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		Rev: 01
KLM Technology Group #03-12 Block Aronia, Jalan Sri Perkasa 2 Taman Tampoi Utama 81200 Johor Bahru Malaysia	OLEFIN FURNACE (ENGINEERING DESIGN GUIDELINE)	July 2012
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INTRODUCTION

Scope

This guideline provides a basic review of an olefin (ethylene) furnace design. This design guideline provides operations personnel and engineers sizing, materials of construction and heat of combustion parameters.

The choice of a furnace layout and the coil design is crucial to give the best performance of furnace. The performance of furnace is also influenced by the maximum the heat absorbed by the coils and capacity of burner. This guideline will provide tools to calculate the burners, radiant, convection, stack design, and efficiency of furnace.

The design of olefin furnace may be influenced by factors, including process requirements, economics and safety. There are tables provided for making factored calculations from the various referenced sources. All the important parameters use in the guideline are explained in the definition section.

The theory section explains how to best select an olefin furnace design and the combustion concept. The application of the olefin furnace theory with an example will assist the study of an olefin furnace.

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General Design Considerations

Olefin manufacturing is the third largest petrochemical industries after ammonia manufacturing and petroleum refining. Annual global production of ethylene is about 120 million tons with a continuous annual increase of some 4 - 5 %. Ethylene and propylene are building blocks for a large variety of chemicals and petrochemical products.

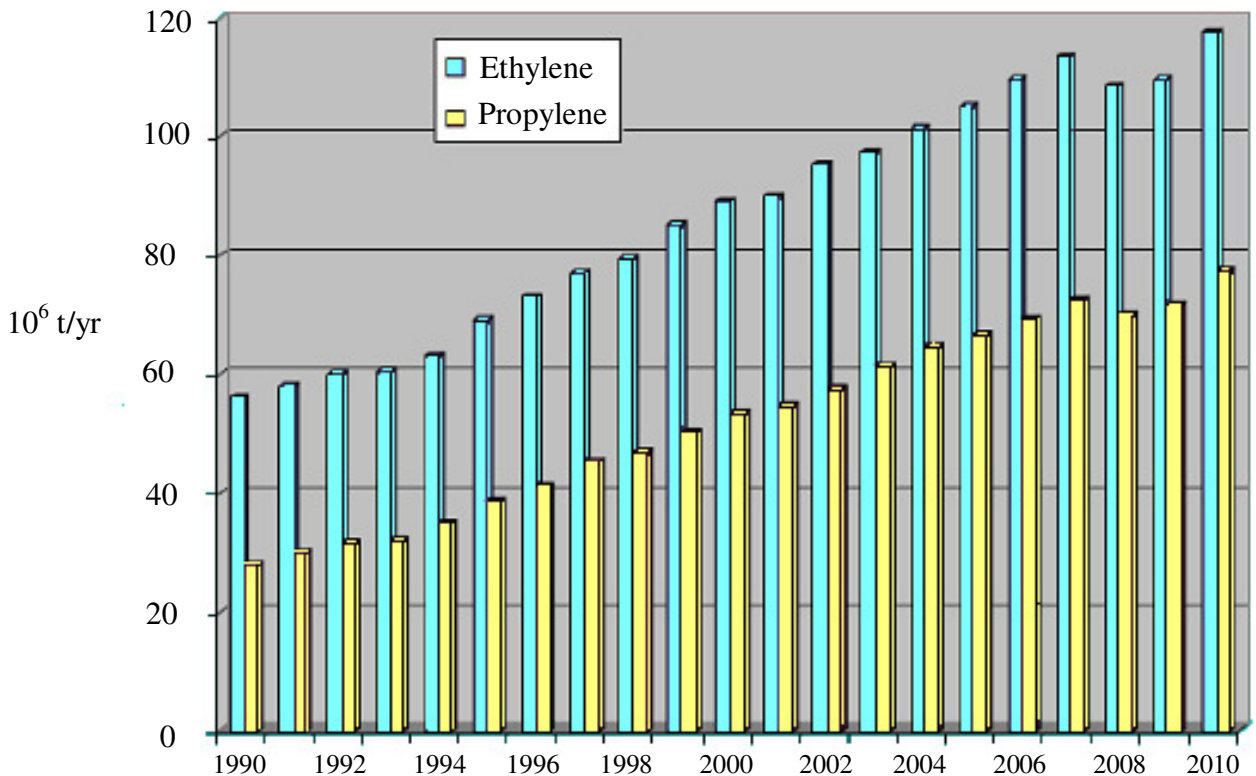


Figure 1: Global consumption of ethylene and propylene.

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Ethylene process is one of most complex systems in petrochemical industry. The reactions that result in the transformation of saturated hydrocarbons to olefins are highly endothermic, thus requiring high levels of heat input. This heat input must occur at the elevated reaction temperatures. It is generally recognized in the industry that for most feed stocks, and especially for heavier feed stocks such as naphtha, shorter residence times will lead to higher selectivity to ethylene and propylene since secondary degradation reactions will be reduced. Further it is recognized that the lower the partial pressure of the hydrocarbon within the reaction environment, the higher the selectivity.

In the steam cracking process, hydrocarbon is mixed with steam and passed continuously through coils heated in a furnace to obtain the desired conversion via thermal cracking. The reaction mixture is then cooled and separated into its constituents. The following challenges have to be faced in cracking furnace:

1. Safety first
2. High energy efficiency and minimum environmental emissions
3. Low production costs and low investment costs
4. High plant reliability
5. Simple operation
6. Good maintainability
7. Minimum losses

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DEFINITIONS

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

Burner – Equipment wher the gas or fuel oil is delivered and burned to produce heat.

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

Coke - Solid residue remaining after certain types of coals are heated to a high temperature out of contact with air until substantially all components that easily vaporize have been driven off.

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

Combustion - the oxidation of a mixture of fuel and air. Terms of combustion will take place perfectly when time, temperature and turbulence.

Cracking - The process whereby complex organic molecules such as kerogens or heavy hydrocarbons are broken down into simpler molecules such as light hydrocarbons, by the breaking of carbon-carbon bonds in the precursors.

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.

Dilution steam – Steam which is added to reduce the partial pressure of hydrocarbons. This is done to aid the reaction to proceed in the forward direction to get desired products as per Le Chatlier's principle.

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

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

Endothermic - A process or reaction that absorbs heat, i.e. a process or reaction for which the change in enthalpy, ΔH , is positive at constant pressure and temperature

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.

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

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

Hydrogen abstraction - Any chemical reaction in which a hydrogen free radical is abstracted from a substrate

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.

Naphtha - Any of several highly volatile, flammable liquid mixtures of hydrocarbons distilled from petroleum, coal tar, and natural gas and used as fuel, as solvents, and in making various chemicals.

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

Olefin - Any of a class of unsaturated open-chain hydrocarbons such as ethylene, having the general formula C_nH_{2n} ; an alkene with only one carbon-carbon double bond.

Pyrolysis - A gas-phase reaction at very high temperature. As the reaction is highly endothermic and requires high temperature, it is carried out in tubular coils within a fired furnace.

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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.

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

SLE exchangers - Double pipe exchangers consisting two sections, or legs in series, with the process stream in the inner pipe and the boiler feedwater/steam in the outer annulus.

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.

Steam cracking - High-temperature cracking of petroleum hydrocarbons in the presence of steam.

Steam System – the system which is to generate super high pressure

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NOMENCLATURES

A_r	Radiant surface area, ft ²
$C_{p_{air}}$	Specific heat of air, btu/lb F
$C_{p_{fuel}}$	Specific heat of fuel, btu/lb F
CtC/Do	Ratio, CtC/Do
D_i	Tube diameter, in
D_o	Tube outside diameter, in
Eff	Furnace Efficiency, %
EPA	Effective plane area, ft ²
G_f	Flue gas rate, lb/hr
G_{fuel}	Fuel flow required, lb/hr
G_{air}	Air flow required, lb/hr
H_a	heat input in the form of sensible heat of air, btu/lb fuel
H_f	heat input in the form of sensible heat of fuel, btu/lb fuel
LHV	Lower heating value of fuel, btu/lb fuel
L_{tube}	Tube length, ft
N_{tube}	Number of tube
$\%Q_r$	Radiation losses, %
$\%Q_{rabs}$	%radiant absorbed, %
Q_{comb}	Heat combustion, btu/hr
Q_s	Stack heat loss, btu/lb fuel
Q_r	Radiant heat loss, btu/lb fuel
Q_{in}	Heat input, btu/hr
Q_{abs}	Heat absorbed, btu/hr
Q_{rduty}	Heat radiant duty btu/hr, ft ²
Q_{rabs}	Radiant heat absorbed, btu/hr
Q_{rf}	Flux rate, btu/ft ²
Q_{conv}	Heat in convective zone, btu/hr
T_{flue}	Flue gas exit temperature, F
T_{air}	Combustion air temperature, F
T_{fuel}	Fuel gas temperature, F
T_{in}	Fluid in temperature, F
T_{out}	Fluid out temperature, F
TWT_{avg}	Tube wall temperature average, F
T_f	Pseudo firebox temperature, F
T_{fb}	firebox wall temperature, F
T_{us}	Unshielded firebox walls temperature, F

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T_{sh} Shielded wall temperature, F
 T_c convection temperature, F
 X Excess air, %

Greek Letters

α Effectiveness factor

Superscript

BWT Bridge wall temperature, F
 PA Plane area, ft²
 T Temperature, F

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THEORY

Olefins are produced by steam cracking of small and large hydrocarbon molecules to form a complex mixture rich in ethylene and other olefin gases, called pyrolysis. Pyrolysis is a gas-phase reaction at very high temperature. As the reaction is highly endothermic and requires high temperatures, it is carried out in tubular coils within a fired furnace. A hydrocarbon mixture is heated in metal tubes inside a furnace in the presence of steam to a temperature at which the hydrocarbon molecules thermally decomposes

The cracking reactions are divided into primary and secondary reactions. Primary reactions involve the breaking down of molecules of the hydrocarbon feedstock to form free radicals, then recombine to form new molecules (olefins: ethylene, propylene, and butadiene). This process is depends on the reaction temperature, time and predominantly on the highest reaction temperature or the coil outlet temperature.

Then process is followed by secondary reactions in which the olefins combine to form larger molecules and hydrogen. The cracked effluent should be cool quickly to prevent undesirable secondary reactions from taking place. Typical furnace cracking coil reaction time is 0.15 – 0.2 second and quenching is started within 0.01 second after leaving the reaction zone. The secondary reactions are affected by the partial pressure of hydrocarbon. Partial pressure can be thought of as a combination of the steam ratio and the total reaction pressure.

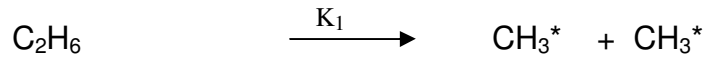
Lowering steam ratio or increasing the coil outlet pressure reduces the ethylene yield. Thus the main control on product yield distribution is by varying the coil outlet temperature. The secondary reactions become more significant with the higher temperature and olefin partial pressure. Besides degrading the desirable olefin products, the secondary products can also lead the production of coke. Figure 2 describes the process reactions.

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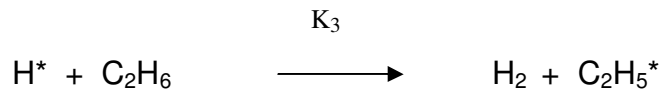
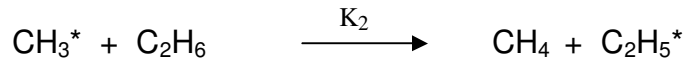
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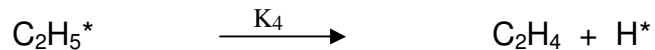
Initiation



Hydrogen abstraction



Radical decomposition



Termination

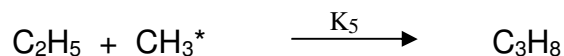
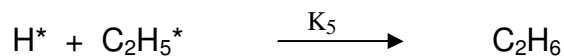
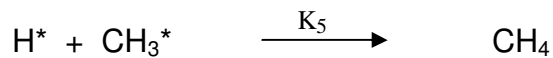
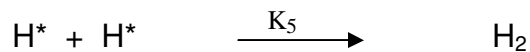


Figure 2: Process cracking

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An industrial pyrolysis furnace is a complicated piece of equipment that functions as both a reactor and high-pressure steam generator. A typical design might consist of four furnaces for cracking fresh and recycles feed. Each furnace has two independently fed and controlled radiant boxes which share a common convection section. Burners may be arranged on the walls and on the floor of the firebox for indirect firing.

The draft for the furnace is provided by an induced draft fan located on each furnace. The pyrolysis reactions proceeds in tubular coils made of Cr/Ni alloys. These coils are hung vertically in a firebox. Depending of furnace design, there may be between 16-128 coils per firebox.

At the end of the pyrolysis, the reaction needs to be quenched rapidly to avoid further decomposition of the desired olefins. This is achieved by either indirect cooling using a quench exchanger or direct cooling by injecting quench oil into the gas effluent.

Each furnace system is fitted with cracking effluent quench exchangers for heat recovery in the form of super high pressure (SHP) steam. The cracked effluent is collected from all the collection headers, and is then sent downstream to quench oil tower.

A steam drum is associated with furnace, mounted at a sufficient elevation above the heat exchanger to provide boiler feed water circulation on the shell side of the exchanger by thermosyphon action.

The heat carried by the flue gas is recovered at the convection section of the furnace. A typical design might consists of a series of "tube banks" where the heat is recovered for hydrocarbon preheat, a boiler feedwater economizer, hydrocarbon plus dilution steam which is staged in two banks, super high pressure steam superheating, and dilution steam superheating.

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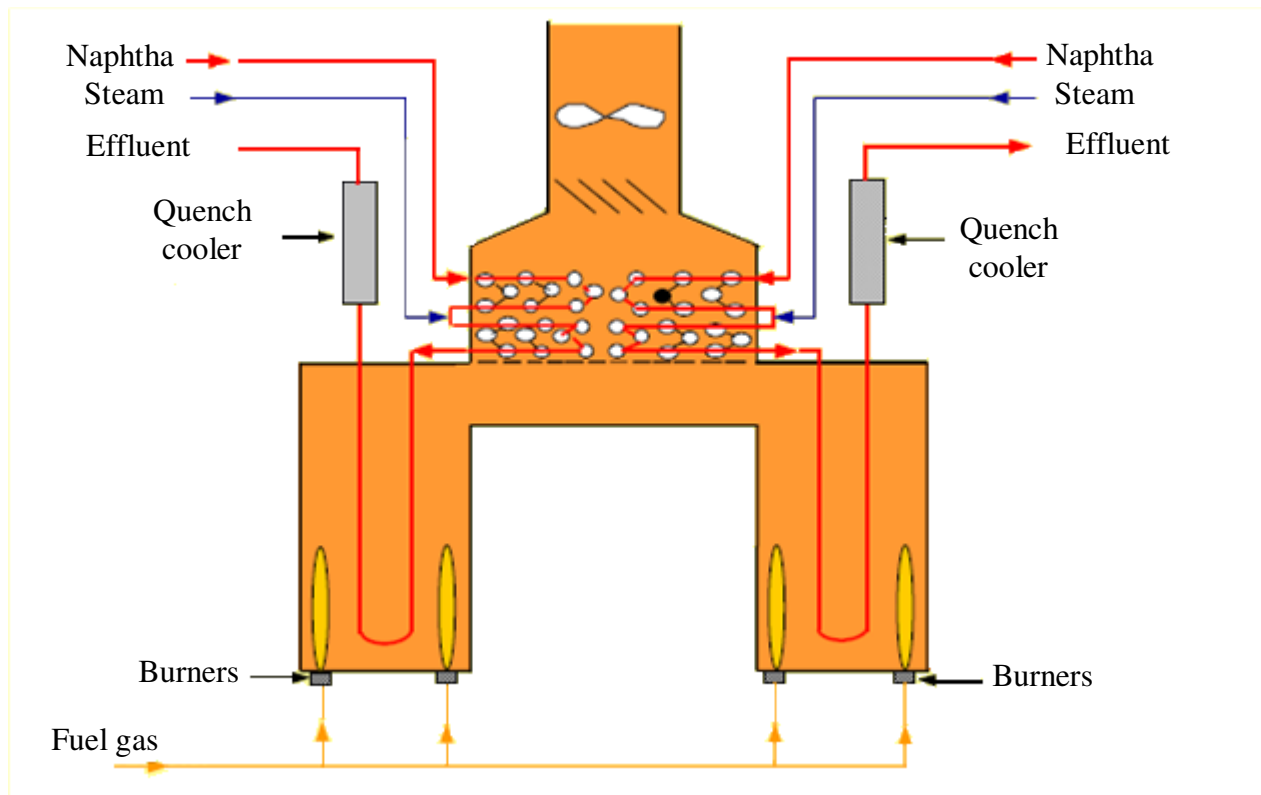


Figure 3: U type Olefin furnace layout

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The process flows through the convection section, radiant coils and associated heat exchangers has independently controlled, segregated flow paths or zones. The selected vapor or liquid hydrocarbon feed flow is controlled by a separate flow control valve for each flow path. Each selected flow path has an associated radiant box zone and the fuel gas firing for each radiant box zone is independently controlled. Thus through the distinct process flow paths and controls incorporated into the furnace.

A pyrolysis furnace should be moved in the direction of short residence time, low hydrocarbon pressures and high temperatures for optimum production of ethylene from any feedstock. The process chemistry review reveals at least three design requirements:

1. Low Pressure. Any time the moles of products are larger than the moles of reactants the equilibrium favors low pressures. Modern furnaces operate under low pressure of 175-240 kPa. The required compressor horsepower becomes very large to achieve lower coil outlet pressure,.
2. Low Hydrogen Partial Pressures. To reduce the unwanted hydrogenation reaction, lower hydrogen partial pressures would produce more of the desired products.
3. Short Residence Time. To reduce the unwanted condensation reaction, shorter residence times would produce more of the desired products. In order to reduce the residence time, engineers have designed radiant tubes of smaller diameters, better metallurgy and burners that are more efficient. Modern cracking furnaces operate in residence time range between 0.08-0.25 s. Tube diameter has reduced to the range of 25.4 – 101.6 mm (1-4 in).
4. Inert. Dilution steam is an inert that premixed with hydrocarbon feed before feeding to the pyrolysis coils. Dilution steam was added then forth to reduce coking and carburization. Also to lower the hydrocarbon partial pressures. The mass ratio of steam to hydrocarbon feed is 0.3 for ethane feed to 0.6 for gas oil cracking. It is a controlled parameter in furnace operations.
5. High temperature. Pyrolysis is a highly endothermic reaction. The operating temperature of pyrolysis furnace is the region of 750 – 900°C. The downside of higher operating temperature is more rapid coking rate and carburization, which shortens the tube-life.

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Table 1: Typical Residence Times Yields for Light Naphtha

Residence Time (seconds)	0.1	0.2	0.5
Methane	15.48	15.78	16.16
Ethylene	34.16	32.16	29.37
Propylene	17.02	17.35	17.78
Butadiene	5.2	5.1	5
Benzene	5.89	6	5.75
Toluene	2.59	2.65	2.52
Fuel oil	3.12	3.35	3.61

The pyrolysis reactions are endothermic and time dependant reactions. The flame pattern and the resulting heat flux can have the net effect of changing the effective length of the coil. The heat flux should be uniform; if the heat flux is not uniform the coil effective length can be reduced. If heat flux is not uniform hot areas can cause over cracking and shorting coil life. The shape of the flame is determined by burner designers according to heat input requirements by the technology provider. The shape of the fire box will affect the flame pattern and heat flux. Deviation from rectangular has not proved to be successful.

In a typical ethylene furnace the pyrolysis reaction is endothermic. For this reason, furnace tube material must be suitable to accommodate the high process temperature. Continual improvement of furnace tube materials and furnace design has made it possible to accommodate 750 – 850°C and up to 900°C or even higher. The tubular coils within an industrial pyrolysis furnace are usually made of the base Cr/Ni alloys. Cr/Ni alloys for furnace tubes are selected for their better coking erosion resistance, high creep strength, carburization resistance, ductility, and thermal shock resistance. Furnace tube are usually produced of the following steel grades 304L, 316, 321, 304H, 347H (formally stabilized at 1650 °F for 4 hours - preferred if it can be done internally at the mill), 317L, and 2205.

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