KLM Technology Group

Practical Engineering Guidelines for Processing Plant Solutions

www.klmtechgroup.com

Rev: 02

December 2011

KLM Technology Group
#03-12 Block Aronia,
Jalan Sri Perkasa 2
Taman Tampoi Utama
81200 Johor Bahru
Malaysia

FURNACE (ENGINEERING DESIGN GUIDELINE)

Author:
Rev 1 Maidafitri Dewi Priati
Rev 2 Aprilia Jaya

Checked by:
Karl Kolmetz

TABLE OF CONTENT

LIST OF TABLE

LIST OF FIGURE

INTRODUCTION

Scope

This guideline provides assistance in how to design a furnace. This design guideline can help engineers to understand the basic design of furnace with suitable size, material and heat of combustion.

The choice of furnace design is crucial to give the best performance of furnace. For good performance of furnace is influenced by the maximum the heat absorbed and capacity of burner. The design of furnace may be influenced by factors, including process requirements, economics and safety.

The theory section explains fundamentals of the furnace and how to calculate sizing and selection of the furnace.

General Design Consideration

Heat is one of the most important things in the process plant. One of the equipments that produces heat and supplies the heat requirements to process plant is called a furnace.

The term *furnace* can also refer to a direct fired heater. They expose hydrocarbon stream to heat that drives a distillation tower, a reactor, and in some cases, change the stream's molecular structure through cracking. Basically furnace has four basic components, consisting of box, burner, coil, and stack. The burner will produce the heat then the heat liberated by the combustion of fuel is transfer to a process fluid flowing through tubular coils. Below are several types of furnaces:

1. Vertical cylindrical fired heater

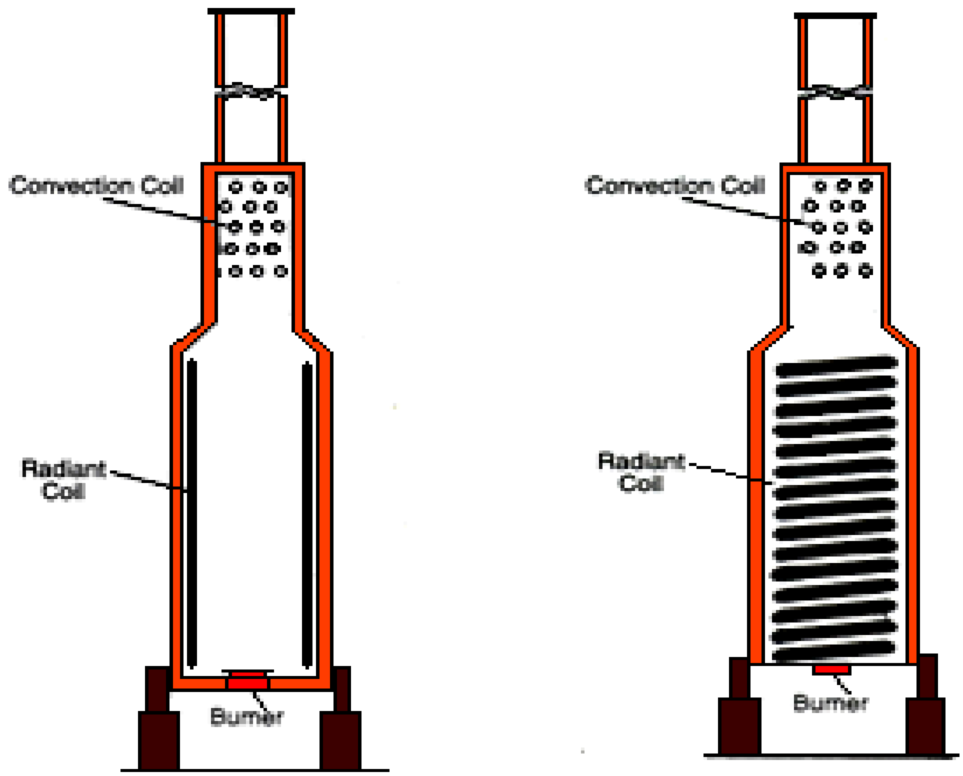
This furnace is commonly used in hot oil service and other processes where the duties are usually small. These heaters are probably the most common in use today and are used for heat duties up to about 150 MBtu/hr. This type of cylindrical upright, tube in the radiant section mounted vertically in a circle round of the burner. The burner is located on the bottom floor, so that the flame is parallel with the tube. Fire heater of this type can be design without or with convection section. Below is the cross section of vertical-cylindrical fired heater.

a. **Vertical cylindrical all radiant**: The all-radiant heater is inexpensive, but since the temperature of flue gases leaving the heater is high, 1500 – 1800oF . Heater of this type does not have convection section. Usually this type have low efficiency and heat duty ranges from 3-7 million kcal/hour.

b. **Vertical cylindrical helical coil**: The coil is arranged helically along the cylindrical wall of the combustion chamber. Its primary use is to heat thermal fluids and natural gas. Capacities range from 1 to 30 million Btu/hour.

c. **Vertical cylindrical with crossflow convection section**: The convection section is installed above the combustion chamber. Mostly, air preheater are added to increase the efficiency. Heat duty of this type from 5-35 million kcal/hour.

d. **Vertical cylindrical with integral convection**: The distinguishing feature of this type is the use of added surface area on the upper part of the radiant coil to promote convection heating. This type is added surface area on the upper part of the radiant coil to promote convection heating. Duties are from 2.5 – 25 million kcal /hr.



(a) (b)

Figure 1: Vertical cylindrical fired heater: (a) all radiant, and (b) helical coil

2. Horizontal tube cabin fired heaters

This cabin has room type consists of the radiation and convection. Tube-tube mounted horizontally while the burner is located on the floor furnace, so that the flame is not straight and parallel to the wall heater. The first layer of tubes in the convection section directly facing into combustion chamber or the radiant fire box called shield tubes. The burner mounted on the floor of the cabin and fire is directed vertically.

Cabin fired heater have some variation in the application. It is like cabin furnace with a centre wall. In the figure below the fire heater usually can be used for the large fired heater and has two separate heating zones are required in the radiant section. This design is economical, high efficiency duties are from 20 - 50 million kcal/hour.
In many operations, about 75% of the heat is absorbed in the radiant zone of a fired heater.

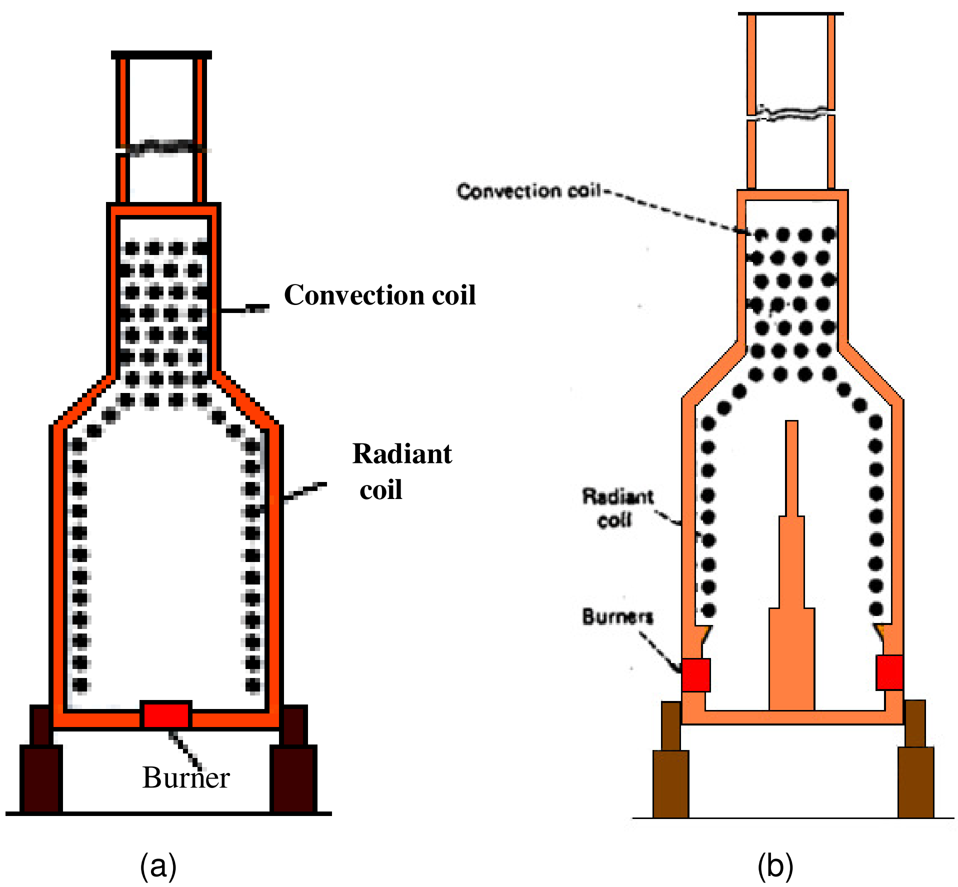


Figure 2: Horizontal tube cabin fired heaters: (a) cabin with convection section and (b) cabin with dividing bridge wall

3. Hoop-tube fired heater

This fire heater has tube bent like U-type with vertically oriented. In all-vapor flow, non-coking services where low coil pressure drop is desired (such as POWERFORMING units). This design is used where the pressure drop must be very low since the path through each tube provides a design with many passes. Application of this type is in the catalytic reformers charge heater. Duties are from 13-25 million kcal/hr.

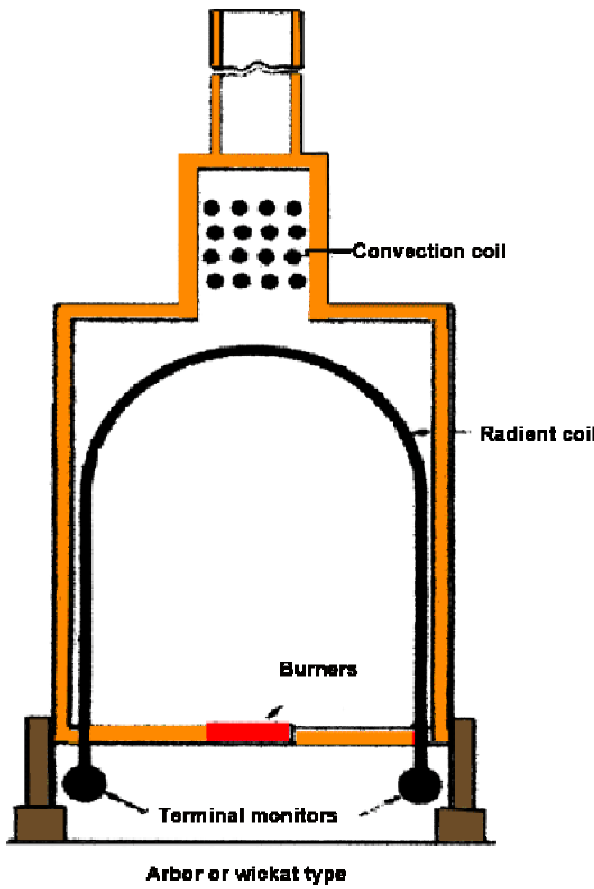


Figure 3:. Hoop-tube fired heater

4. Vertical tube box fired heaters

In this fire heater, tubes stand vertically along wall in the radiant section. Vertical radiant tubes are arranged in a single row in each combustion cell (there are often two cells) and are fired from both sides of the row. Such an arrangement yields a uniform distribution of heat-transfer rates about the tube circumference. This heater is suitable for the large forced-draft burners. Requirement of heat input to each cell provided by burner.

5. Horizontal tube box fired heaters

The radiant and convection section in a typical of horizontal tube box in the **Figure 5** are separate by a wall called bridge wall. Function of bridgewall is to create a good direction of flame and to stream the smoke in to flue stack. Burners are firing from the floor along both sides of the bridgewall. Duties are from 30 to 8 million kcal /hour.

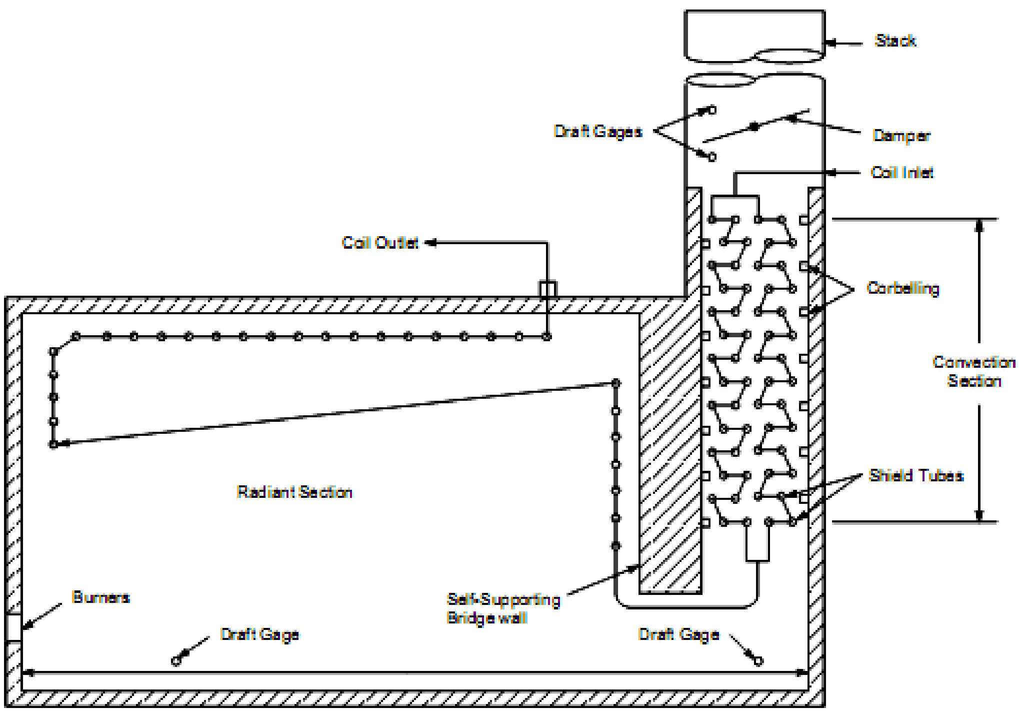


Figure 5: Horizontal tube box fired heaters

6. Multiple cell heaters

For two-cell horizontal tube box have high efficiency, duties from 25-65 million kcal/hour.

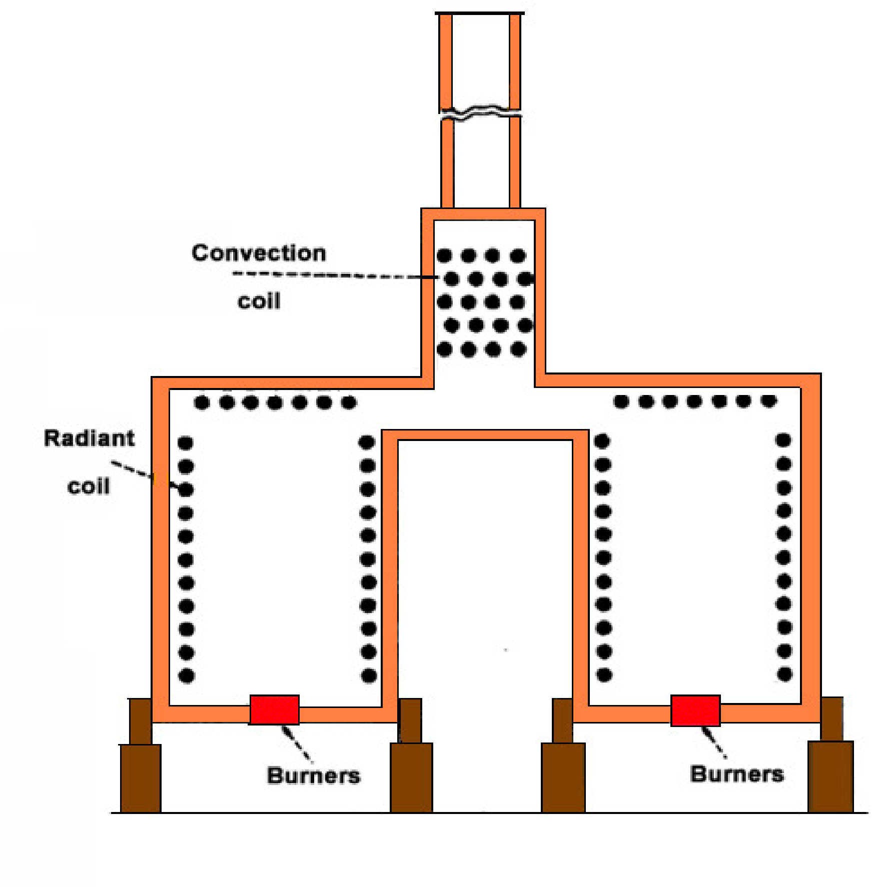


Figure 6: Multiple cell heaters

7. **Helical coil fired heater**

   This heater configuration is commonly used where the duties are small. Since each pass consists of a separate winding of the coil, pressure drop options are limited. Many of these only have a radiant section, since efficiency is often not that critical, especially in intermittent services like for a regeneration heater.

Fire heater will work well if design of fire heater is designed well. The design requirements must be properly addressed. Fire heater performance can be satisfactory if be measured by a combination of operability and maintenance. Operability is fire heater ability to meet the requirements of a safe process and in the maintenance should consider the cost and manpower required to meet the requirements process. These two factors effecting fired heater selection and design: all-liquid or vaporizing service and all-vapor service.

1. Fire heaters in all-liquid or vaporizing service

   In the tube wall is usually formed coke fire heater that can interfere with heat transfer process. Fire while the heater should be design to minimize coke. Incipient coke begins to form at a film temperature above about 660oF, usually equivalent to a bulk fluid temperature of about 600oF. In other services such as visbreaking and thermal cracking, where fluid cracking is an inherent characteristic of the process, acceptable coke formation and run length can usually be attained if film temperatures do not exceed 910^{o}F equivalent to a bulk fluid temperature of about 880^{o}F.

   For reduce the formation of coke, a high inside film coefficient is necessary to minimize the difference between bulk fluid and film temperature. The higher the speed of the mass of the heat transfer coefficient will be better. Therefore, the mass of turbulent flow must be maintaining in the tube.

2. Fire heater in all-vapor service

   For this fire heater generally not susceptible to the same severe coking problems as those in vaporizing services because of the lighter nature of the process fluid. A fired heater selection guide is given in Figure 8. Types of service this figure all liquid or vaporizing services and all vapor services. From these figures are obtained heat duty absorbed.

DEFINITIONS

Air Preheater - Heat exchanger device that uses some of the heat in the flue gases to raise the temperature of the air supply to the burners.

Breeching - The hood that collects the flue gas at the convection section exit.

Bridgewall Temperature - The temperature of the flue gas leaving the radiant section

Bulk Temperature - The average temperature of the process fluid at any tube cross section.

Burner - A device for mixing fuel and air for combustion.

Casing - A steel sheathing that encloses the heater box and makes it essentially air-tight.

Cell - A portion of the radiant section. Also called a **"zone".**

Center Wall - A refractory wall in the radiant section, which divides it into two separate cells.

Coil - A series of straight tube lengths connected by 180^o return bends, forming a continuous path through which the process fluid passes and is heated.

Convection Section - The portion of a heater, consisting of a bank of tubes, which receives heat from the hot flue gases, mainly by convection.

Corbelling - Narrow ledges extending from the convection section side walls to prevent flue gas from flowing preferentially up the side of the convection section, between the wall and the nearest tubes.

Crossover - Piping which transfers the process fluid either externally or internally from one section of the heater to another.

Damper - A device to regulate flow of gas through a stack or duct and to control draft in a heater.

Draft - The negative pressure (vacuum) at a given point inside the heater, usually expressed in inches of water.

Excess Air - The percentage of air in the heater in excess of the stoichiometric amount required for combustion.

Extended Surface - Surface added to the outside of bare tubes in the convection section to provide more heat transfer area.

Film - A thin fluid layer adjacent to a pipe wall that remains in laminar flow, even when the bulk flow is turbulent.

Film Coefficient - The convective heat transfer coefficient of the film.

Film Temperature - The maximum temperature in the film, at the tube wall.

Fire Box - A term used to describe the structure which surrounds the radiant coils and into which the burners protrude.

Flue Gas - A mixture of gaseous products resulting from combustion of the fuel.

Fouling - The building up of a film of dirt, ash, soot or coke on heat transfer surfaces, resulting in increased resistance to heat flow.

Forced Draft - Use of a fan to supply combustion air to the burners and to overcome the pressure drop through the burners.

Fired Heater Efficiency - The ratio of heat absorbed to heat fired, on a lower heating value basis.

Gross Fuel - The total fuel fired in the heater, including all losses.

Header - The fitting, which connects two, tubes in a coil.

Header Box - The compartment at the end of the convection section where the headers are located.

Heat Available - The heat absorbed from the products of combustion (flue gas) as they are cooled from the flame temperature to a given flue gas temperature.

Heat Density - The rate of heat transfer per unit area to a tube, usually based on total outside surface area.

Heat Duty - The total heat absorbed by the process fluid, usually expressed in MBtu/hr

Heat Fired - The total heat released in the heater, equal to gross fuel times lower heating value (LHV) of the fuel. Usually expressed in MBtu/hr.

Induced Draft - Use of a fan to provide the additional draft required over that supplied by the stack, to draw the flue gas through the convection section, and any downstream heat recovery equipment.

Lower Heating Value (LHV) - The theoretical heat of combustion of a fuel, when no credit is taken for the heat of condensation of water in the flue gas.

Mass Velocity - The mass flow rate per unit of flow area through the coil. Typical units are lb/s-sq. ft.

Natural Draft - System in which the draft required to move combustion air into the heater and flue gas through the heater and out the stack is provided by stack effect alone.

Net Fuel - The fuel that would be required in the heater if there were no radiation losses.

One-Side Fired Tubes - Radiant section tubes located adjacent to a heater wall have only one side directly exposed to a burner flame. Radiation to the back side of the tubes is by reflection/reradiation from the refractory wall.

Pass - A coil that transports the process fluid from fired heater inlet to outlet.

Radiant Section - The section of the fired heater in which heat is transferred to the heater tubes primarily by radiation from high-temperature flue gas.

Service Factor - Ameasure of the continuity of operation, generally expressed as the ratio of total running days for a given time period to the total calendar days in the period.

Shield Section - The first two tube rows of the convection section.

Sootblower - A steam lance (usually movable) in the convection section for blowing soot and ash from the tubes using high-pressure steam.

Stack - A cylindrical steel, concrete or brick shell which carries flue gas to the atmosphere and provides necessary draft.

Stack Effect - The difference between the weight of a column of high-temperature gases inside the heater and/or stack and the weight of an equivalent column of external air, usually expressed in inches of water per foot of height.

Stack Temperature - The temperature of the flue gas as it leaves the convection section, or air preheater directly upstream of the stack.

Two-Side Fired Tubes - Radiant section tubes which are exposed on both sides to direct radiation from the burners.

NOMENCLATURES

A_{cp}	Cold plane area, (ft^2)
A_{shield}	Tube shield area, (ft^2)
A_{shield}	Tube shield area, (ft^2)
A_w	Refractory surface (ft^2)
A_{tube}	Area of tube, (ft^2)
A_{rl}	Right and left area (ft)
A_w	Refractory surface (ft^2)
A_r	Radiant surface area (ft^2)
C	Capacity design (btu/hr)
E_{ff}	Efficiency of furnace
F	Exchange factor
G_f	Flue gas rate, (lb/hr)
G	Flue gas flow rate (lb/sec ft2)
H	Shell height (ft)
H_{wall}	Wall height (ft)
$H_{persection}$	Height per section (in)
H_{CS}	Height of convection section (in)
L	Shell length (ft)
L_{bm}	Mean beam length (ft)
L_{bft}	The total length of bare of finned tubes, (ft)
L_{exp}	Exposed length (ft)
N_{burner}	The number of burner
N_{tr}	Number of tube in radiant section,

N_r	Amount of radiant section
N_{ts}	Number of tube in shield area,
N_{tc}	Number of tube in ceiling area,
N_{trl}	Number of tube in right and left area,
$N_{tchamber}$	Number of tube in 1 chamber,
N_{ts}	Number of tube in shield area,
N_{tc}	Number of tube in ceiling area,
N_{trl}	Number of tube in right and left area,
$N_{tchamber}$	Number of tube in 1 chamber,
$N_{bsection}$	Number of radiant burner per section
N_{tr}	Number of tube in radiant section
$N_{t1\ section}$	Number of tube in 1 section
OD	Outside tube diameter (in)
P	Partial pressure of CO2 and H2O (atm)
Q_a	Heat absorbed (btu/hr)
Q_{rfc}	Radiant heat flux (btu/hr ft^2)
Q_{rac}	Radiant heat absorbed calculated (btu/hr)
Q_n	Heat released (btu/lb)
Q_a	Heat absorbed needed (btu/hr)
Q_{ra}	Radiant heat absorption (btu/hr)
Q_{rf}	Radiant heat flux (btu/hr ft^2)
Q_{conv}	Heat in convective zone, (btu/lb)
Q_{rac}	Heat radiant absorbed calculated (lb/hr)
T_i	Inlet process stream temperature (^{o}F)
T_o	Outlet process stream temperature (^{o}F)
T_t	Tube wall temperature (^{o}F)
T_{LO}	Outlet temperature (^{o}F)

T_{LI}	Inlet temperature (^oF)
T_S	Stack temperature (^oF) T_{LI}
T_{SA}	Stack approach temperature (^oF)
Uc	Overall heat transfer coefficient (btu/hr ft^2)
$V_{furnace}$	Furnace volume (ft^3)
W	Shell wide (ft)
Xair	Fraction excess air

Greek Leters

Φ	Gas emissivity
αA_r	Effective absortivity (ft^2)
ρ	Density (lb/ft^3)

Superscript

M	Mass molecular