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Practical Engineering Guidelines for Processing Plant Solutions

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Page : 1 of 126

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Kolmetz Handbook Of Process Equipment Design

MANUFACTURING ETHYLENE

(ENGINEERING DESIGN GUIDELINES)

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TABLE OF CONTENT

LIST OF TABLE

LIST OF FIGURE

INTRODUCTION

Scope

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.

This guideline covers of many of the items to conside in the standard manufacturing of ethylene. The major sections of ethylene plant which consist of Cracking Section (Furnace), Quenching Hot Gas section, Compression, and downstream section like C_2, C_3, and C_4 splitter.

Manufacturing by Thermal Cracking is the most common method utilized to manufacture the ethylene and co products. The decision of suitable design and equipment for standard manufacturing ethylene is different between each plant depending of overall investment and how much production of each of the different products and co products are desired.

General Design Considerations

Ethylene, Ethene, $H_2C{=}CH_2$, *MW* 28.52, is the largest-volume petrochemical produced worldwide. Ethylene, however, has no direct end uses, being used almost exclusively as a chemical building block. Ethylene is also an important natural plant hormone, used in agriculture to force the ripening of fruits. It has been recovered from coke-oven gas and other sources in Europe since 1930.

Ethylene emerged as a large-volume intermediate in the 1940s when U.S. oil and chemical companies began separating it from refinery waste gas and producing it from ethane obtained from refinery by product streams and from natural gas. Since then, ethylene has almost completely replaced acetylene for many syntheses. Ethylene is produced mainly by thermal cracking of hydrocarbons in the presence of steam, and by recovery from refinery cracked gas. In 2005 total worldwide ethylene production capacity was 112.9 x 10^6 t, with an actual demand of ca. 105 x 10^6 t/a, which has growth projections of 3.7 to 4.3 % per year worldwide for the period of 2005 – 2010.

Ethylene is produced in the petrochemical industry by steam cracking. In this process, gaseous, gaseous or light liquid hydrocarbons are heated to 750 – 950^oC, inducing numerous free radical reactions follower by immediate quench to stop these reactions. This process converts large hydrocarbons into smaller ones and introduces unsaturation.

Ethylene is separated from the resulting complex mixture by repeated compression and distillatio. In a related proces used in oil refineries, high molecular weight hydrocarbons are cracked over zeolite catalysts. Heavier feedstocks, such as naphtha and gas oils require at least two “quench towers” downstream of the cracking furnaces to recirculate pyrolysis-derived gasoline and process water. When cracking a mixture of ethane and propane, only one water quench tower is required :

The areas of an ethylene plant are :

1) Steam cracking furnaces.
2) Primary and Secondary heat recovery with quench;
3) A dilution steam recycle system between the furnaces and the quench system;
4) Primary compression of the cracked gas;

5) Hydrogen sulfide and carbon dioxide removal;
6) Secondary compression;
7) Drying of the cracked gas;
8) Cryogenic treatment;
9) Demethanizer;
10) Deethanizer;
11) Depropanizer;
12) Debutanizer.

Since ethylene production is energy intensive, much effort has been dedicated to recovering heat from the gas leaving the furnaces. Most of the energy recovered from the cracked gas is used to make high pressure (1200 psig) steam. This steam is in turn used to drive the turbines for compressing cracked gas, the propylene refrigeration compressor, and the ethylene refrigeration compressor.

An ethylene plant, once running, does not need to import steam to drive its steam turbines. A typical world scale ethylene plant (about 1.5 billion pounds of ethylene per year) uses a 45 000 horsepower (34 000 kW) cracked gas compressor, a 30 000 hp (22 000 kW) propylene compressor, and a 15 000 hp (11 000 kW) ethylene compressor.

DEFINITIONS

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

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).

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^o 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.

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).

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.

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

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.

Downcomer Area - is the area available for the transport of liquid from one tray to the next tray below.

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

Entrainment – liquid carried by vapor up to tray above and caused by high vapor flow rates

Equation of state – A relation between the pressure, volume and temperature of a system, from which other thermodynamic properties may be derived. The relation employs any number of ‘constants’ specific to the system. For example, for a pure component, the constants may be generalized functions of critical temperature, critical pressure and acentric factor, while for a mixture, mixing rules (which may be dependent on composition or density), are also used.

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

Flooding – brought about by excessive vapor flow, causing liquid to be entrained in the vapor up the column.

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

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.

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.

Operating reflux - An amount in excess of the minimum that ultimately should be established by an economic balance between operating and capital costs for the operation.

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.

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.

Reboiler –Is a heat exchanger typically used to provide heat to the bottom of industrial distillation columns. They boil the liquid from the bottom of a distillation column to generate vapors which are returned to the column to drive the distillation separation.

Reflux ratio – 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 –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. $\alpha = P2/P1$

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

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

Splitter - A name applied to fractionators, particularly those separating isomers

NOMENCLATURES

atm	Standard atmosphere, 101325 Pascal
BMCI	The U.S Bureau of Mines Correation Index
bp	Boiling Point
dBA	decibel A-weighting
mp	Melting Point
K	Quality characterization factor
kWh	kilowatthour
MJ	MegaJoule
MW	MegaWatt
Pa	Pascal
P_c	Critical Pressure
ppm	Part per million
SG	Spesific Gravity
T_c	Critical Temperature
T_k	Molal average boiling point, Kelvin
TLE	Transfer-line Exchanger
t/a	Tons/Annual
t/yr	Tons/Year
wt %	Percent weight

THEORY

Properties

Ethylene is colorless flammable gas with a sweet odor. The physical properties of ehtylene are as follows :

mp	-169.15^{o}C
bp	-103.71^{o}C
Critical Temperature, T_c	9.90oC
Critical Pressure, P_c	5.117 MPa
Critical Density	0.21 g/cm^3
Density	
At *bp*	0.57 g/cm^3
At 0^{o}C	0.34 g/cm^3
Gas Density at STP	1.2603 g/L
Density relative to air	0.9686
Molar volume at STP	22.258 L
Heat of fusion	119.5 kJ/kg
Heat of combustion	47.183 MJ/kg
Heat of vaporization	
At *bp*	488 kJ/kg
At 0^{o}C	191 kJ/kg
Spesific heat	
Of liquid at *bp*	2.63 kJ/kg.K
Of gas at T_c	1.55 kJ/kg.K
Enthalpy of formation	52.32 kJ/mol
Entropy	0.220 kJ/mol.K
Thermal conductivity	
At 0^{o}C	177x10-4 W/m.K
At 100^{o}C	294x10-4 W/m.K
At 400^{o}C	805x10-4 W/m.K
Viscosity of liquid	
At *mp*	0.73 mPa.s
At *bp*	0.17 mPa.s
At 0^{o}C	0.07 mPa.s

Of gas	
At *mp*	36x10-4 mPa.s
At 0^{o}C	93x10-4 mPa.s
At 150^{o}C	143x10-4 mPas
Vapor Pressure	
At -150^{o}C	0.002 MPa
At *bp*	0.102 MPa
At -50^{o}C	1.10 MPa
At 0^{o}C	4.27 MPa

The chemical properties of ethylene result from the carbon-carbon double bond, with a bond length 0.134 nm and a planar structure. Ethylene is a very reactive intermediate, which can undergo all typical reactions of a short-chain olefin. Due to its reactivity ethylene gained importance as achemical building block. The complex product mixtures that have to be separated during the production of ehtylene are also due to the reactivity of ethylene.

Ethylene can be converted to saturated hydrocarbons, oligomers, polymers, and derivatives thereof. Chemical reactions of ethylene with commercial importance are : addition, alkylation, halogenation, hydroformylation, hydration, oligomerization, oxidation, and polymerization.

The following industrial process are listed in order of their 2000 world ethylene consumption :

- Polymerization to low-density polyethylene (LDPE) and linear low-density polyethylene (LLDPE).
- Polymerization to high-density polyehtylene (HDPE).
- Addition of chlorine to form 1,2-dichloro-ethane.
- Oxidation to oxirane (ethylene oxide) over a silver catalyst.
- Reaction with benzene to form ethylbenzene, which is dehydrogenated to styrene.
- Oxidation to acetaldehyde.
- Hydration to ethanol.
- Reaction with acetic acid and oxygen to form vinyl acetate.

- Other uses, including production of linear alcohols, linear olefins, and ethylchloride, and copolymerization with propene to make ethylene-propylene (EP) and ehtylene-propylene-diene (EPDM) rubber.

Polymerization

Very high purity ethylene (>99.9% plus) is polimerized under spesific conditions of temperature and pressure in the presence of an iniatiator or catalyst.

$$_nCH_2 = CH_2 \rightarrow -(CH_2 - CH_2)_n-$$

This is an exothermic reaction, and both homogenous (radical or cationic) and heterogenous (solid catalyst) are used. The products range in molecular weight from below 1000 to a few million.

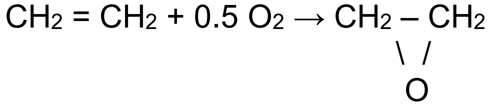
There are four types of reactions systems for the production of polyethylene of commercial importance :

- High Pressure (60 – 350 Mpa) free radical polymerization using oxygen, preoxide, or other strong oxidizers as initiatiors at temperatures of up to 350°C to produce low density polyehtylene (LDPE), a highly branched polymer, with densities from 0.91 to 0.94 g/cm^3.
- Low Pressure (0.1 to 20 Mpa) and temperatures of 50 to 300°C using heterogeneous catalysts such as molybdenum oxide or chromium oxide supported on inorganic carriers to produce high density polyethylene (HDPE), which is more linear in nature, with densities of 0.94 to 0.97 g/cm^3.
- Low pressure polymerization via ironic catalysts, using Ziegler catalysts (alumunium alkyls and titanium halides).
- Low Pressure polymerization with Ziegler catalysts supported on inorganic carriers.

A more recent development in ethylene polymerization is the simplified low pressure LDPE process. The pressure range is 0.7 – 2.1 MPa with temperature less than 100°C. The reaction takes place in the gas phase instead of liquid phase as in the conventional LDPE techology. These new technologies demand ultra high purity ethylene.

Oxidation

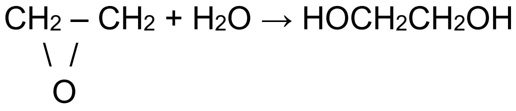
Ethylene Oxide is produce by oxiding ethylene as reaction below.



$$CH_2 = CH_2 + 0.5\ O_2 \rightarrow \underset{O}{\underset{\backslash\ /}{CH_2 - CH_2}}$$

The reaction is carried out over a supported mettalic silver catalyst at 250 – 300°C and 1 – 2 MPa (10 – 20 bar). A few parts per million (ppm) of 1,2dichloroethane are added to the ethylene to inhibit fruther oxidation to carbon dioxide and water. This result in chlorine generation, which deactivates the surface of the catalyst.

About 60% of the ethylene oxide produced is converted to ethylene glycol by reaction of ethylene oxide in the presence of excess water and an acidic catalyst at 50 – 70°C. This is followed by hydrolysis at relatively high temperatures (140°C – 230°C) and 2 – 4 MPa (20 – 40 bar). When the water concentration is lowered, polyethylene glycol is obtained.



$$\underset{O}{\underset{\backslash\ /}{CH_2 - CH_2}} + H_2O \rightarrow HOCH_2CH_2OH$$

Acetaldehyde can be obtained by the Wacker process, in which a homogenous $CuCl_2$-$PdCl_2$ system is used for the oxidation.

$$CH_2 = CH_2 + 0.5\ O_2 \rightarrow CH_3CHO$$

The reaction is carried out in a bubble column at 120 – 130°C and 0.3 MPa (3 bar). Palladium chloride is reduced to palladium during the reaction, and then is reoxidized by cupric chloride. Oxygen converts the reduced cuprous chloride to cupric chloride.

Vinyl acetate is obtained by vapor-phase oxidation of ethylene with acetic acid. Acetic acid is obtained by oxidation of acetyldehyde.

$$CH_2 = CH_2 + CH_3COOH + 0.5\ O_2 \rightarrow CH_2 = CH - OOCCH_3 + H_2O$$

This process employs a palladium on carbon, alumina, or silica-alumina catalyst at 175 – 200°C and 0.4 to 1.0 MPa (58 – 145 psi).

Addition

Addition reactions of ethylene have considerable importance and lead to the production of ethylene dichloride, ethylene dibromide, and ethyl chloride by halogenation – hydrohalogenation; ethylbenzene, ethyltoluene, and aluminum alkyls by alkylation; α – olefins by oligomerization; ethanol by hydration; and propionaldehyde by hydroformylation.

Halogenation – Hydrohalogenation.

The most important intermediate is ethylene dichloride (EDC) which is produced from ethylene either by direct chlorination or by oxy chlorination. Direct chlorination is carried out in the liquid or vapor phase over catalysts of iron, aluminum, copper, or antimony chlorides, and at conditions of 60°C. Oxychlorination is carried out in a fixed or fludizied bed at 220°C with a suitable solid chloride catalyst.

$$CH_2 = CH_2 + Cl_2 \rightarrow ClCH_2CH_2Cl$$

$$CH_2 = CH_2 + O_2 + 4HCl \rightarrow 2\ ClCH_2CH_2Cl + 2\ H_2O$$

By similar methods, ethylene dibromide can also be obtained. This compound is used in gasoline as an antiknocking additive. The leading derivative of ethylene dichloride is vinyl chloride monomer (VCM), which is subsequently used to produce polyvinyl chloride and chlorinated hydrocarbons. Vinyl chloride is obtained by dehydrochlorination of ethylene dichloride in the gas phase (500 – 600°C and 2.5 and 3.5 MPa).

$$ClCH_2CH_2Cl \rightarrow CH_2 = CHCl + HCl$$

Trichloro- and tetrachloroethylene are important organic solvents. These produced by furhter chlorination of 1,2 – dicholoroethylene in the gas phase with simultaneous dehydrochlorination in the presence of a suitable chloride catalyst.

Ethyl chloride is obtained by reaction of ethylene with hydrogen chloride in the presence of $AlCl_3$ of $FeCl_3$ at 300 – 500 kPa (3 – 5 bar) and 30 – 90°C (liquid phase), or at 130 – 250°C (vapor phase).

$$CH_2 = CH_2 + HCl \rightarrow CH_3CH_2Cl$$

Alkylation

Ethylbenzene, the precursor of styrene, is produced from benzene and ethylene. The ethylation of benzene is conducted either in the liquid phase in the presence of a Friedel – Crafts catalyst ($AlCl_3$, BF_3, $FeCl_3$) or in the vapor phase with suitable catalyst. The Monsanto / Lummus process uses an aluminum chloride catalyst that yields more thatn 99% ethylbenzene. More recently, Lummus and Union Oil commercialized a zeolite catalyst process for liqui-phase alkylation. Badger and Mobil also have a vapor-phase alkylation process using zeolite catalysts. Almost all ethylbenzene is obtained by dehydrogenation in the presence of suitable catalyst at 550 – 640°C and relatively low pressure, < 0.1 MPa (< 1 atm).

Toluene also reacts with ethylene to produce p-ethyltoluene or p-methylethylbenzene, which can be dehydrogenated to give p-methylstyrene. The polymer has a high glass-transition point and better flow properties, and has gained significant commercial importance in recent ears.

Alkylation of aluminum with ethylene yields products that find application as initiatiors and starter compounds in the production of α-olefins and linear primary alcohols, as polymerization catalysts, and in the synthesis of some monomers like 1,4-hexadiene. Triethylalunium, $Al(C_2H_5)_3$, is the most imprtant of ethylene-derived aluminum alkyls.

In the production of α-olefins, ethylene reacts with an aluminum alkyl at relatively low temperature to produce a higher alkylaluminum. This is the subjected to a displacement reaction with ethylene at high temperatures to yield a mixture of α-olefins and triethlyaluminum. In an alternative process, both reactions are combined at high temperatures and pressures where triethylaluminum functions as a catalyst in the polymerizaion process.

These design guideline are believed to be as accurate as possible, but are very general and not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

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Hydration

Ethanol is manufactured from ethylene by direct catalytic hydration over a H_3PO_4–SiO_2 catalyst at process conditions of 300°C and 7.0 MPa (1015 psi). Diethyl ether is also formed as a by product.

$$CH_2 = CH_2 + H_2O \rightarrow C_2H_5OH$$

In another process, ethylene is absorbed in 90 – 98% sulfuric acid at 50 – 85°C and 1.0 – 1.4 MPa (145-200 psi) to give a mixture of ethyl sulfates. These can be hydrolyzed to ethanol and dilute sulfuric acid.

Hydroformylation

In hydroformylation, the oxo reaction, ethylene reacts with synthesis gas ($CO + H_2$) over a cobalt catalyst at 60 – 200°C and 4 – 35 MPa (39 – 345 atm) to form propionaldehyde. This reaction is usally carried out in an organic liquid-phase where inert diluents are used as liquids.

Other reactions.

Comprehensive discussions of the following reactions, which are primarily of academic interest, are provided in various references. Ethylene may be hydrogenated to ethane under a variety of conditions. For example, hydrogenation is feasible for systems utilizing finely divided platinum or palladium at room temperature and atmospheric pressure, or utilizing nickel at 150 – 300°C and elevated pressure. These reactions are mainly used in research work.

Acyl halydes may also be added to ethylene in presence of aluminum chloride to form halogenated ketones. At low temperatures, ethylene reacts with halogens to yield dihaloethanes. At high temperatures, tricholorethylene and perchloroethylene are formed. The most profitable route for chloroethylene is via ethylene dichloride.

Ethylene is lightly more potent as an anesthetic than nitrous oxide, and the smell of ehtylene causes choking. Diffusion through the alveolar membrane is sufficiently rapid for equilibrium to be established between alveolar and the pulmonary capillary blood with a single exposure. Ethylene is held both in cells and in plasma in simple in simple physical solution. The lipoid stroma of the red blood cells absorb ethylene, but it does not combine with hemoglobin. The concentration in the blood is 1.4 mg/mL when ethylene is used by itself for anesthesia. However, in the 1990's it is not used as an anesthetic agent. Ethylene is eliminated from the body unchanged, primarily by the lungs, and most elimination is complete within three minutes of administration.

The controlled ripening of various fruits vegetables and vegetables by ethylene is of considerable importance. Ethylene was identified as one of the volatiles emitted by ripening fruits as early as the 1930's, and its biological use had been mentioned as early as 1901. A few ppm of ehtylene (<10 ppm) is often used for ripening bananas and others fruits. However, the ethylene concentration varies with the type of fruit and environtmental conditions. Ethylene can also have adverse affects on plants. It causes the bleaching of green tissue, gives rise to foliar abscission, suppresses certain types of dormancy, and promotes cellular swelling.

Raw Materials

Table 1 lists the percentage of ethylene produced worldwide from various feedstocks for 1981 and 1992. In Western Europe and Japan, over 80% of ethylene is produced from naphthas – the principal ethylene raw materials.

Table 1. Raw materials for ethylene production

Raw Material	USA 1979	USA 1995	Western Europe 1981	Western Europe 1995	Japan 1981	Japan 1993
Refinery gas	1	4		3		
LPG, NGL	65	76	4*	17	10*	3*
Naphtha	14	11	80	71	90	97
Gas Oil	20	9	16	9	0	0

*Including refinery gas

A shift in feedstocks occured for the period from 1980 to 1991. In the United States and Europe larger amounts of light feedstocks (liquified petroleum gas LPG : propane + butanes) and NGL (natural gas liquids : ethane, propane, butane) are used for ethylene production, whereas in Japan more naphtha was used in 1995 compared to 1981. The use of gas oils for ethylene production decreased slightly during the 1980's. Since 2000 a huge amount of new capacities have been installed in the Middle East based on ethane as feedstock, increasing the share of ethane-based production significantly (Fig. 1). This trend will continue in the coming years due to favorable production costs for ethane-based crackers. As a result the production of propene from new crackers will decrease requiring different ways of production of this cracker coproduct.

Ethane is obtained from wet natrual gases and refinery waste gases. It may be cracked alone or as mixture with propane. Propane is obtained from wet natural gases, natural gasolines, and refinery waste gases. Butanes are obtained from natural gasolines and refinery waste gases.

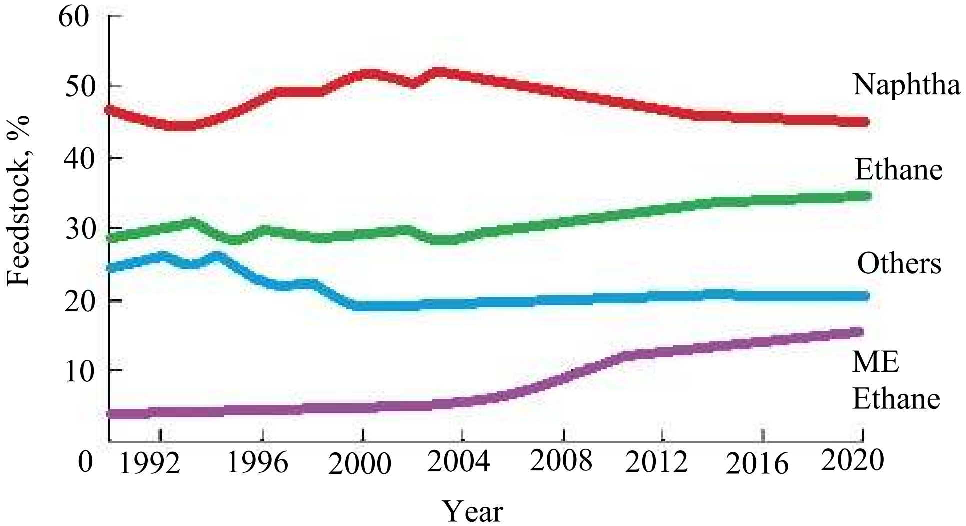

Figure 1. Feedstocks for ethylene production.

Naphthas, which are the most important feedstocks for ethylene production, are mixtures of hydrocarbons in the boiling range of 30-200°C. Processing of light naphthas (boiling range 30 – 90°C, full range naphthas (30-200°C)) and special cuts (C_6 – C_8 raffinates) as feedstocks is typical for naphtha crackers.

A natural-cut full-range naphtha contains more than 100 individual components, which can be detected individually by gas chromatography (GC). Depending on the origin naphtha quality control of the complex feed mixtures. Characterization is typically based on boiling range; density; and content of parrafins (n-alkanes), isoalkanes, olefins, naphthenes, and aromatics by carbon number. This characterization can be carried out by GC analysis of by a newly developed infrared method. Full characterization of feedstocks is even more important when production is based on varying feedstocks, e.g feedstocks of different origins pruchased on spot markets.

The quality of a feedstock is depending on the potential to produce the target products (ethylene and propylene). Simple yiled correlations for these products can be used to express the quality of a feedstock in a simple figure, the quality factor, which indicates whether yields of the target products are high or low, with aromatic feedstocks being poor and saturated feedstocks being good feedstocks.

Quality characterization factors for naphthas have been developed, which indicate the aromatics content by empirical correlation. Since aromatics contribute little to ethylene yields in naphtha cracking, a rough quality estimate can be made for naphthas with a typical weight ratio of h- to isoparaffins of 1-1.1. The factor is define as :

$$K = \frac{(1.8T_k)^{1/3}}{d}$$

Where T_k is the molal average boiling point in K. Naphthas with a K factor of 12 or higher are considered saturated; those below 12 are considered naphthenic or aromatic. The factor does not differentiate between iso- and *n*-alkanes. The U.S Bureau of Mines Correlation Index (BMCI) can also be used as a rough quality measure of naphthas :

$$\text{BMCI} = 48640/T + 473.7d - 456.8$$

Where T is the molal average boiling point K and d is the relatve density. A high value of BMCI indicates a highly aromatic naphtha; a low value, a highly saturated naphtha.