KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions	**Engineering Solutions** **www.klmtechgroup.com**	Page : 1 of 78 Rev: 02 Rev 01 Nov 2013 Rev 02 July 2014
KLM Technology Group P. O. Box 281 Bandar Johor Bahru, 80000 Johor Bahru, Johor, West Malaysia	**Kolmetz Handbook Of Process Equipment Design** **ETHYLENE QUENCH OIL TOWER SELECTION, SIZING AND TROUBLESHOOTING** **(ENGINEERING DESIGN GUIDELINES)**	Co Author: Rev 01 Mochamad Adha Firdaus Rev 02 Apriliana Dwijayanti Author / Editor Karl Kolmetz

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INTRODUCTION

Scope

This design guideline covers the basic elements of Ethylene Quench Oil Tower design to allow an engineer, operations personell and maintance personnel to design and / or review the deisgn of a quench water tower system. Included in the Guideline is sizing for trays and baffel trays, log mean temperature, heat transfer coefficient, rate of heat transfer, and the important numbers (Reynolds, Nusselt, and Prandtl).

Ethylene quench oil and quench water towers generally are known to have the one of the highest failure rates in the industry. Combination of high temperatures, solids, oxygenates, polymerization potential, fouling material and a mixture of hydrogen, steam, and C1 to C20s gives the a high challenge in one column system.

Due to this challenge KLM Technology Group only recommends special anti-fouling trays in the top of the column and baffle trays in the tower bottom section. 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

Ethylene pyrolysis cracking units, fluidized catalytic cracking, vinyl chloride monomer, ethylene oxide, and ethylene glycol are some process that quench towers included. Quench tower utilize heat transfer sections or pump rounds to remove heat from the column. The benefits of this removed heat are a better distribution of tower loads, reduces tower diameter at the column upper sections and the recovery of heat at a higher temperature. The higher level of heat can then be utilized in the process for improved energy recovery and higher overall efficiency.

Quenching is the rapid cooling of any hot material (such as in metallurgy) or gas, as in the case of ethylene production. Cracked gases leave the furnace at 1382 F to 1607 F (750 C to 875 C).To obtain the optimum yield from the cracked gas, the exit gas is quick cooled or quenched (to 550 – 600^{o}C / 1022 – 1112^{o}F). The gases must be cooled immediately in order to preserve the current composition of the gas and prevent undesirable side reactions from taking place. These side reactions are generally the secondary reactions listed in Table 1.This quick cooling avoids the degradation of the olefins and therefore increases the yield of ethylene. It also avoids further coke formation.

Table 1. Furnace Reactions

Primary Reactions			Secondary Reactions		
Feedstock/steam	→	Ethylene	→	C4 products
		Propylene		C5 products
		Acetylene		C6 products
		Hydrogen		Aromatics
		Methane		C7 products
		Etc		Heavier products

There are three types of quench units

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

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.

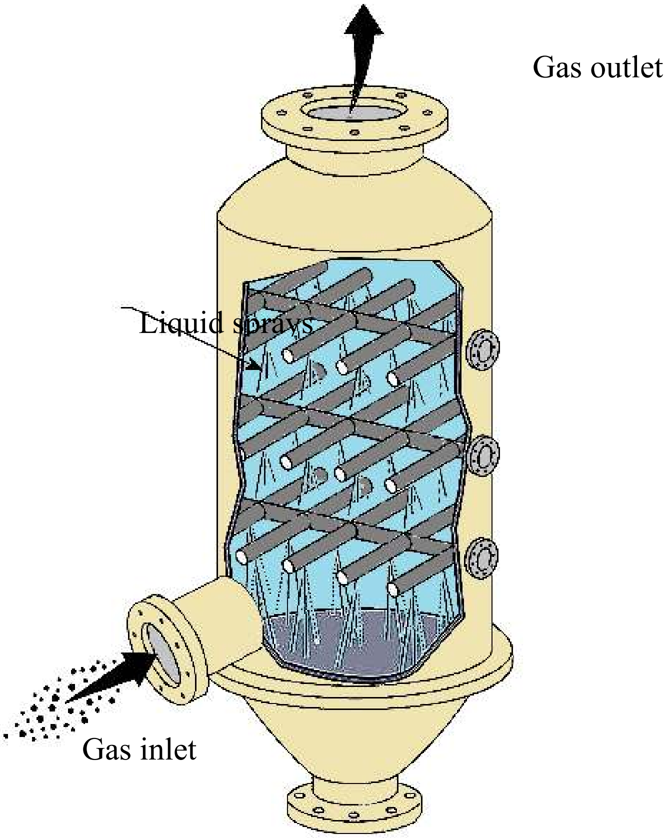

Figure 1: Spray tower

Gas outlet

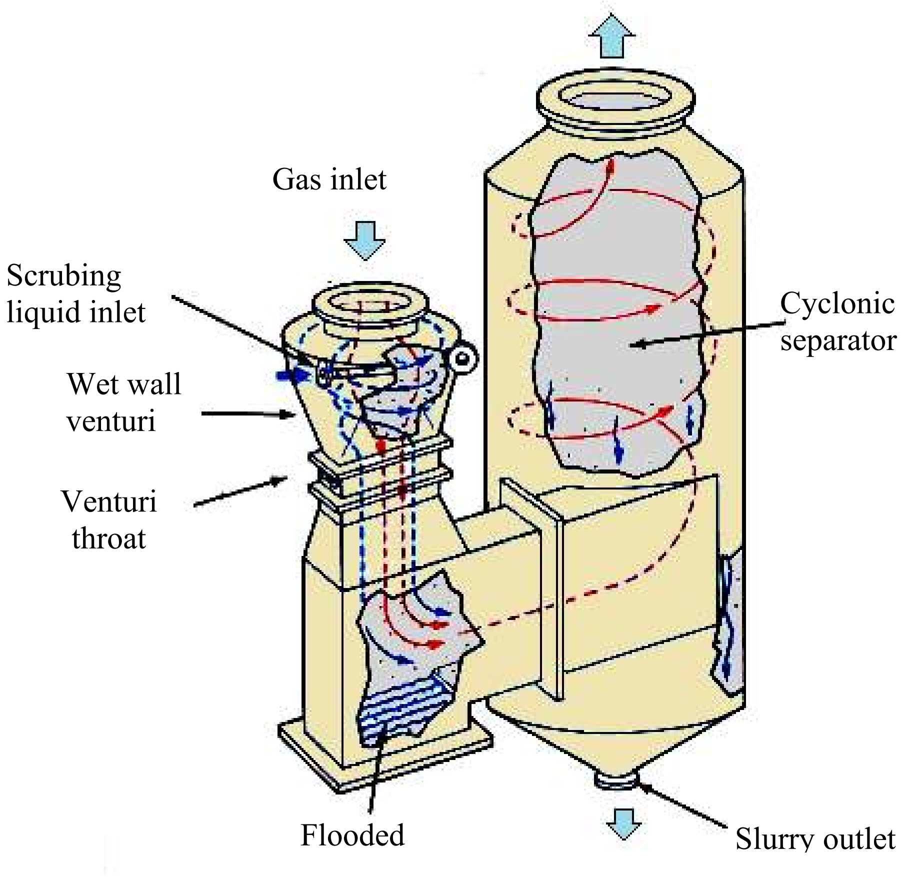

Figure 2: venture scrubbers

The configuration of the quench system primarily depends on the nature of feed. For liquid cracker that handle heavy feed such as gas oils and naphtha, generating massive amounts of fuel oil, the quench system uses fuel oil fractionation to recover the same followed by its integration with a quench water tower. If the fractionation is not employed, some of the fuel oil would form emulsions in the oil-water separator because some of these fuel oils have equal density as water.

For gas crackers that handle light feed such as ethane, propane and butane, only a quench water tower is used, because not much fuel oil is produced in the cracking heaters with such feed. The primary use of the oil quench tower depends on the quantity of heavy elements such as gasoline and other fuel oil generated at the furnace unit effluent and contained in the cracked gas.

The entire effluent from the cracking heaters becomes the feed for the oil quench tower for cooling the cracked gas and condensing the fuel oil and other heavy hydrocarbons. The cracked gas first passes through a quench fitting which is only a mixing valve, where gas cools from 380^{o}C to 185^{o}C by direct contact with heavy reafractory fuel oil.

This cold mixture then enters primary fractionatior, the oil quench tower which is considered to be the trickiest system, as serious fouling and total plugging of the system is often experienced. The risk of water condensation and foaming at the top are avoided by keeping the temperature at the top of the primary fractionatior above the condensation temperature of water.

The waste heat recovered from the circulation of the quench oil finds its use in generating low pressure steam. One use of this steam is the generation of dilution steam to be used in the furnaces. This use is however not very popular as it sets a minimum temperature for the quench oil affecting the viscosity of the quench oil. A portion of the quench oil is sometimes directly used for quenching of the cracked gas in the fitting for quench in the cracking heaters and the rest of it is used as the pump-around liquid for the underlying part of the oil fractionator.

The gaseous stream exiting at the top of the primary fractionatior (oil quench tower) is at 111^{o}C, consisting of cracked gas along with the steam and evaporated reflux then enters the water quench tower where the bulk of the process steam is condensed due to the circulating quench water, which when cooled is returned to the column at two different temperature levels depending on the plant feedstock capacity and local conditions. Here most of the gasoline fraction and the evaporated naphtha reflux is condensed and is passed along with the quench water to an oil water separator.

The oil-water separator is generally an overflowing drum that has a high residence time, allowing the coke and heavier-than-water components to separate. The slurry (i.e. water saturated with tar and coke) are separated by a series of purges located at the separator bottom and routed to the coke removal unit. The coke removal unit usually handles he coke particles accumulated at the oil-water separator bottom.

The quench tower can use either quench oil or quench water. Generally, only quench water is used on natural gas-based systems whereas naphtha plants use quench oil and may use a quench water tower as well. For situations in which a quench oil tower is being used for a naphtha fed plant, the quench oil is an extremely erosive fluid. It is usually dirty with entrained carbon particles. In order to have a long lasting solution, the erosive nature of the fluid must be taken into account when selecting an appropriate valve.

Some of the designers may combine the water and oil quench fractionator in a single tower with two separate sections. The combined tower performs the same functions as the two separate quench towers. The upper section is primarily used for condensing pyrolysis gasoline and the dilution steam, whereas the lower portion is used to recover the pyrolysis gasoline. The quench water circulation stream is usually also passed through the filtration unit so that no coke or tar is recycled back to the quench tower, which otherwise might lead to plant shut down because of the fouling of the tower packing and/or trays and the recycle distribution.

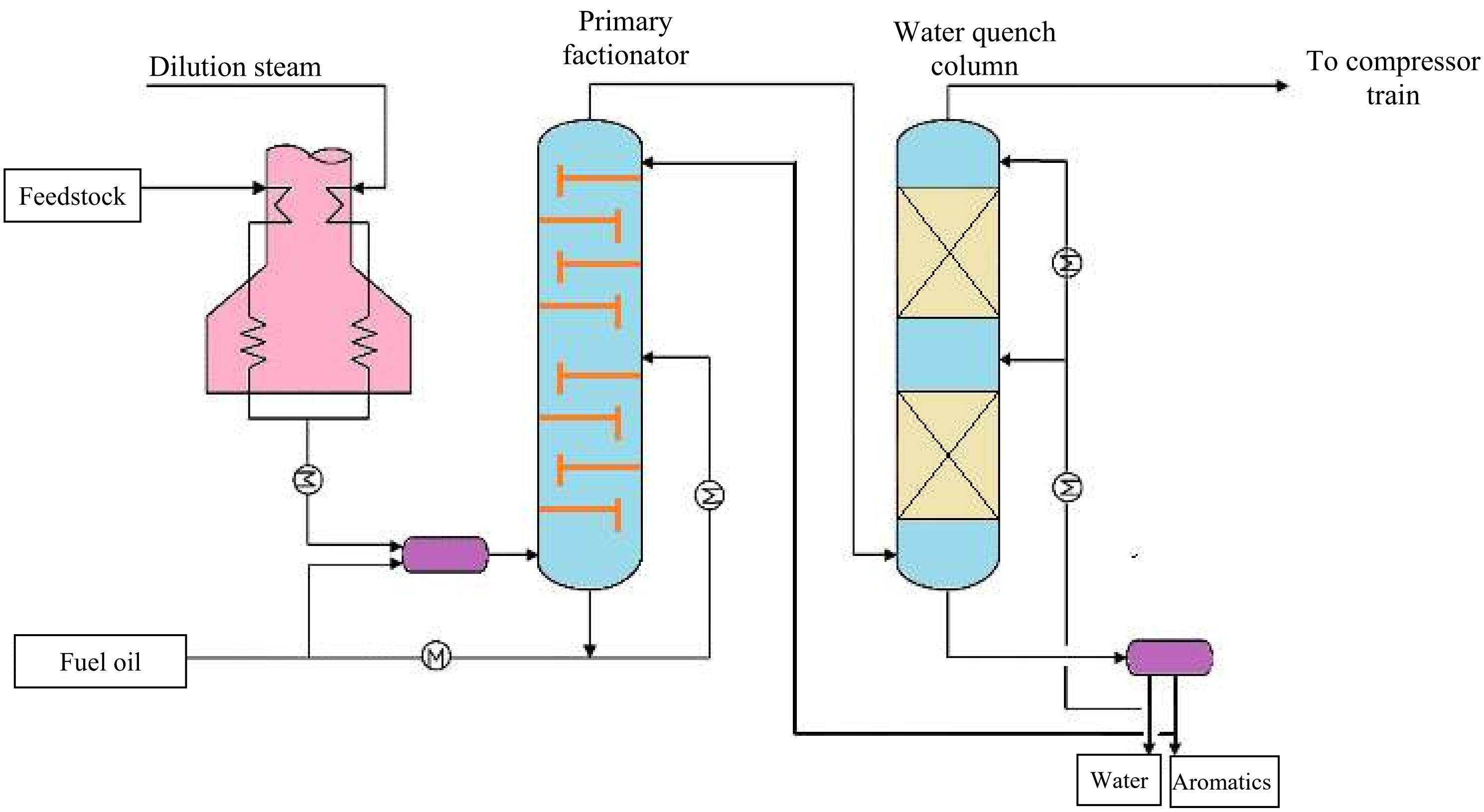

Figure 4: Flow Schematic of Typical Ethylene Quench System

Thermal Energy

Figure 13 shows the exmaple of a typical pump around section which removed heat transfer from a quench column. The amount of heat that removed is equal to the exchanger duty (Q). This exchanger reduces the pump around liquid temperature from the draw off temperature T1 to the return temperature T2.

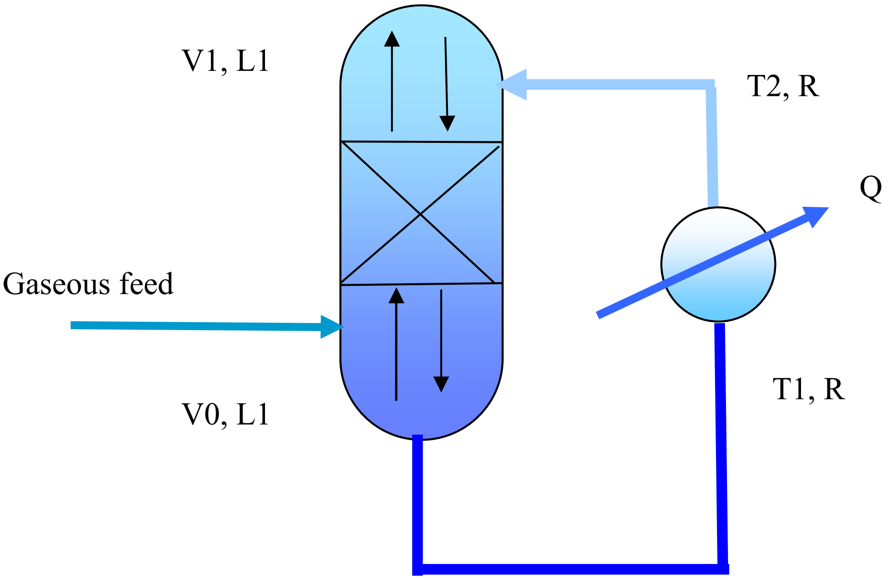

Figure 13. Example of a typical pump around section.

In a typical design, Q and T1 are usully set by the heat and material balances and the engineer should select approriate values of T2 and the pump around rate R. The variables are related to the folowing equation :

$$Q = M \cdot Cp \cdot \Delta T \qquad \text{Eq (5)}$$

$$Q = M_{PA}\, C_{PL}\, (T1 - T2) \qquad \text{Eq (6)}$$

Where :
Q = Exchanger duty
M_{PA} = Pump around liquid rate
C_{PL} = Spesific heat capacity of liquid
T1 = Temperature of Pump around liquid draw off
T2 = Temperature of Pump around liquid return temperature

DEFINITIONS

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.

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.

Downcomer - a vertical channel that connects a tray with the next tray below which carries froth and creates residence time which helps the vapor disengage from the froth.

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

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.

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

The effective residence time - The time needed to separate a mixture in a discontinuous operation.

The mean residence time - The time needed to separate a mixture in a continuous operation.

Thermal separation processes - Mass transfer operations, driven by molecular forces. Mass, and often heat, is exchanged between at least two phases of different composition.

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

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.

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.

Heat exchanger - a piece of equipment that continually transfers heat from one medium to another.

Heterogeneous mixture – any combination of substances that does not have uniform composition and properties. A mixture of physically distinct substances with different propeties

Homogeneous mixture - A mixture which has uniform composition and properties throughout. For example, air is a homogeneous mixture of gases.

Countercurrent Flow – A current that flows in an opposite direction to the flow of another current. System composed of two streams which flow in opposite directions, between which transfer of material occurs. During all stages, more saturated organic phase is in contact with the more saturated aqueous phase, to ensure rapid distribution between the phases

Fractionation column - a long vertical cylinder used in fractional distillation, in which internal reflux enables separation of high and low boiling fractios to take place

Pyrolysis- a thermochemical decomposition of organic material at elevated temperatures in the absence of oxygen (or any halogen). It involves the simultaneous change of chemical composition and physical phase, and is irreversible. The word is coined from the Greek-derived elements pyro "fire" and lysis "separating".

Coke - The solid product resulting from the destructive distillation of coal in an oven or closed chamber or by imperfect combustion, consisting principally of carbon

Entalphy - Enthalpy is the amount of heat content used or released in a system at constant pressure. Enthalpy is usually expressed as the change in enthalpy. The change in enthalpy is related to a change in internal energy (U) and a change in the volume (V), which is multiplied by the constant pressure of the system.

Polymer chemical compound that is made of small molecules that are arranged in a simple repeating structure to form a larger molecule.
Any of numerous natural and synthetic compounds of usually high molecular weight consisting of up to millions of repeated linked units,each a relatively light and simple molecule.

NOMENCLATURE

A	Column cross-sectional area (m^2)
A_{ht}	Heat transfer area of the packing
a	Aconstant, the value which is for different feedstocks. For naphtha feedstocks the value is a = 0.138.
$a_{I,eff}$	The effective interfacial area.
A_p	Spec. packing area (m^2/m^3)
C_{PL}	Spesific heat capacity of liquid
$c_{P,G}$	Specific heat capacity of the gas
C_s	Heat capacity of quench liquid (Kj/Kg°C).
D	Column inner diameter (m)
d_h	Hydraulic diameter of packing
E	Exchange ratio, Enrichment ratio, Murphree Efficiency.
F_i	F-Factor at inlet ($Pa^{0.5}$)
F_o	F-Factor at outlet ($Pa^{0.5}$)
F_v	Vapor capacity factor ($Pa^{0.5}$).
HP	Downflowing heavy phase
h	Cracked feed gas enthalphy (Kcal/Kg of ethylene)
h_G	Entalphy of the bulk gas phase.
h_I	Entalphy of the gas phase at the interface
h_s	Cracked gas enthalpy after the section (Kcal/Kg of ethylene).
h_{s+1}	Cracked gas enthalpy before entering the section (Kcal/Kg of ethylene).
H_{gi}	Gas enthalpy inlet (kJ/kg)
H_{go}	Gas enthalpy outlet (kJ/kg)
k	Av. therm. conductivity (W/m K)
$\mathbf{k_G}$	The mass transfer coefficient for the gas phase

k_L	The mass transfer coefficient for the liquid phase
k_L *a*	The mass transfer coefficient times
LP	Upflowing light phase
Lo	Liquid rate
L_{hc}	Latent heat of hydrocarbons (kJ/kg)
M_{PA}	Pump around liquid rate
NTU_{OG}	The number of overall transfer units for the gas phase
Nu_G	Nusselt number = $4U/(a_l k_G)$
$n-1, n$	Stages connected in series
OTR	The oxygen transfer rate
Pr_G	Prandtl number ($= \mu_G\ c_{p,G}/k_G$)
Q	Exchanger duty, Heat flow
Sh	The Sherwood number
T	Temperature of the cracked gas (°C)
t_m	The mean residence time
T_s	Temperature of the cracked gas after the section (°C).
T_{s+1}	Temperature of the cracked gas before entering the section (°C).
t_s	Temperature of the quench liquid before entering the section (°C).
t_{s-1}	Temperature of the quench liwuid after section (°C).
T1	Temperature of Pump around liquid draw off
T2	Temperature of Pump around liquid return temperature
U	Overall heat transfer coefficient
V	filled volume of the mixture in the separation (determined by the volume of the apparatus and the degree of filling).
V_G	Superficial velocity of the gas phase
V*	Effective volumetric flow of the mixture.
v_L	The superficial velocity of the liquid phase
x	Molar fraction of the key component in the heavy phase
y	Molar fraction of the key component in the light phase
$y_n^* - y_{n-1}$	Possible theoretical enrichment of the key component in the light phase
$y_n - y_{n-1}$	Actual enrichment of the key component in the light phase.
Z	Height of quencher (m)
Zp	Packing height (m)

SYMBOLS

$1 - \varepsilon$	The liquid holdup
δ^+	The bulk/film volume ratio
ε	Void volume for gas
ΔT_{LM}	Mean logarithmic temperature difference
μ_G	Dynamic viscosity of gas phase
γ	Corrugation angle of packing
ρ_G	Gas density