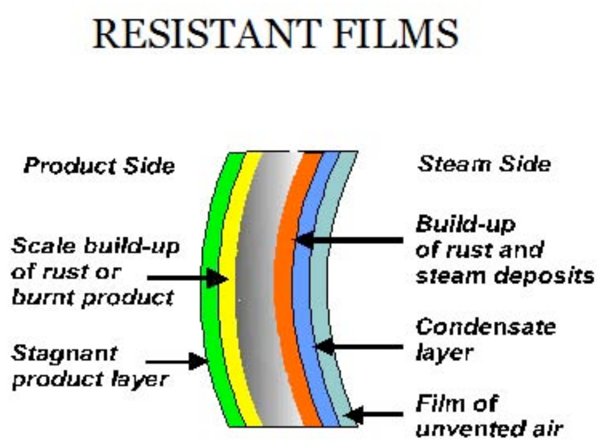

Figure 4.8 Resistant Film Buildups on an Indirect Steam Heater Tube

Scale or internal deposits will reduce the internal surface temperature in contact with the product. This results in a lower product temperature and higher tube temperature, decreasing the efficiency of the system. A typical reaction to restoration of product temperature would be to increase steam pressure or reduce product flow, both of which will place the system outside its design parameters. An example would be an instantaneous water heater with scale build-up in the tubes. As scale deposits increase water temperature decreases. In an effort to increase the heat transfer, the temperature control valve will open wider. Eventually, the unit will not be able to hold the set water temperature even at maximum steam pressure. To achieve original heating capacity, the water coil will need to be cleaned or replaced.

A properly designed heat exchanger will handle its rated load under the conditions for which it was specified. To compensate for products or vapors that inhibit or "foul" the process, it may be necessary to increase the heat transfer area. End users can specify a fouling factor to estimate the affect of vapors that inhibit or foul the process might have on the heat transfer area. This fouling factor is used to determine how much to increase the heat transfer area in the unit, thus allowing it to continue to meet performance standards when the fouling on the heat transfer surface occurs. The increased heat transfer area as a result of the fouling factor is typically a modest additional cost compared to the value it can provide to the process operation. It is also important to note that not all manufacturers include fouling considerations in their designs. There is no savings in assuming an optimistically low fouling factor even if it seems to make a more cost-effective heat exchanger. Later on, difficulties with reduced capacity, low process yields, frequent shutdown for cleaning, and extra maintenance can quickly dissipate this savings.

Best Practices—Clean Heat Transfer Surfaces

- Examine flue-side heat transfer surfaces on a regularly scheduled interval; remove deposits and contaminants.
- Use a soot blower to automatically clean heat transfer surfaces if required
- Use soot burnout practices for radiant tubes or muffles used in high-temperature furnaces.
- Use continuing agitation or other methods to avoid build-up of contaminants on heat-transfer surfaces.
- Clean heat-transfer surfaces frequently in indirectly heated systems, such as process stream coils, radiant tubes, and electrical elements.
- If necessary, add a fouling factor when designing a new system or selecting new heat transfer equipment.

Concerns Using Water as Heat Transfer Medium

Heat-transfer systems that use water and chemical processes that use water-based liquids are subject to scaling, which contain calcium, magnesium and silica deposits. Formed by layers of minerals accumulating on the waterside of heat-transfer surfaces, scale deposits have a thermal conductivity an order of magnitude less than bare metal. Efficiency losses from scale deposits can range from 1 to 7%. Primarily caused by inadequate water treatment, scale deposits can shorten the lifecycle of heat-transfer equipment, leading to its premature replacement. Scale removal can be achieved by mechanical means (manual brushing) or through acid cleaning.

Best Practices—Concerns Using Water as Heat-Transfer Medium

- Examine the waterside of heat-transfer surfaces for scale; remove any deposits.
- If scale is present, consult a local water treatment specialist about modifying chemical additives.

4.4.4 Insulation for Heat Transfer Components

Exposed surface areas should be insulated. Please refer to the DOE Best Practices Steam Tip Sheet[31] on insulation for details on payback and material selection.

Best Practices—Insulation for Heat Transfer Components

- Insulate all heat transfer units and ancillary components.

4.4.5 Maintenance and Servicing Considerations

Heat-transfer equipment must be designed and installed to allow easy access for cleaning. For example, a heat exchange application that requires constant cleaning should use a single-pass shell-and-tube heat exchanger or plate-and-frame unit that can be easily cleaned, either chemically or mechanically. Therefore, if you suspect that a heat exchanger will need to be cleaned frequently, make sure it of a design that is easy to clean and installed so that cleaning can take place with minimal problems. Ensuring that the heat exchanger can be properly and quickly cleaned will further ensure that routine maintenance procedures will not hinder system operation.

Best Practices—Maintenance and Servicing Considerations

- The design and installation of heat-exchange equipment must permit access to the heat-transfer area for cleaning.
- Use the correct type of heat exchanger for the job. A process that requires constant cleaning should use a heat exchanger that is easy to clean, using either chemical or mechanical means.

4.5 Heat Containment Best Practices

The efficient operation of a system is contingent upon the ability to maximize heat retention. Best practices for containing heat are often the most cost-effective and easiest to implement. Examples of such practices include:

- Reducing containment vessel heat losses through the proper use of insulation.
- Reducing radiation losses from walls and openings.
- Eliminating unnecessary losses imposed from unnecessary or inefficient cooling.

4.5.1 Reduce Containment Vessel Heat Losses

Heat energy is lost through the walls, roof, and floors of all process heating equipment, especially process furnaces. The walls of any process furnace containment vessel expel heat into the atmosphere by means of conduction, convection, and radiation heat transfer (Figure 4.9). To keep the walls at an equilibrium temperature during operation of the equipment, lost heat must be replaced. For most industrial furnaces or ovens, wall losses represent 3-10% of the total heat input in the furnace.

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[31] DOE Best Practices Steam Tip Sheet, http://www.oit.doe.gov/bestpractices/steam/

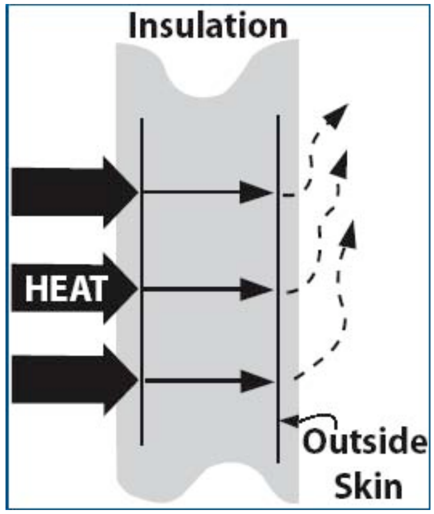

Figure 4.9 Heat Losses through Wall[32]

The amount of heat conducted through insulation depends on the temperature difference between the interior and exterior of the furnace, the thickness of the insulation, and the insulating value (thermal conductivity) of the product being used. These factors also determine the temperature of the furnace wall that is exposed to the surroundings.

Using the proper type and thickness of insulation can reduce furnace heat losses. Insulation serves as a sort of thermal strainer, holding most of the heat in the furnace, while allowing only a small amount of it to escape. The incremental benefit of insulation in the walls decreases as the thickness of the insulation increases. Beyond a certain point, it is uneconomical to continue adding insulation. The challenge is to determine the combination of insulating material and thickness that is the best compromise between energy efficiency and installation cost.

If existing insulation is in good condition and its composition and thickness are known, technical literature or computer programs published by the insulation industry can be used to calculate the heat losses and forecast the effect of insulation changes on these losses. If the insulation materials are unknown or if they've deteriorated significantly, heat loss can be estimated using the chart in Figure 4.10. The key to using this chart is to first determine an average surface temperature across the walls of the equipment by taking many measurements. This is especially important if the walls exhibit a large differentiating temperature profile, indicating deterioration of the insulation. By using the average you obtain a more accurate assessment of the heat losses from the chart. Once the average temperature is known, the chart can be used to determine the amount of heat being lost and, subsequently, the cost of the energy or heat being lost. This, in turn, can be related to the expense of adding additional insulation to prevent those losses from occurring to find a cost effective solution to this heat loss problem.

[32] U.S Department of Energy: Office of Energy Efficiency and Renewable Energy, *Waste Heat Reduction and Recovery for Improving Furnace Efficiency, Productivity and Emissions Performance*, 2003.

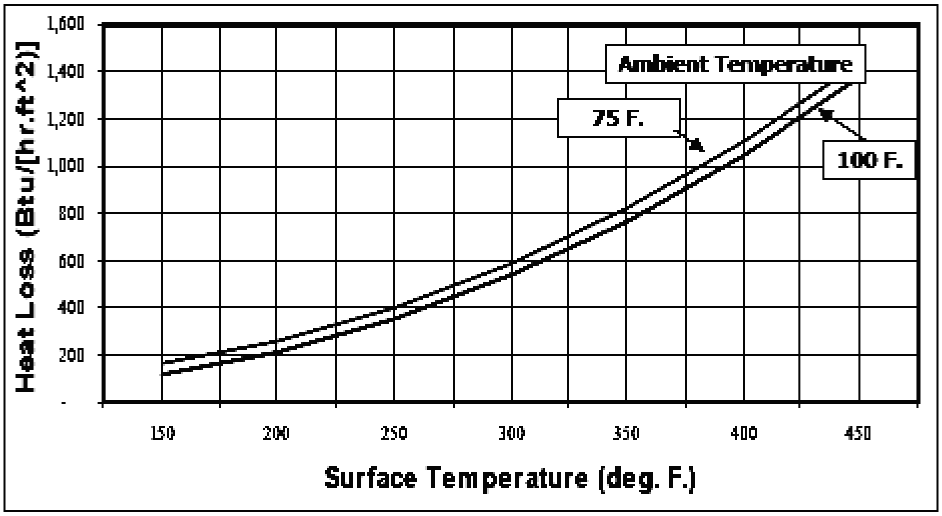

Figure 4.10 Chart for Estimating Wall Heat Losses

Best Practices—Reduce Containment Vessel Heat Losses

- Create a temperature profile of the furnace wall surface using readings from an infrared thermograph or other temperature-measuring instrument.
- Identify "hot-spots" with higher than average temperature and check sources of excessive heat loss (e.g., openings, cracks, damaged or missing insulation etc.).
- If the average surface temperature exceeds 250ºF, review the type and thickness of insulation; consult a furnace or insulation supplier to identify improvement opportunities.
- Use fiber insulation, replacing insulating bricks where possible.
- Always perform periodic maintenance of the insulation, inspecting for cracks and missing insulation; repair or replace as needed.

General Insulation Needs

Proper insulation is important to keep valuable heat energy from dissipating. Any undesirable heat loss has to be replaced by generating more heat, thus increasing fuel expenses.

Best Practices—General Insulation Needs

- Use proper insulation on all exposed piping, fittings, fixtures, traps, and process use equipment. Use the proper type of insulation for the application. Safety issues, temperature, and ambient environment can affect the choice of insulating materials.
- Fiber insulation, which is less costly and easier to install, should be used wherever possible.

4.5.2 Reduce Radiation Losses from Openings

Process furnaces operating at high temperatures, for example, above 1000ºF, are very susceptible to large radiation heat losses. Also known as opening losses, radiation heat losses occur when the containment vessel is exposed to the atmosphere, allowing radiation heat energy to escape the vessel and transport to a colder surface (Figure 4.11). Anyone who has ever looked into a boiler or reformer can testify to the large amount heat felt on one's face.

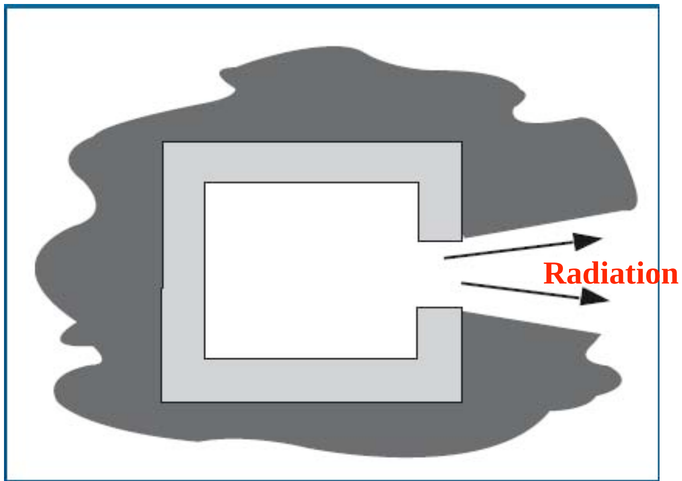

Figure 4.11 Radiation Heat Losses from an Opening[33]

Best Practices—Reduce Radiation Losses from Openings

- Never allow an opening to be continuously ajar.
- Use and maintain proper seals to reduce or eliminate openings.
- Regularly inspect seals for cracks around components such as burners, feed pipes, and cooling tubes; repair as need.
- If closing or sealing doesn't eliminate openings, install a "radiation shield" such as a metal plate or a "ceramic fiber" curtain to reduce direct radiation losses (such as in the case of sight glass openings in a boiler or reformer). A simple shield may reduce radiation losses by half.

4.5.3 Reduce Cooling Losses

Some applications require the use of a cooling media to reduce the temperature of the physical structure of the process furnace. Heat energy that is transferred to the cooling medium represents heat loss from the operation that cannot be applied to the desired process, and therefore an additional fuel cost.

Best Practices—Reduce Cooling Losses

- Reduce the amount of equipment that must be cooled by using more advanced, less heat sensitive materials, especially in retrofits and new installation.
- Be sure to apply proper insulation to all parts cooled by a cooling medium.
- Always perform periodic maintenance of the insulation, inspecting for cracks and missing insulation, repairing and replacing as necessary.

4.6 Waste Heat Recovery Best Practices

The thermal efficiency of process heating equipment such as furnaces and ovens is defined as the ratio of heat delivered to the material being heated to the heat supplied to the heating equipment. For most fuel-fired heating equipment, a large amount of the heat exhaust or flue gases is

[33] U.S Department of Energy: Office of Energy Efficiency and Renewable Energy, *Waste Heat Reduction and Recovery for Improving Furnace Efficiency, Productivity and Emissions Performance*, 2003.

discharged from the furnace. These gases hold considerable thermal energy. In many fuel-fired heating systems, this waste heat is the single, most significant heat loss in the process, often greater than all of the other losses combined. In many cases, the energy efficiency of the system can be increased by using waste heat gas recovery systems to capture and use some of the energy in the flue gas. Benefits from using waste heat recovery include:

- Improved heating system efficiency; energy consumption can typically be reduced by 5-30%.
- A lower flue gas temperature in chimney.
- Increased flame temperature and efficiency.
- Faster furnace startup
- Increased productivity, particularly when waste heat is used for load preheating.

Reducing exhaust losses from the heating system should always be done before starting a waste heat recovery project (Section 4.3.1). The most commonly used waste heat recovery methods are listed below.

- Combustion air preheating (See Section 4.3.1.3)
- Load preheating
- Steam generation
- Use of direct contact water heater
- Cascading of heat to lower temperature processes

4.6.1 Load Preheating

If exhaust gases from the high-temperature portion of a chemical process can be brought into contact with a relatively cool incoming load (the material being heated), energy will be transferred to the load, preheating it and reducing overall energy consumption. Load preheating has the highest potential efficiency of any system that uses waste gases. Fuel savings using flue gases depend on the amount of heat (percentage of total required for heating) delivered to the load before it enters the heater as well as the available heat for the heater. Load preheating can also increase the productivity of existing equipment, often to a point that exceeds fuel cost savings.

It should be noted that load preheating systems can be difficult to retrofit and hard to implement for batch furnaces. Use of load preheating should be planned during the process design stage to ensure proper design of the heating equipment. A typical system used for fluid heaters in the chemical industry is shown in Figure 4.12. Flue gases from a heater convection section are used to preheat the fluid before entering the fluid heater. Fuel savings in the heater are much more than the actual heat transferred to the fluid in the pre-heater and represent the most effective method of waste heat recovery.

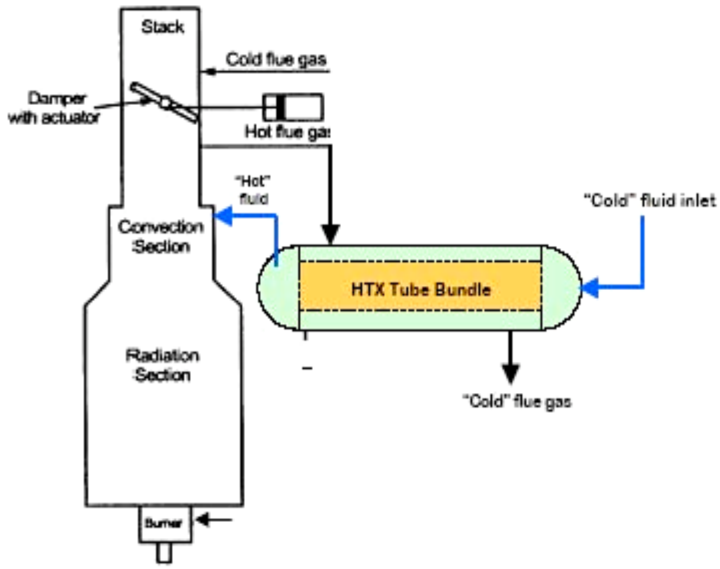

Figure 4.12 Typical Load Preheating System Using Exhaust Gases

In a few cases, waste heat from other can be used for load preheating. For example, the incoming fluid for a fluid heating application can be preheated with steam or hot gases from other heating processes. In this case, fuel savings can still be realized; however, it is necessary to make sure that both processes are operating simultaneously.

Best Practice—Load Preheating

- Use hot furnace products or other waste heat from process streams to preheat incoming loads in a separate unit. This is especially applicable during retrofits or new installations.

4.6.2 Waste Heat Boiler Steam Generation

Steam is a major commodity that can be produced by utilizing waste heat. Boilers that use waste heat from process equipment (furnaces, heaters etc.) are commonly used throughout the chemical industry. These steam boilers are similar to conventional boilers but larger because exhaust gas temperatures are lower than the flame temperatures in conventional systems. Use of the waste heat boilers can reduce a plant's energy demand and, in many cases, eliminate the use of one or many of the boilers currently in operation.

Systems may be relatively small and often do not require special boiler operators, as long as local code and regulatory requirements of monitoring performance are met. Waste heat boilers can be used on most furnace applications, and there are special designs and materials available for systems with corrosive waste gases. They are an ideal option for plants seeking added steam capacity, although it must be remembered that steam is generated only when the fuel-fired process is running. A typical waste heat boiler steam generation system is shown in Figure 4.13.

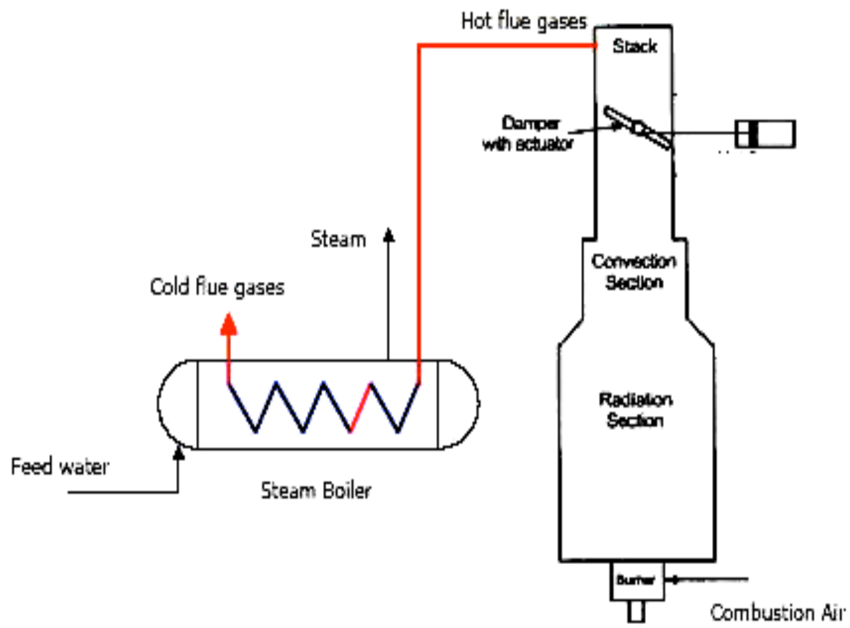

Figure 4.13 Typical Waste heat Boiler Steam generation System

Best Practices—Waste Heat Boiler Steam Generation

- The addition of waste heat boilers to any process heating system is encouraged, especially if additional steam capacity is required or would be beneficial. The boiler can use the waste heat in hot gases as well as liquids from the flue gas of process furnaces or from hot process streams to produce steam. The additional steam capacity maybe sufficient enough to shut down or reduce the load on existing high energy consuming boilers.
- Check the steam demand schedule against the furnace-operating schedule, as steam from a waste heat boiler can be produced only when a source of waste heat is present.

4.6.3 Waste Heat Hot Water Generation

Even after primary heat recovery systems are implemented, a large amount of heat energy may escape through flue gases. The flue gas temperatures may range from 250ºF to as high as 800ºF. Commonly known as “low-grade” heat, this additional waste heat energy can be recovered and used to heat water in a direct contact water heater.

In a direct contact water heater (Figure 4.14), incoming water flows downward through a vertical column filled with stainless steel packing rings. As cold water comes into direct contact with rising hot gases from a heat source (e.g., exhaust gases from a process furnace) heat transfer occurs very rapidly, absorbing 95 to 99% of the heat energy into the water. Pure, heated water can then accumulate in a storage tank for "on demand" use, and clean CO_2 and H_2O combustion gas can leave the stack at near ambient temperature.

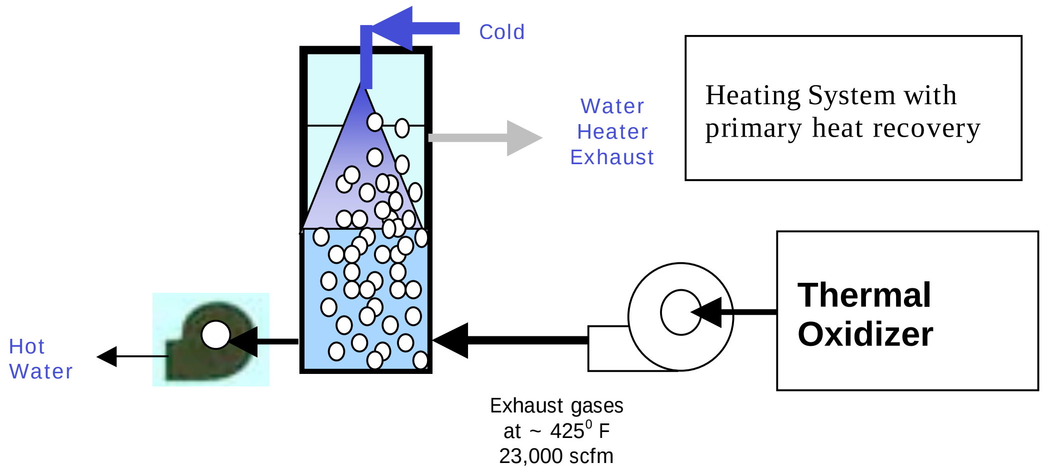

Figure 4.14 Typical Direct Contact Water Heater Systems

It should be noted that the hot water might contain a very small amount of carbonic acid produced from CO_2 dissolving in the water. This is not problematic for most one-time uses, such as cleaning vessels, washing, or certain processes where mild acidity is not a concern. In some cases, the presence of a small amount of carbonic acid may actually beneficial. One should consider all possible consequences of carbonic acid before implementing this type of system. It is not advisable to use this water in a re-circulating loop because the carbonic acid may build up and cause undesirable effects on the system piping, pumps, or even the process itself. This particular system should not be used if flue gases are contaminated with other known or unknown components or potentially undesirable particulates.

Best Practice—Waste Heat Hot Water Generation

- Determine water quality requirements and where possible, use water from a direct contact water heater for one-time activities like general washing and sterilization. The slightly acidic water can also be used in chemical mixing tanks, certain aspects of grain mill operations, and general washing applications.

4.6.4 Cascading of Heat to Lower Temperature Operations

The term "energy cascading" is used to describe the flow of energy from high temperature to low temperature in combination with an effective heat utilization system between the two different temperatures. In this process, thermal recovery systems are used to recapture heat that's transferred between two temperature differentials in smaller temperature differentials or steps rather than all in one large differential. Such systems enable efficient utilization of thermal energy. Waste heat from a primary process may still contain enough energy to operate a secondary process, as long as its temperature is high enough to drive the energy to its intended destination. The goal of cascading heat is to use a continuous flow of waste gases through process after process, operating everything in the factory, until only a stream of lukewarm gases exits the building. Although theoretically possible, multiple process hookups like these are rarely practical. In the majority of cases, it's feasible to drive only one secondary process.

A common example of cascading heat is the heating of high pressure water or heat transfer fluid with waste heat boilers that uses the exhaust of other high temperature process furnaces to heat the water. Another example is adding air to control the temperature of exhaust gases from high temperature furnaces and then using that mixture to heat lower-temperature flash or direct contact dryers or evaporators. Over the years, numerous companies have installed heat exchangers to create warm air for space heating.

The chart in Figure 4.15 shows heating processes that frequently operate on waste heat from higher temperature processes, and the approximate range of waste gas temperatures they require. These temperatures are only approximate – sometimes lower temperature gases can be used if the heat recovery device is deliberately oversized.

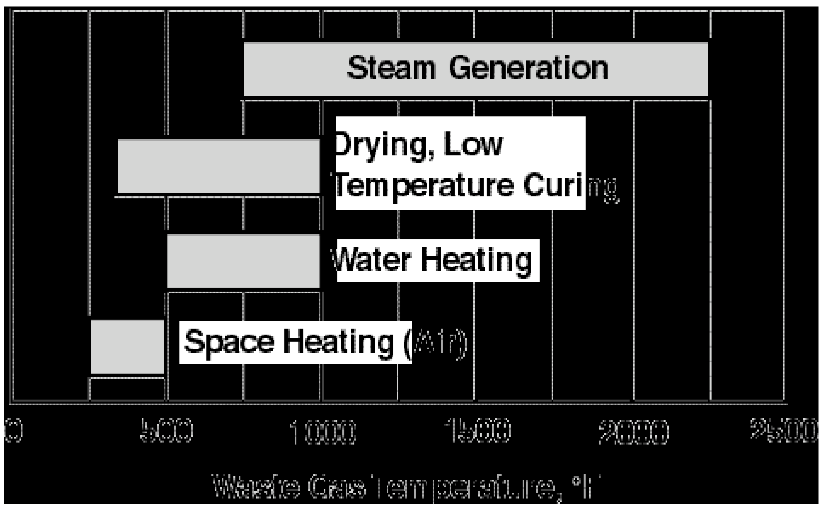

Figure 4.15 Approximate Exhaust Temperatures Required to Support Secondary Processes

Tying two processes together using cascading heat requires more than just the correct temperatures and heat flows. To make the system operate effectively, the logistics must also be set up correctly. For example, if a chemical plant needs a constant supply of heated water for a specific process, and the water heater is totally dependent on the exhaust from an oven, then the oven has to be run continuously. If this is unacceptable, an auxiliary burner can be installed on the water heater to carry the load when the primary process isn't running. In contrast, as long as the oven is being operated, there will be a supply of hot water, whether it is needed or not.

Another key consideration is the placement of equipment. The closer the primary and secondary processes are situated, the better. Carrying exhaust gases through long runs of ductwork can create an expensive and difficult-to-maintain infrastructure, and the efficiency of energy recovery will be compromised by the heat losses between the two processes. This is of less concern if the primary energy source is liquid or hot oil because these heat transfer mediums can carry energy over greater distances.

The following questions should be considered when evaluating heat cascading in secondary processes with hot waste flue gases:

- Is the temperature of waste gases high enough to heat the secondary process?
- Do the waste gases contain enough transferable energy?
- Are the waste gases compatible with the secondary process (cleanliness, corrosiveness, etc.)?
- Do the primary and secondary processes operate on similar schedules?
- Are the two processes in close enough proximity to avoid excessive heat losses from waste gas ducting?
- Will the waste gases leave the secondary process at a high enough temperature to avoid problems with moisture condensation?
- Can the exhaust ductwork and secondary process be designed to avoid excessive pressure resistance to the waste gases? (Exhaust fans may be necessary.)

Best Practices—Cascading Heat to Lower Temperature Operations

- Review processes where heat is used at temperatures lower than the flue gas or other process stream temperatures. Evaluate appropriateness of applying cascading heat.
- Use flue gases or other high temperature process streams to to lower temperature processes. This energy-saving method is most effective when the primary and secondary processes operate similar schedules.

4.7 Process Sensors and Controls Best Practices

Process controls should be installed to optimize the performance of components in the process heating system. Controls provide benefit in three areas:

- Improves process stream condition measurement, allowing better decisions to be made on management of the system as well as equipment selection and optimization.
- Ensures that the highest potential energy efficiency is being reached.
- Helps to decrease the amount of feedstock needed for the process, providing further savings.

Best Practices—Process Sensors and Controls

- Develop procedures for regular operation, calibration, and maintenance of process sensors. (For example, pressure temperature and flow sensors and controls)
- For further information about controls, visit www.ashrae.org.

4.8 Additional Process Use Best Practices

Many of the best practices for process use operations are intended to cover a wide variety of equipment and applications. The same practice often times applies to equipment varying from distillation columns and evaporators to piping and heat exchangers. General equipment best practices will be presented first in this section, followed by a few suggestions for specific equipment situations.

4.8.1 Proper Maintenance

Maintenance for process use equipment varies by type and use. However, to ensure continued, efficient operation and to prevent costly failures, preventative maintenance by a qualified person is critical.

Best Practices—Proper Maintenance

- Follow the manufacturer's suggested maintenance plan. If this is not possible, establish a regularly scheduled maintenance program that closely resembles the recommended plan.
- Assign a highly qualified person to maintain steam traps (may also supervise preventative maintenance, root cause analysis, purchasing, and equipment installation). Steam traps are a major source of heat loss and inefficiency for the chemical industry.
- Perform root cause analysis on failed parts to determine the impact of installation and placement. Determine the exact cause of failure; do not simply assume that the part failed due to non-preventative issues.
- Clean heat exchangers regularly; develop a schedule based on the level of fouling on surfaces.
- Ensure that water used for steam is properly treated.

4.8.2 Proper Equipment Selection

Process use equipment drives the efficiency and operation cost of the entire system: distillation columns, evaporators, dryers, steam traps, etc. Always use the correct equipment for the application. The selection of this equipment is dependant on process stream conditions. Poor equipment choice is another source of energy and productivity losses in the process heating system.

Best Practices—Proper Equipment Selection

- Use the proper selection criteria when ordering from a manufacturer.
- Best practices for proper equipment selection vary, but steam equipment can be used as one example. The process furnace may produce 100 psi steam, but at the point where the equipment is installed the pressure may be 90 psi. Therefore, the device should be used at this rating and not at 100 psi to ensure the most efficient operation.

4.8.3 Low Pressure Separation

A decrease in the pressure used in devices such as distillation columns and evaporators will result in a corresponding decrease in the temperature needed to separate constituents. And lower process temperatures mean lower fuel costs.

Best Practice—Low Pressure Separation

- Decrease pressure as much feasible in separation devices using electric vacuum pumps, thermo compressors, steam jets, and condensers. In turn, this will lower the heat input required for the process.

4.8.4 Proper Energy Transfer Medium

Operations such as tracing usually use steam or electricity to transfer energy to the process stream. Energy transfer mediums should be chosen based on the application and current utility prices.

4.8.5 Proper Air Venting

All process heat exchangers— shell and tube, plate and frame, or any other type—require air venting. Air is an insulator and , unless eliminated, will negatively influence start-up times, process operating temperatures, and heat transfer. For further information, see Section 5.6.3.

Best Practices—Proper Air Venting

- All heat transfer mechanisms should have air vents installed at the locations indicated by the manufacturer.
- Typical points of installation are close to the steam inlet or on the top portion of the unit.