KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions	KLM Technology Group www.klmtechgroup.com	Rev: 01 Rev 01 Dec 2013 Rev 02 June 2014
KLM Technology Group #03-12 Block Aronia, Jalan Sri Perkasa 2 Taman Tampoi Utama 81200 Johor Bahru Malaysia	**ETHYLENE QUENCH WATER TOWER (ENGINEERING DESIGN GUIDELINE)**	Co-authors Rev 01 Mochamad A Firdaus Rev 02 Apriliana Dwijayanti Editor Karl Kolmetz

TABLE OF CONTENT

LIST OF FIGURE

INTRODUCTION

Scope

This design guideline covers the basic elements in the field of Ethylene Quench Water Tower in sufficient detail to allow an engineer to design a quench water tower with the suitable size of the quench tower, log mean temperature, heat transfer coefficient, rate of heat transfer, and the important numbers (Reynolds, Nusselt, and Prandtl).

Water-cooling towers are a particular example of direct-contact heat exchange. In direct-contact heat exchange, the hot and Cod streams are brought into contact wihout any separating wall, and high rates of heat transfer are achieved. It should be considered whenever the process streams are compatible. For some situations, the designer must work from first principles, setting up the differential equations for mass and heat transfer, and using jugdement in making the simplifications necessary to achieve a solution.

One of the issues of quench tower system design is that they may be heat transfer limited. Most distillation columns are mass transfer limited and the heat transfer equation can be negelected. In quench tower system both must be verified.

KLM Technogoly Group and other distillation consultants do not recommend the use of random packing in fouling services. An ethylene quench oil and quench water towers will qualify as a fouling services.

General Design Considerations

Quenching of the reactor products is sometimes needed for sudden cooling, for removing impurities and to avoid side reactions. Cooling by liquid quenching is essentially accomplished by introducing the hot gases into a liquid contacting device.

When the liquid evaporates the energy necessary to vaporize the liquid is obtained at the expense of hot combustion gases, resulting in a reduction of gas temperature. The temperature of the combustion gases discharge from the quencher is at the adiabatic saturation temperature of the combustion gases if the operation is adiabatic and the gas leaves the quencher saturated with water vapors.

There are three types of quenchers

1. Spray towers
2. Venture scrubbers
3. Packed towers

A. Spray Towers

Spray towers or spray chambers consist of empty cylindrical vessels made of steel or plastic and nozzles that spray liquid into the vessels. The inlet gas stream usually enters the bottom of the tower and moves upward, while liquid is sprayed downward from one or more levels. This flow of inlet gas and liquid in the opposite direction (countercurrent flow). Countercurrent flow exposes the outlet gas with the lowest pollutant concentration to the freshest scrubbing liquid.

Many nozzles are placed across the tower at different heights to spray all of the gas as it moves up through the tower. The reasons for using many nozzles is to maximize the number of fine droplets impacting the pollutant particles and to provide a large surface area for absorbing gas. The liquid droplets must be large enough to not be carried out of the scrubber by the scrubbed outlet gas stream In a spray tower, absorption can be increased by decreasing the size of the liquid droplets and/or increasing the liquid-to-gas ratio (L/G).

The advantages of spray tower

1. Spray towers can be used for gas absorption, which removes impurities.
2. The design is completely open design. It is simple to construct. This feature eliminates many of the scale build up and plugging problems associated with other scrubbers.
3. This is an inexpensive controlled device primarily used for gas conditioning.
4. It requires very little space and only that amount of water is used that is needed to maintain the desired temperature of the gases at the discharge.
5. Their installation and operation cost are generally considered to b less than that for other cooling method.
6. Spray towers are very effective in removing pollutants (particles from reactor) if the pollutants are highly soluble.

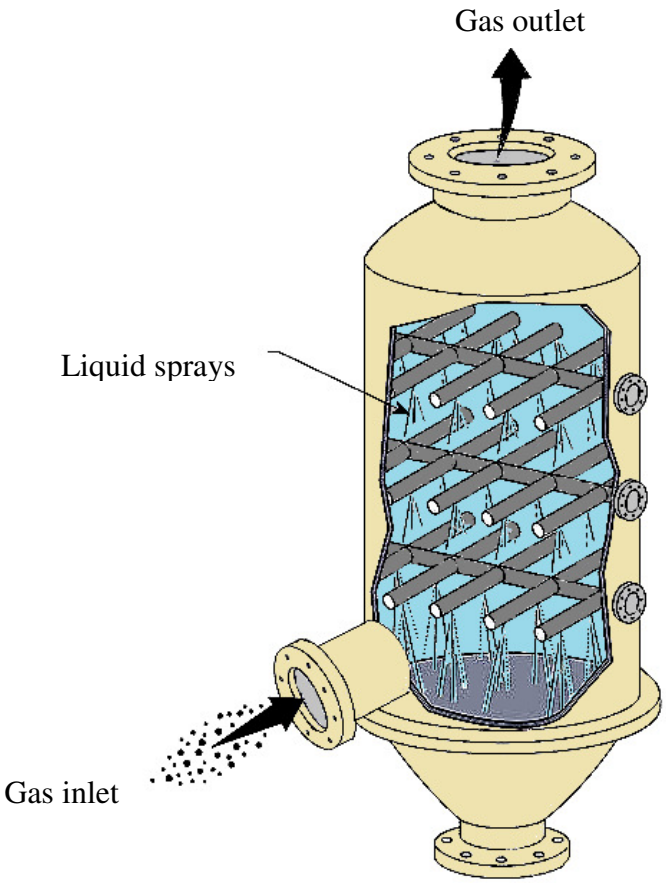

Figure 1: Spray tower

B. Venture Scrubber

This type of technology is a part of the group of air pollution controls **c**ollectively referred to as wet scrubbers. A venturi scrubber accelerates the waste gas stream to atomize the scrubbing liquid and to improve gas-liquid contact. In a venturi scrubber, a “throat” section is built into the duct that forces the gas stream to accelerate as the duct narrows and then expands. As the gas enters the venturi throat, both gas velocity and turbulence increase.

Depending upon the scrubber design, the scrubbing liquid is sprayed into the gas stream before the gas encounters the venturi throat, or in the throat, or upwards against the gas flow in the throat. The scrubbing liquid is then atomized into small droplets by the turbulence in the throat and droplet-particle interaction is increased.

The disadvantage of venture scrubbers

1. In venture scrubber contact area available for water and gases is less.
2. A precooler is to be used when venture scrubber is used for removing particulates.
3. There construction is not so simple.
4. Large amount of water is required for cooling.

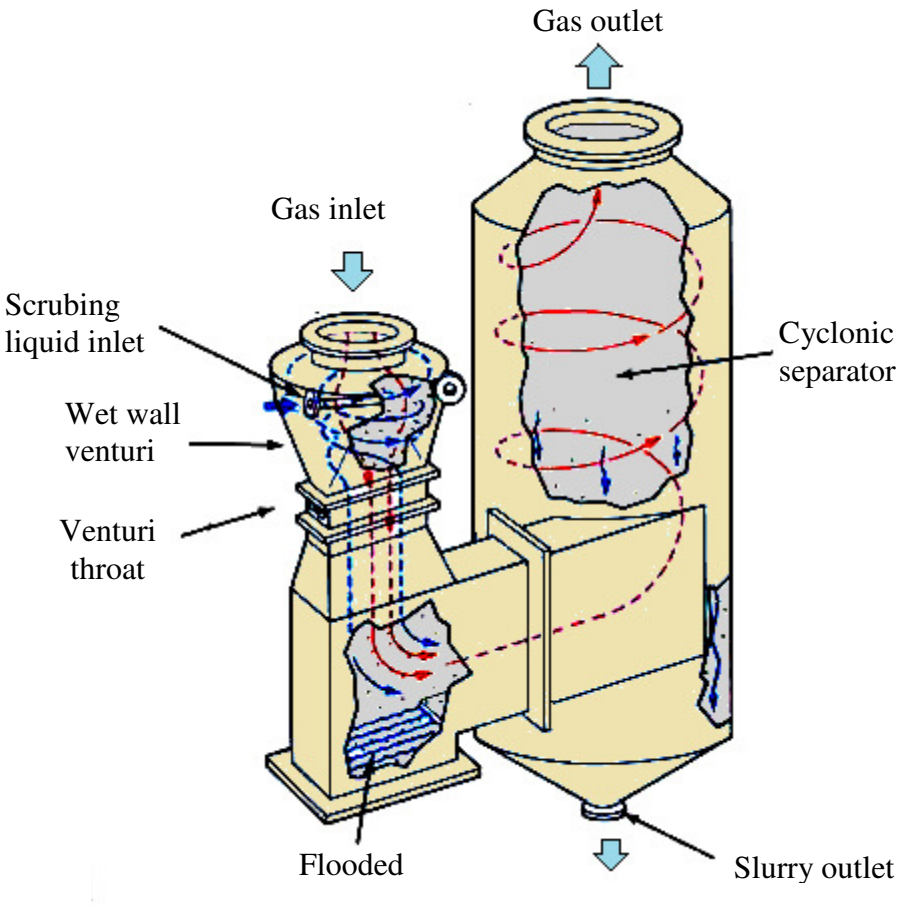

Figure 2: venture scrubbers

C. Packed Tower

Packed-bed scrubbers consist of a chamber containing layers of variously-shaped packing material, such as Raschig rings, spiral rings, or Berl saddles, that provide a large surface area for liquid-particle contact. The packing is held in place by wire mesh retainers and supported by a plate near the bottom of the scrubber. Scrubbing liquid is evenly introduced above the packing and flows down through the bed. The liquid coats the packing and establishes a thin film. The pollutant to be absorbed must be soluble in the fluid. In vertical designs (packed towers), the gas stream flows up the chamber (countercurrent to the liquid). Some packed beds are designed horizontally for gas flow across the packing (crosscurrent).

The disadvantage of packed tower

1. In packed tower pressure drop is higher.
2. Packing material increases the cost of the tower.
3. It is less efficient than cooler.
4. Problems like plugging, fouling and channeling are associated with it.
5. May create water (or liquid) disposal problem

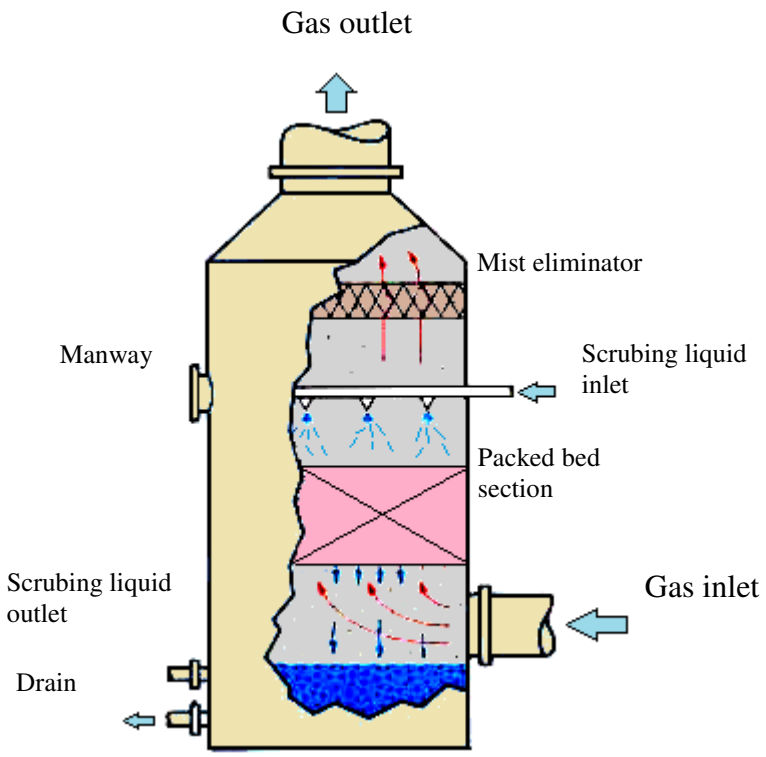

Figure 3: Packed tower scrubber

Quench Towers

There are many process unit quench towers including; Fluidized Catalytic Cracking Units, Vinyl Chloride Monomer Units, Ethylene Oxide, Ethylene Glycol and Ethylene Pyrolysis Cracking Units. The reactor effluent from the process requires cooling for further fractionation and therefore the temperature is reduced or quenched.

Quench Towers can either be cooled by a water or oil medium, this regulates whether it is called a Quench Water Tower (QWT) or Quench Oil Tower (QOT). These towers can vary in size, but are essential in the separation of hydrocarbons. Their function is to cool the superheated cracked gas in order to eliminate any further chemical reactions that might occur and to also decrease the temperature enough in order for the gas to be "scrubbed" of pollutants. This is important since the scrubber needs to be closer to ambient temperature in order to be unchanged physically or chemically.

In ethylene (olefins) plants, the potential for significant fouling exists in the quench columns that are used to cool the hot process gas from the cracking furnaces. FIGURE 1 shows a typical flow schematic of the quench columns. The furnace effluent is a full range mixture of hydrocarbons and water. Coke fines from the cracking furnaces are entrained with the vapor to the first column in the quench unit. This first column will be an oil quench (primary fractionator) or a water quench column, depending upon whether the plant has been designed to crack naphtha liquids or ethane and propane (E/P) gases.

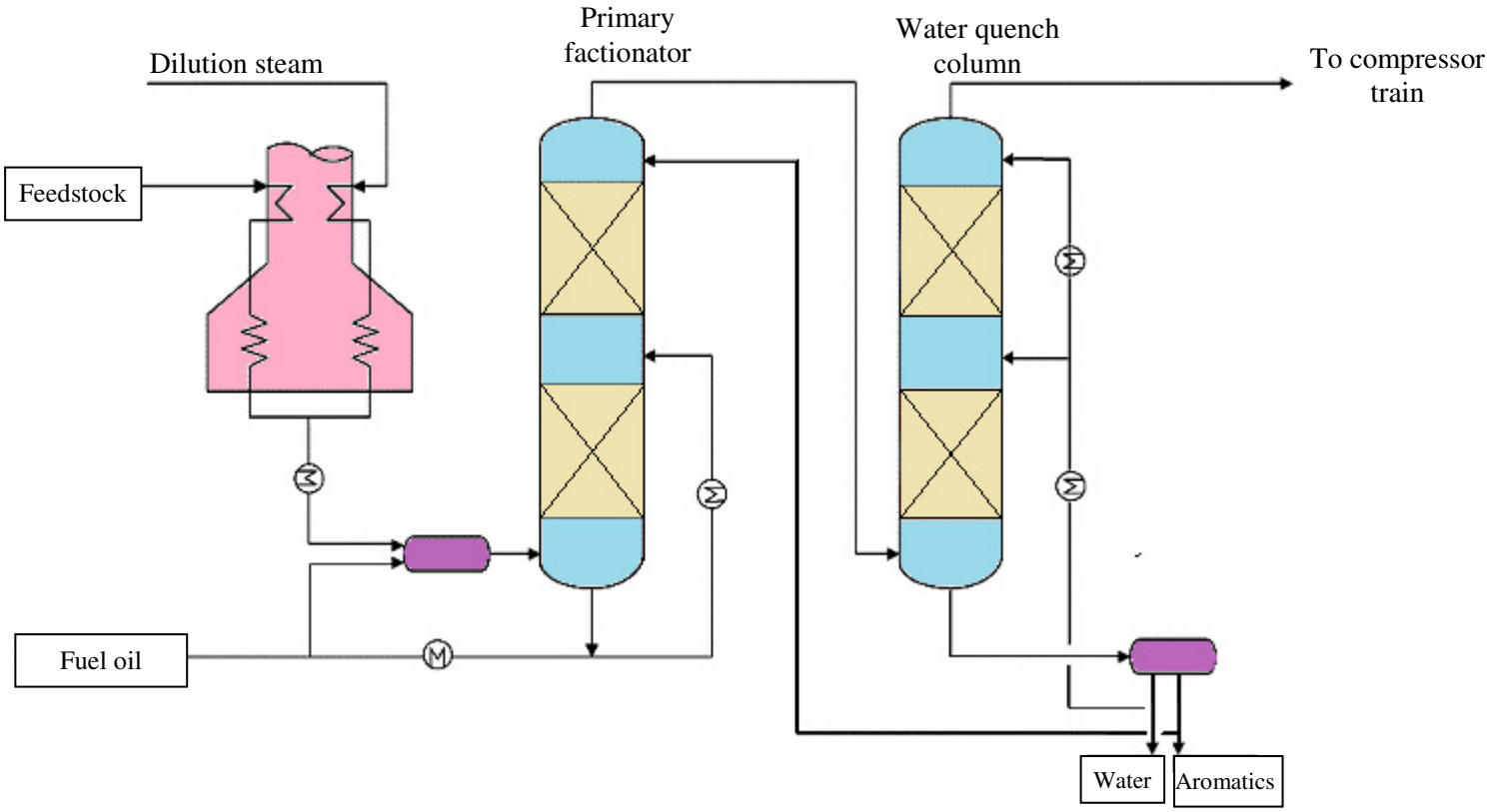

Figure 4: Flow Schematic of Typical Ethylene Quench System

Water-cooling towers are a particular example of direct-contact heat exchange. In direct-contact cooler-condensers, the condens liquid is frequently used as the coolant. The hot and cold are brought into contact wihout any separating wall, and high rates of heat transfer are achieved as shown in Figure 5.

Direct-contact heat exchangers should be considered whenever the process stream are compatible. The equipment used is basically simple and cheap, and is suitable for use with heavily fouling fluids and with liquids containing solids; spray chambers, spray column, and plate and packed column are used.

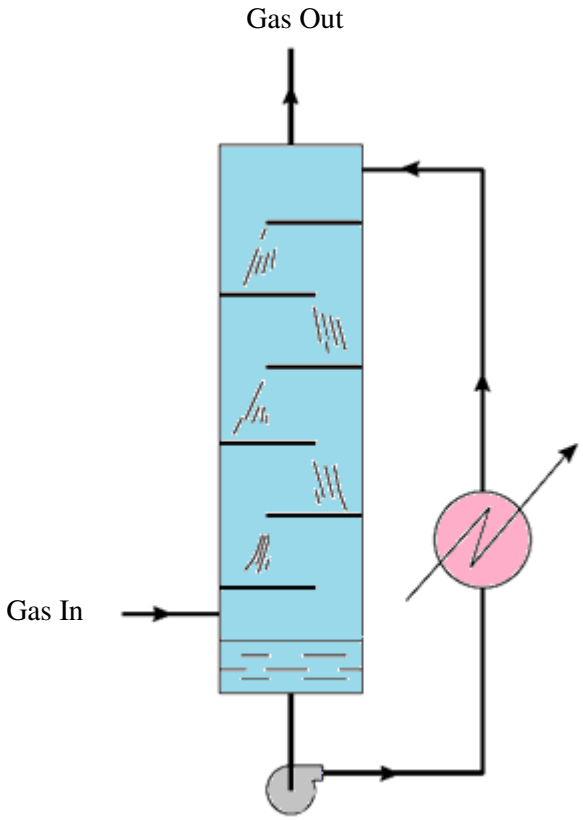

Figure 5: Typical direct-contact cooler

Water-cooling towers has some functions:

- Prepare heater effluent for compression by cooling and condensing a major portion of dilution steam
- Reduce undesirable side reaction
- Condense and recover heavy gasoline product

The System of Quench Water consists of

- Quench Tower
- Quench Water Settler
- Group of Heat Exchangers

Incoming hot, cracked gas is cooled to a suitable temperature for compression. The cooling is done by spraying cool water from the top of the tower onto upward flowing hot gases. The partially cooled gas enters the bottom of the quench column and is cooled by direct contact with a circulating stream of quench water. As the gas is cooled to 100-120℉, most of the water vapor produced by the upstream reactions (Claus, combustion, and hydrogenation) is condensed and removed from the gas stream. In addition to cooling the gas, direct contact with the quench water serves to absorb trace quantities of SO2 that may “break through” the reactor periodically.

The quench water leaving the bottom of the column is pumped to filtration and the cooler. A side stream of the quench water is filtered to remove solids from the quench water system. A portion of the filtrate is bled from the system to balance the water condensed from the gas in the quench column, and the remainder returns to the pump suction. Before returning to the quench column, the quench water is cooled to reject the heat removed in the column. Water and/or air cooling may be used in this service.

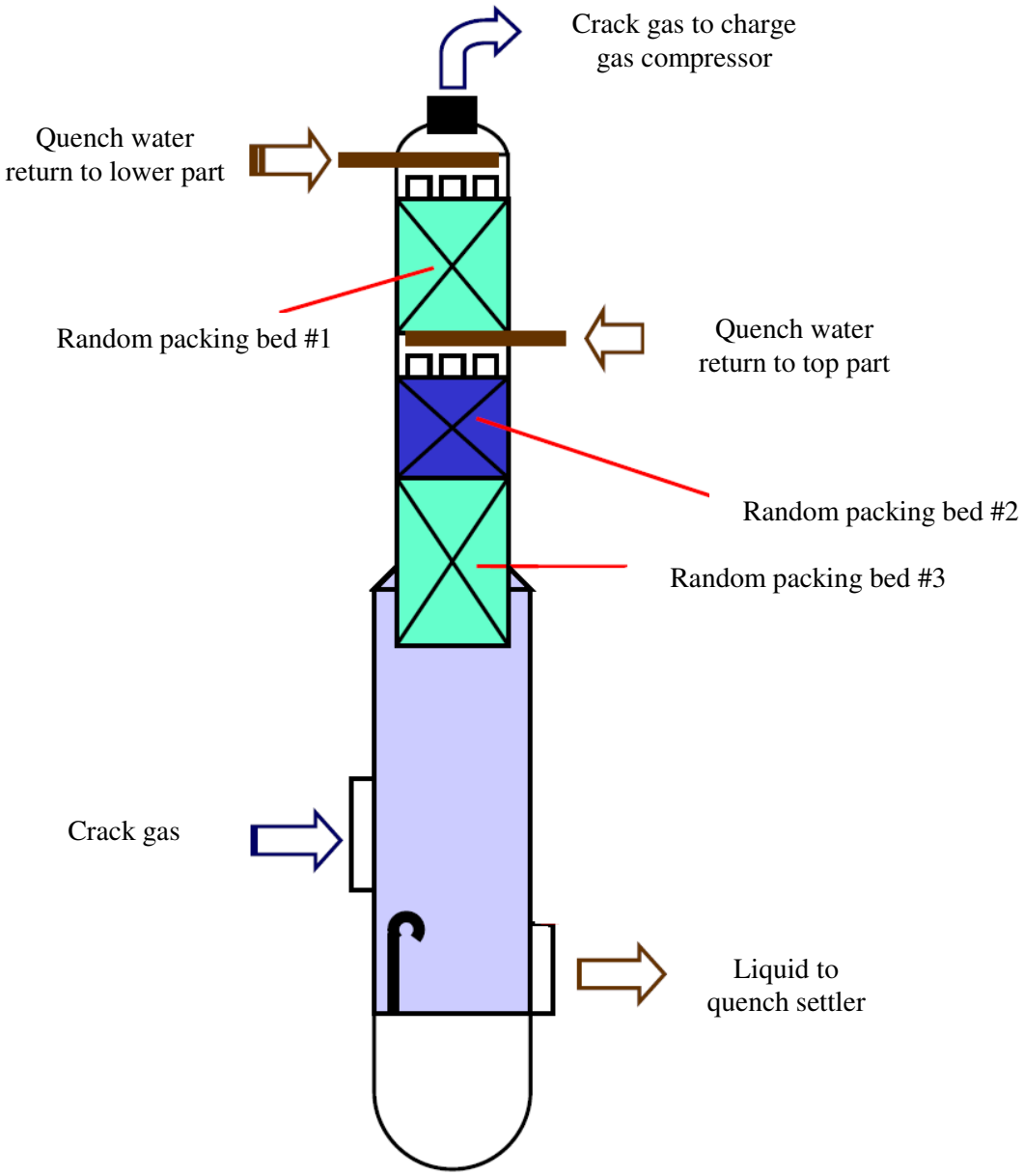

Figure 6: Quench Water Assembly

There is no general design method for direct-contact exchangers. Most applications will involve the transfer of latent heat as well as sensible heat, and the process is one of simultaneous heat and mass transfer. When the approach to thermal equilibrium is rapid, as it will be in many applications, the size of the contacting vessel is not critical, and the design can be based on experience with similar processes.

For other situations, the designer must work from first principles, setting up the differential equations for mass and heat transfer, and using jugdement in making the simplifications necessary to achieve a solution. The design procedures used are analogous to those for gas absorption and distillation. The rates of heat transfer will be high, with coefficicents for packed columns typically in the range 2000 to 20,000 $W/m^{3o}C$ (i.e., per cubic meter of packing).

The packed tower as a heat transfer device presents some very important advantages when heat is transferred between a gas or vapor phase and a liquid phase, which are mutually insoluble. While most other equipment offered for this service imposes some sort of surface between two fluids exchanging heat, in the packed tower, heat is transferred by intimate contact between the fluids. Although heat transfer is the primary purpose in such direct contact operations, in most cases, exchange of mass between fluids occurs simultaneously. However, heat transfer can occur without aprreciable mass transfer, as when a hot gas stream is cooled by a very high-boiling liquid.

Fouling and Toubleshooting

In non fouling services most fractionation devices can be utilized for heat transfer sections. Typically trays cost less than other fractionation devices and would be the first choice. In a revamp where higher capacity is required structured packing can be utilized in non fouling services. Packing is best when low pressure drop is desired, while still providing good heat transfer and efficiency. Compared to grid, beds heights can be lower with packing to achieve the same separation.

Fouling services are where the fluids contain solids such as coke, catalyst or scale, and other components that might lead to solid, crystallization or polymer formation. In fouling service the order of preference would be grids, trays, structured packing, and last random packing.

In ethylene (olefins) plants, the potential for significant fouling exists in the quench columns that are used to cool the hot process gas from the cracking furnaces. The

furnace effluent is a full range mixture of hydrocarbons and water. Coke fines from the cracking furnaces are entrained with the vapor to the water quench column in the quench unit.

In many ethylene units because of the coke fines, the column section above the cracked gas inlet will often utilize open-type baffle trays such as angle trays, disk and donut trays or splash decks depending on the licensor. In light naphtha units dual flow ripple trays have been successful, but in heavy naphtha units there have been some issues with dual flow trays. Some units will use a grid style packing in this section or a combination bed of grid packing with structured packing or trays. Some units still utilize random packing and pan distributors even though they have been shown to be problematic.

Quench tower fouling effect:

- Ethylene Production Decreased 16%.
- Overhead Temperature of Crack Gas Higher Than 42 ^{O}C can make effects to Charge Gas Compressor.
- Switching Time higher than normal (can't cut Feed and Feed in counter current) Decreased Load Cracking Heater

As the vapor cools and the worst fouling is eliminated, the packing type can be changed to a higher efficiency style while retaining effective fouling resistance. As a result of the additional packing efficiency, the liquid outlet temperature from the column can be increased, resulting in greater heat recovery from the ethylene quench unit. In the upper section of these columns, where fouling is less of a concern, high performance random packings are often used to provide greater efficiency for increased cooling of the process gas.

With the coke fines being washed from the process vapor, the liquid at the bottom of the quench column is usually dirty. Recirculating the liquid in the bottom pumparound calls for a fouling resistant liquid distributor design such as a spray nozzle distributor or a weir trough distributor.

The quench water decanter (settler) can have emulsification problems when the pH of the water is not neutral which results in circulation of heavy hydrocarbons back to the water quench tower with the water feeds. This is another primary source of fouling.

The disadvantage of random packing in fouling service is that occasionally one of the random packing will be vertical and the liquid on the horizontal section will have a high residence time leading to fouling. Once the fouling starts it will grow and eventually block the vapor and liquid flows.

Grids are preferred over trays when low pressure drop is desired, entrainment needs to be reduced, and when coking or fouling potential is high due to their low liquid hold up and resident times. Grids have seen excellent service in many quench towers.

In any random packed column, such as the quench column case above, the mass transfer area is generated by providing a large surface area over which the liquid phase can transfer heat and mass to the vapor phase. Any deviation that develops that restricts the liquid from generating this large surface area will deteriorate the column's ability to meet design specifications. Deviations that will restrict the ability of a column to generate this area include, but are not restricted to:

- Packing damaged during installation
- Incorrect distributor design or installation
- Fouled packing
- Packing flooding
- Contaminates that cause foaming
- Liquid entrainment into a packed bed
- Physical damage

Example

The furnace feed rates were reduced in an attempt to achieve adequate heat exchange in the water quench tower. When the pressure drop became negligible and the temperature differential across was still poor, a column problem did occur because of the upset. The symptoms suggest the column was prematurely flooded due to excessive fouling when the feed swing occurred. Then liquid hold-up in the tower increased until the packing support grids reached mechanical failure. Another indication of mechanical damage was that random packing was found in the pump strainers for the quench water recirculation. Additional troubleshooting would be required to determine the tower condition.

Although the spray distributors allowed the column to develop some heat transfer, it is not desirable to operate the column in this condition long term. The high overhead vapor temperature causes inefficiencies in both the downstream compressor section and the quench water heat integration.

DEFINITIONS

Acid Gas - a particular typology of natural gas or any other gas mixture containing significant quantities of hydrogen sulfide (H_2S), carbon dioxide (CO_2), or similar acidic gases. The hydrogen sulfide and carbon dioxide found in natural and refinery gases which, when combined with moisture, form corrosive acids; known as sour gases when hydrogen sulfide and mercaptans are present.

Bottoms – The stream of liquid product collected from the reboiler at the bottom of a distillation tower. The high boiling liquid product effluent from a distillation column.

Bubble point – The temperature at constant pressure (or the pressure at constant temperature) at which the first vapor bubble forms when a liquid is heated (or decompressed).

Capacity factor – Superficila vapor velocity corrected for vapor and liquid densities.

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.

Condenser- Is a heat exchanger which condenses a substance from its gaseous to its liquid state.

Dew point – The temperature at constant pressure (or the pressure at constant temperature) at which the first liquid droplet forms when a gas (vapor) is cooled (or compressed).

Distillate – The vapor from the top of a distillation column is usually condensed by a total or partial condenser. Part of the condensed fluid is recycled into the column (reflux) while the remaining fluid collected for further separation or as final product is known as distillate or overhead product. That portion of the condensate overhead vapor from a distillation column that is withdrawn as product.

Distillation – Separation of feed components by differences in boiling temperatures at a fixed pressure.

Extractive Distillation – Distillation in which a high boiling solvent is added to alter the relative volatility of components in the feed.

Fractionator – Device that physically separates a mixture of components in the feed, usually by distillation.

Gas Liquid contactors – Devices that used for direct contact heat exchange such as distillation, absorption, stripping, scrubbers and wide variety or reactors

Log mean temperature difference - the difference in temperature between the air surrounding the duct, and the inlet and outlet temperature of the 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.

Olefin - Any of a class of unsaturated open-chain hydrocarbons such as ethylene, having the general formula CnH2n; an alkene with only one carbon-carbon double bond.

Overall coefficient of heat transfer - the reciprocal of the overall resistance to heat flow. It is a function of the individual heat transfer coefficient

Packed towers - A fractionating or absorber tower filled with small objects (packing) to bring about intimate contact between rising fluid (vapor or liquid) and falling liquid.

Pressure Drop - The difference in pressure between two points in a flow system, usually caused by frictional resistance to a fluid flowing through a conduit, filter media, or other flow-conducting system.

Quenching Process – Rapid cooling of a material. the rapid cooling of a workpiece to obtain certain material properties. It prevents low-temperature processes, such as phase transformations, from occurring by only providing a narrow window of time in which the reaction is both thermodynamically favorable and kinetically accessible.

Quenching Tower – Column that rapidly cools a hot gas stream.

Rate of heat transfer - a function of the resistances to heat flow, the mean temperature difference between the hot gas and the air surrounding the duct and the surface area of the duct.

Reflux – Condensate returned to a distillation column to rectify the rising vapor.

Reflux ratio – Ratio of reflux flow to distillate product flow. The ratio of the reflux stream to the distillate. The operating reflux ratio could affect the number of theoretical stages and the duties of reboiler and condenser.

Relative volatility – Relative volatility is defined as the ratio of the concentration of one component in the vapor over the concentration of that component in the liquid divided by the ratio of the concentration of a second component in the vapor over the concentration of that second component in the liquid. For an ideal system, relative volatility is the ratio of vapor pressures i.e. $\alpha = P2/P1$

Spray nozzle - a device that facilitates the formation of spray. When a liquid is dispersed as a stream of droplets (atomization), it is called a spray.

Spray towers - A vertical column, at the top of which is a liquid spray device; used to contact liquids with gas streams for absorption, humidification, or drying. They consist of empty cylindrical vessels made of steelor plastic and nozzles that spray liquid into the vessels. The inlet gas stream usually enters the bottom of the tower and moves upward, while liquid is sprayed downward from one or more levels. This flow of inlet gas and liquid in the opposite direction is called countercurrent flow.

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

Theoretical stage – A mass transfer stage from which the two phases leave in equilibrium.

Venture scrubbers - A gas-cleaning device in which liquid injected at the throat of a venturi is used to scrub dust and mist from the gas flowing through the venturi. It is designed to effectively use the energy from the inlet gas stream to atomize the liquid being used to scrub the gas stream.

Water cooling tower – Column that reduces water temperature by partial evaporation into an air stream.

NOMENCLATURE

A	Column cross-sectional area (m^2)
A_{ht}	Area for heat transfer (m^2)
A_p	Spec. packing area (m^2/m^3)
BDG	Bone dry gas
C_{pl}	Heat capacity of liquid (J/kg.^oC)
C_p	Heat capacity (J/kmol C)
C_{pv}	Heat capacity of gas (J/kg.^oC)
C_s	Capacity factor
D	Column inner diameter (m)
F_i	F-Factor at inlet ($Pa^{0.5}$)
F_o	F-Factor at outlet ($Pa^{0.5}$)
F_v	Vapor capacity factor ($Pa^{0.5}$).
G	Superficial gas mass velocities (kg/hr m^2)
W_d	Bone dry gas flow (kg/h)
H_{gi}	Gas enthalpy inlet (kJ/kg)
H_{go}	Gas enthalpy outlet (kJ/kg)
H_i	Inlet gas humidity (kg H_2O/kg BDG).
H_o	Outlet gas humidity (kg H_2O/kg BDG).
H_v	Gas enthalpy (J/kg BDG).
H_v^*	Equilibrium gas enthalpy (J/kg BDG).
k	Av. therm. conductivity (W/m K)
L	Superficial liquid mass velocities (kg/hr m^2)
L_{hc}	Latent heat of hydrocarbons (kJ/kg)
L_{hw}	Latent heat of water (kJ/kg)
N_m	Minimum number of theoretical stages
W_{wi}	Inlet water flow (kg/h)
m	molar flowrate of liquid (kmol/hr)
N_{OG}	Number of overall gas transfer units
Nu	Nusselt number
Pr	Prandtl number
Q	rate of heat transfer (J/hr) (kJ/h)
Ql	Latent heat (MJ/h)
Qs	Sensible heat (MJ/h)

R	Reflux ratio
Re	Reynolds number
T_{gi}	Temperature gas inlet (°C)
T_{go}	Temperature gas outlet (°C)
T_{li}	Temperature liquid inlet (°C)
T_{lo}	Temp. liquid outlet (°C)
U	Gas side volumetric Heat transfer ceofficient (W/m² C)
V	Volume quencher (m³)
v_S	Superficial velocity (m/s)
W	Water Evaporated (kg/h)
W_G	Mass flow rate gas (kg/hr)
W_{gi}	Flowrate gas inlet (kg/hr)
W_{go}	Flowrate gas outlet (kg/hr)
W_L	Mass flow rate liquid (kg/hr)
W_w	Condensate water rate (kg/hr)
x	Mole fraction in the liquid phase
Z	Height of quencher (m)
Zp	Packing height (m)

Greek letters

γ	Angle of packing (deg)
ΔH	Heat of vaporization (J/kg)
ΔTLMTD	Log mean temperature (C)
α	relative volatility
ρ_G	Gas density (kg/m³)
ρ_{Gi}	Gas density inlet (kg/m³)
ρ_{Go}	Gas density outlet (kg/m³)
ρ_L	Liquid density (kg/m³).
% wt	Water content in condensate (%)
μ_g	Av. dyn. Gas viscosity (cP)

THEORY

Direct Contact Heat Transfer

Typically quench towers utilize one or more heat transfer sections or pump rounds to remove heat from the column. The use of heat transfer sections or pump rounds results in a better distribution of tower loads than if all of the heat were removed in the tower overhead. Additional benefits include reduced tower diameter at the column upper sections and the recovery of heat at a higher temperature. This higher level of heat can then be utilized in the process for improved energy recovery and higher overall plant efficiency, sometime called specific energy consumption.

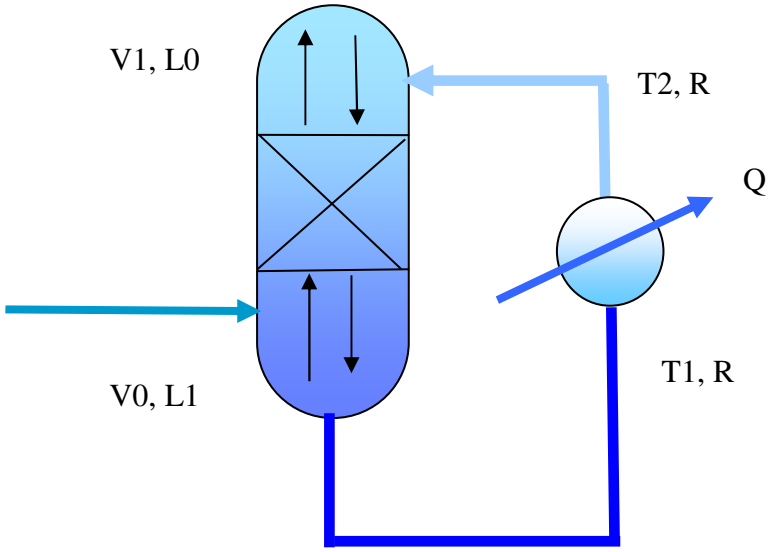

Figure 7: Example of a Typical Pump Around Section.

Specifying internals for heat transfer service requires calculations that account for simultaneous heat and mass transfer effects in which fundamental temperature driving forces are often difficult to evaluate. The calculation method for designing or rating direct contact heat transfer sections is based on a "transfer unit" approach. This method is analogous to the mass transfer unit approach to fractionation efficiency. The number of trays (for tray or baffle internals) or the height of packing (for packing and grid) can be determined on the basis of heat duty, tower loadings, temperature driving forces and tower area.

The amount of heat that is removed in the external pump around circuit of a heat transfer section in a column is equal to the exchanger duty Q. The exchanger reduces the pump around liquid temperature from the draw off temperature T1 to the return temperature T2. In a typical design, Q and T1 are usually set by the heat and material balances and the engineer must select appropriate values of T2 and the pump around rate R.

These variables are related by the following equation:

$$Q = M\, C_p\, \Delta T \qquad \text{Eq (1)}$$

$$Q = M_{PA}\, C_{pL}\, (T1 - T2) \qquad \text{Eq (2)}$$

where:

- Q = Exchanger duty
- M = Pump around liquid rate
- C_{pL} = Liquid specific heat
- T_1 = Pump around liquid draw off temperature
- T_2 = Pump around liquid return temperature

The difference between the internal and external heat transfer requirements can be visualized for systems involving net condensation of vapor if one recognizes that the reflux entering the section, RI, provides some cooling in addition to that of the pumparound liquid. Likewise, in systems with net vaporization, the latent heat required to vaporize the liquid provides cooling in addition to that of the pumparound.

For systems involving net condensation of vapor, the total number of heat transfer units required, N_{GH}, can be calculated by the following equation

$$N_{GH} = \frac{\Delta T}{\Delta T_{LMTD}} + \ln\left(\frac{G_i}{G_o}\right) \qquad \text{Eq (3)}$$

where:

N_{GH} = Total number of heat transfer units required
ΔT = Vapor phase temperature difference, $T_I - T_o$, °C (°F)
ΔT_{LMTD} = Log mean temperature difference, (LMTD), °C (°F)
G_I = Vapor rate entering heat transfer section, kg/h (lb/h)
G_o = Vapor rate leaving heat transfer section, kg/h (lb/h)

For systems involving net vaporization of liquid (such as pipestill wash zones and cat fractionator desuperheating sections) the total number of heat transfer units required is given by

$$N_{GH} = \frac{\Delta T}{\Delta T_{LMTD}} \qquad \text{Eq (4)}$$

Choosing Sequencing of Separation Operations

For sequencing of the separation units, there is another set of guidelines given in Table 2. In the base case, it is often helpful to cinsider the same type of separator for each unit. During optimization, one can compare different separator types for the different duties. Again, some separators can do multiple separations in one unit, but these can be found during optimization. Additional heuristics for separation unit sequaneching are given in Table 3.

Guidelines for Sequencing Separation Units.

- Remove the largest product stream first. This makes all of the subsequent separation units smaller.
- For distillation, remove the product with the highest heat of vaporization first, if possible. This reduces the heating /cooling duties of subsequent units.
- Do not recombine separated streams. (This may seen obvious, but it is often disobeyed).
- Do the easy separations first.