KLM Technology Group #033, Jalan Bayu 8/1, Taman Nusa Bayu, 79200 Iskandar Puteri, Johor, Malaysia	**Kolmetz Handbook Of Process Equipment Design** **EB / STYRENE MANUFACTURING** **(ENGINEERING DESIGN GUIDELINE)**	Co Authors Rev 01 – Apriliana Dwijayanti Author / Editor Karl Kolmetz

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INTRODUCTION

Scope

Styrene monomer is the fourth largest chemical produced on an industrial scale and most ethylbenzene is utilized in styrene monomer production. The largest chemical produced on an industrial scale is ammonia for fertilizer production, followed by crude oil refining, and then ethylene by furnace pyrolysis. Styrene monomer has been manufactured commercially for more than fifty years with advances in the key unit operation areas of reactor design and distillation.

Styrene is essential and important hydrocarbon in the petrochemical industry; primarily the world demand for commercial production of styrene is increasing on a daily basis, the adiabatic dehydrogenation method is extensive used as a widely accepted method to produce styrene, 85% of commercial production utilizes this rout.The process is more of catalytic reaction because the catalyst plays a large part in the production in the production process.

Contemporary styrene unit designs include second generation structured packing and optimized liquid-vapor distributors. In the current designs, consideration of packing bed height and how the packing bed height affect stage efficiency due to mal-distribution should be reviewed. Designs are now limited by the maximum allowable pressure drop in order to avoid bottoms temperatures above 120C.

This guideline will introduce the fundamental concepts that are used by designers to make decisions about system design of Styrene monomer manufacturing.

General Design Consideration

Styrene (a.k.a. Vinylbenzene, Ethenylbenzene, Phenylethene) is an organic compound, the simplest monomer in the aromatic hydrocarbon class. It is a colourless, oily liquid, with aromatic odour, insoluble in water, but soluble in most organic compounds. This organic compound was first isolated in the nineteenth century; however, it only began being industrially produced in the 1930s, with the development of the dehydrogenation process, which allowed for styrene's polymerization. Currently, styrene is one of the most important aromatic members, being the most commercialized.

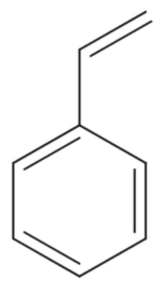

Figure 1. Styrene structure

Styrene monomer is the fourth largest chemical produced on an industrial scale and most ethyl-benzene is utilized in styrene monomer production. Styrene is mainly employed as: monomer in the production of SBR, ABS, SAN and SB; alkyd/epoxy ester resin modifier; cast resins; and reactive diluent (unsaturated polyester resins). Styrene can be used in the manufacture of other products, including: acrylonitrile-butadiene-styrene copolymers; acrylic resins; acrylonitrile-(ethylene-propylene-diene)-styrene copolymers; acrylonitrilestyrene-acrylate copolymers; polystyrene; vinylbenzyl chloride; vinyl ester resins; and vinylpyridine copolymers.

About 65% of styrene is used to produce polystyrene. Polystyrene is used in the manufacture of many commonly used products such as toys, household and kitchen appliances, plastic drinking cups, housings for computers and electronics, foam packaging, and insulation. Polystyrene finds such widespread use because it is relatively inexpensive to produce and is easy to polymerize and copolymerize, resulting in plastics with a broad range of characteristics. In addition to polystyrene, styrene is used to produce acrylonitrile–butadiene– styrene polymer, styrene–acrylonitrile polymer, and styrene–butadiene synthetic rubber (SBR).

The development of styrene technologies was mainly driven by demand for cheap synthetic rubber during and immediately after World War II. Between 5% and 10% of total styrene produced becomes a component of synthetic rubbers, which are copolymers of styrene and butadiene (SBR). Styrene copolymers containing acrylonitrile are specialty materials that are used for specific applications. Demand for styrene for the period 2004–2009 is estimated to grow at a rate of approximately 4% per year.

The ethyl benzene and styrene monomer industry is a mature industry with basically two technology licensers; 1) ABB Lummus and 2) Shaw Stone & Webster Badger. The technology has the typical two unit operations, reaction followed by separation. Each operation can be optimized and there is on going research in each area to improve the conversion of the reactors and the efficiency of the separation.

Styrene Production Pathways

The commercial production of Styrene is largely based on ethylbenzene (EB) raw material. In this context, there are two main production routes: one involves the dehydrogenation of EB to Styrene, while the other, based Arco SM-PO process, involves the production of Styrene and propylene oxide (co-product) from EB and propylene. Styrene production pathways are presented in the diagram below.

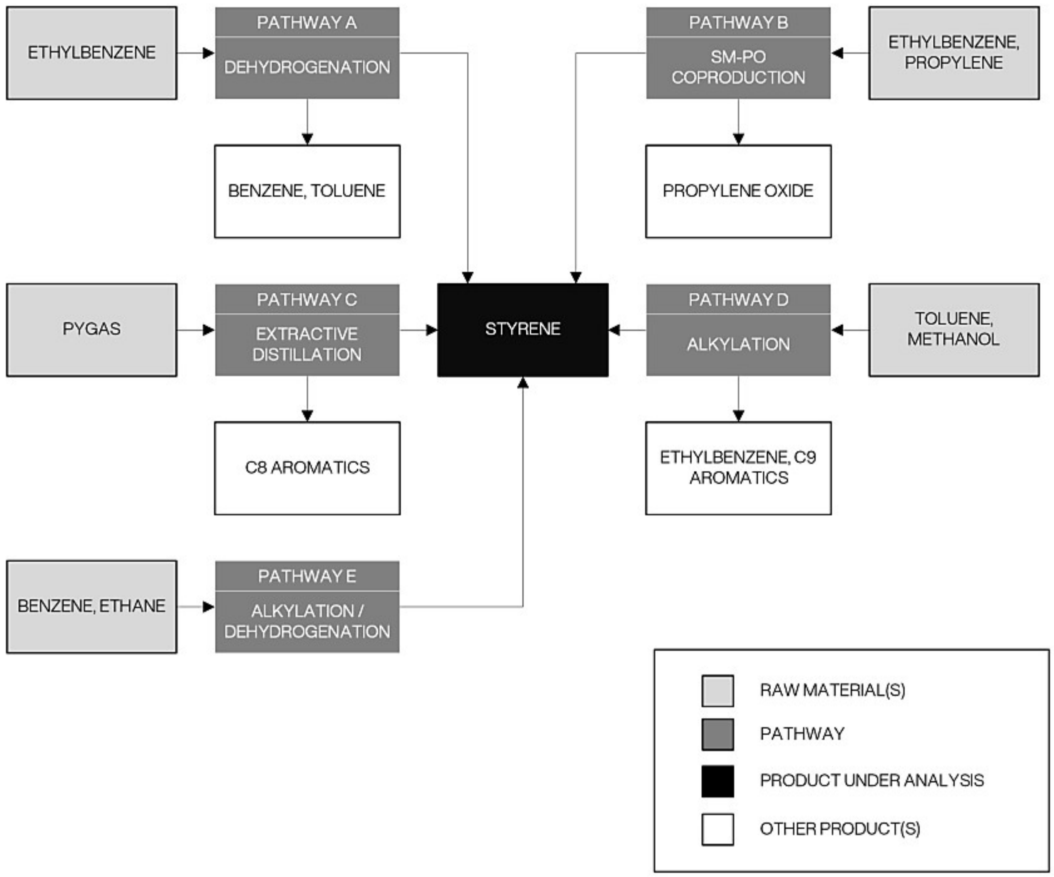

Figure 2. Styrene Production Pathways

The process under analysis comprises the following major sections: (1) dehydrogenation; (2) crude Styrene separation and (3) purification.

- Dehydrogenation. Initially, fresh and recycled ethylbenzene are vaporized, superheated, diluted in steam and fed to dehydrogenation reactors. The reaction is carried out over fixed bed catalysts in two radial-flow, adiabatic reactors operating in series. As the dehydrogenation reaction is endothermic, reaction heat is supplied by preheated steam that is mixed with ethylbenzene upstream the first reactor and by an interreactor reheater. The effluent from the dehydrogenation, containing Styrene, unreacted EB, toluene and benzene by-products and impurities is directed to separation steps downstream.
- Crude Styrene Separation. The effluent from the dehydrogenation step is cooled, partially condensed, and fed to a settling drum. Vapors are disengaged from the liquid phase, compressed, cooled and passed through an absorber/stripper system, for the recovery of residual aromatics which are recycled. The aqueous phase from the settling drum is fed to a steam stripper, in which dissolved trace hydrocarbons are recovered. The organic phase – a crude Styrene stream – is directed to purification steps downstream.
- Purification. The crude Styrene stream is mixed with dinitrophenols, which act as inhibitor to lessen polymer formation throughout distillation steps downstream, carried out under vacuum. In a first distillation step, a mixture of benzene and toluene by-products is separated from the Styrene stream. This mixture is further distilled for the separation of the by-products. In a subsequent distillation step, Styrene is separated from EB, recycled to the dehydrogenation. Finally, Styrene is purified from residual impurities – mainly C9 aromatic compounds – in a last distillation step.

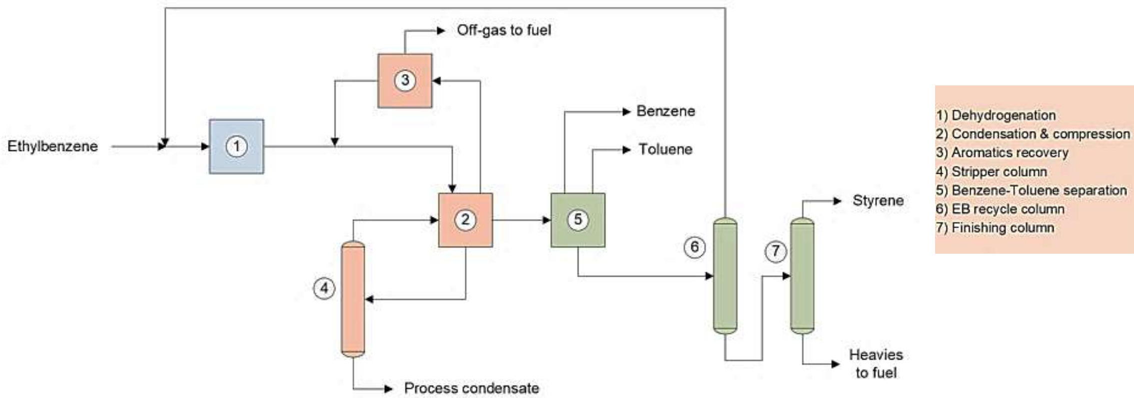

Figure 3. Block diagram of styrene process

The main product obtained in this process is Styrene with a purity of 99.9 wt %. Benzene and toluene are also generated as by-product.

- Benzene
  Benzene (C6H6) is a flammable and volatile liquid. As the simplest aromatic hydrocarbon, it is used as an intermediate to produce many important chemicals, such as Styrene (raw material for polystyrene and synthetic rubber), cyclohexane (used in nylon production), alkylbenzenes (used in detergent industry), aniline (used to produce dyes and polyurethanes), and chlorobenzenes. Also, benzene is used to produce pharmaceuticals, specialty chemicals, plastics, and pesticides. It occurs naturally in crude oil and coal tar.

- Toluene
  Toluene (also known as methylbenzene) is an aromatic hydrocarbon mainly used as an industrial feedstock and as solvent. A significant part of toluene production is blended directly into gasoline pools. Other major use of this chemical is in the manufacture of the more valuable benzene, through hydro-dealkylation. Most of toluene is produced via catalytic reforming of refinery streams (C6–C9 naphthas), along with benzene, xylenes, and C9-aromatics

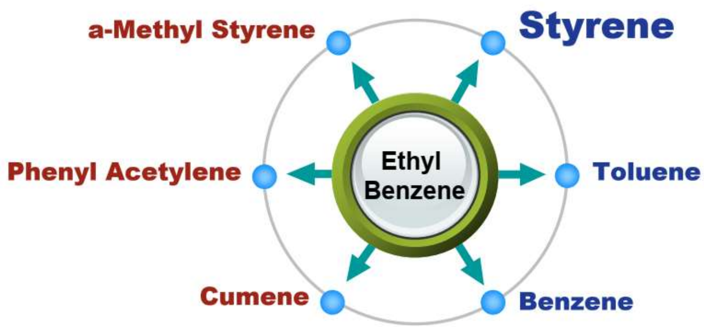

Figure 4. Process chemistry

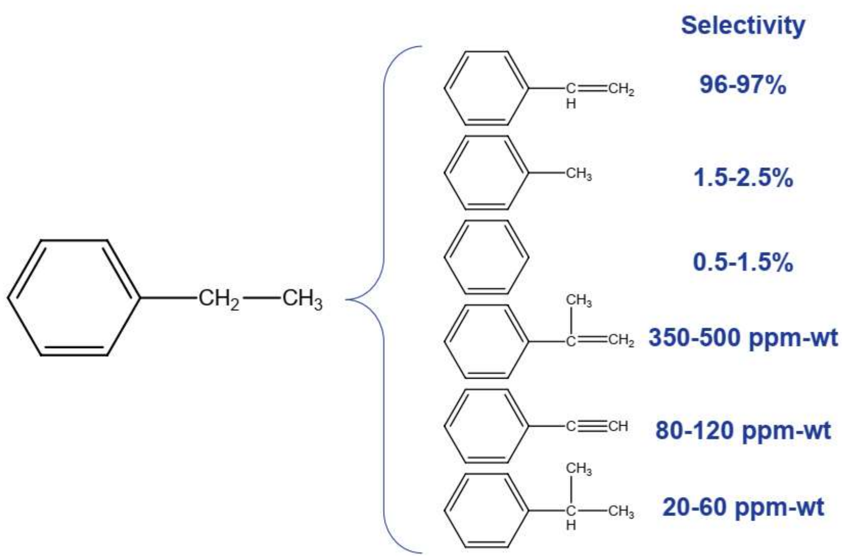

Figure 5. Product distribution

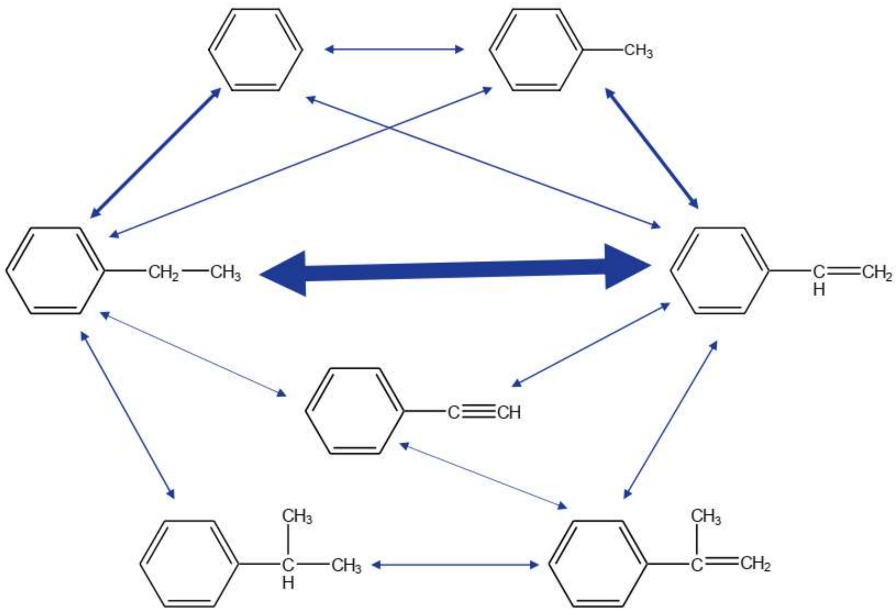

Figure 6. Reaction pathways

Industrial Process

i. Making Styrene with Ethylbenzene Dehydrogenation

Catalytic dehydrogenation is a direct reaction from ethylbenzene to styrene, this method is the process of making styrene which is widely developed in commercial production. The reaction occurs in the vapor phase where the feed gas passes through a solid Fe_2O_3 catalyst. The reaction is endothermic and is an equilibrium reaction. The reactions that occur can be seen in Figure 7.

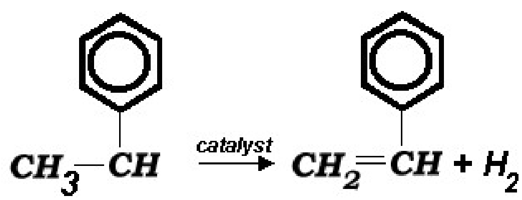

Figure 7. reaction from ethylbenzene to styrene

A low yield is obtained if this reaction takes place without the use of a catalyst. The reactor temperature is 537- 665^{0}C at a pressure of 0.27-1.4. Ethylbenzene conversion reached 97% with 93-97% styrene formation selectivity. The catalyst used is Fe_2O_3 which is suitable for use in high temperature reactions (550- 670^{o}C).

ii. Ethylbenzene oxidation

This process is of two kinds namely from Union Carbide and Halogen International. The process of Union Carbide has two products, namely styrene and acetophenone. Using an acetate catalyst followed by a reduction reaction using a chrome-iron-copper catalyst then followed by an alcohol hydration reaction to styrene with a titania catalyst at 250 - 280 ^{o}C.

The reactions that occur in succession are as follows:

$C_6H_5CH_2CH_3 + O_2 \rightarrow C_6H_5COCH_3 + H_2O$

$C_6H_5COCH_3 + CH_2CHCH_3 \rightarrow H_2COCHCH_3 + C_6H_5CH(OH)CH_3$

$C_6H_5CH(OH)CH_3 \rightarrow C_6H_5CH = CH_2 + H_2O$

The disadvantage of this process is the corrosion at the oxidation stage. The International Halogen Process produces styrene and propylene oxide. Namely the process of oxidizing ethylbenzene to ethylbenzene hydroperoxide then reacted with propylene forms propyleneoxide and α-phenyl-ethylalcohol, then dehydrated to styrene. A comparison of the two processes is presented in Table 1. From the description of the styrene manufacturing process, the styrene plant is designed with a catalytic dehydrogenation process using the Fe_2O_3 catalyst for the following reasons:

1. The dehydrogenation process is the simplest process.
2. The most widely used catalytic dehydrogenation process commercially.
3. Side products such as toluene and benzene can be sold so that they can increase profits.
4. The pressure used is low, so it is safer.
5. High selectivity, so the formation of the main products will be even greater.
6. Needs of little supporting material.

Comparison of advantages and disadvantages of dehydrogenation and oxidation processes ethylbenzene can be found in Table 3.

Table 1. Comparison of ethylbenzene dehydrogenation and oxidation processes

Parameter	Dehydrogenation Process Ethylbenzene catalytic	Oxidation process Ethylbenzene
Temperature of Reaction	537-665°C	250-280°C
Pressure	0,27-1,4 atm	8,16-15 atm
Conversion Yield	97%	25-30%
Selectivity	93-97%	70%
Catalyst Used	Fe_2O_3	Acetat, Chrom ,iron ,copper, and titanium

iii. Process Selection

Styrene is a precursor of polystyrene and some copolymers. Around 25 million tons of styrene were produced in 2010. There are many methods for producing Styrene, namely:

1. Catalytic dehyrogenation of ethyl benzene,
2. Oxidation of ethyl benzene to ethyl benzene hyroperoxide which reacts with propylene oxide after which alcohol is dehydrated to styrene.
3. Chlorination of ethyl benzene side chains followed by dechlorination.
4. Side-chain chlorination of hydrolysis of ethyl benzene with suitable alcohol followed by dehydration.
5. Pyrolysis of petroleum recovery from various petroleum processes.

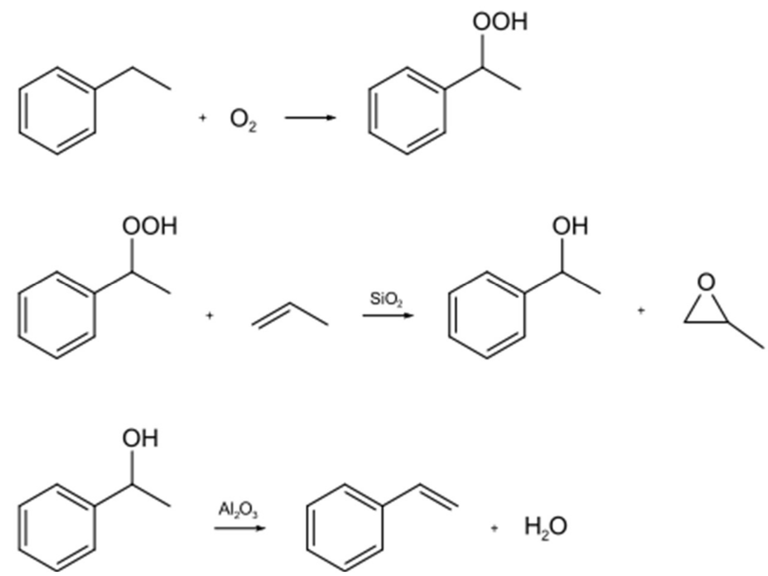

Figure 8. Reaction of ethyl benzene with oxygen to produce propylene oxide which then led to production of styrene

Methods 3 and 4 involve the use of chlorine, generally having suffered from high raw material costs and from chlorinated contaminants in monomers while method 5 recovery of pyrolysis oil from various petroleum processes is not widely available because making styrene directly from petroleum streams is difficult and expensive. In addition, the problem with the pyrolysis process is that carbon is a catalyst poison that makes more costs needed to reactivate the catalyst. The best process for producing styrene on a large scale is method 1 which is a catalytic dehydrogenation of ethyl benzene. This process is the main commercialization process for styrene production around 85% of the industrial processes used today. Ethyl benzene is reacted with a catalyst, usually iron oxide to produce styrene.

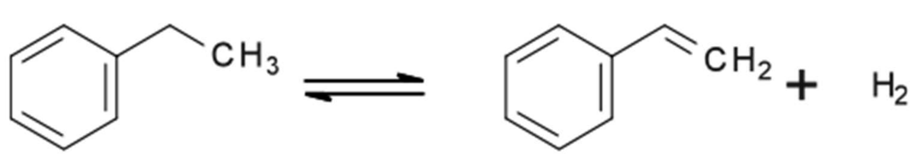

Figure 9. Reaction of ethyl benzene to produce styrene

The reaction of this process is limited to equilibrium and with the addition of steam, the process can be controlled. During the process, the vapor does not react with ethyl benzene and the catalyst which prevents coke. The advantages of dissolving ethyl benzene with super hot steam in this process are:

1. It lowers the partial pressure of ethyl benzene and shifts the balance towards higher styrene production and minimizes losses due to thermal cracking,
2. Stock up part of the heat needed for endothermic reactions,
3. Reducing carbon deposits by the reaction of vapor formation,
4. Avoid the catalyst in reduction and deactivation by controlling the state of the iron.

iv. Alternative Processes

One commercial route for producing styrene involves the re-production of propylene oxide. Direct air oxidation of ethylbenzene produces ethylbenzene hydroperoxide (EBHP) and other byproducts with ~ 13% conversion and ~ 90% selectivity to EBHP.3 EBHP reacts later with more propylene than metal catalysts and gives α-methylbenzyl alcohol. Finally, α-methylbenzyl alcohol is dehydrated to styrene.

This process is commercialized by ARCO Chemical (formerly Oxirane) and by Shell. Approximately 1.2×10^6 tons/year is produced with this technology. The SMART process licensed by ABB Lummus oxidizes H_2 formed by ethylbenzene dehydrogenation on a noble metal catalyst site between a single iron catalyst bed. H_2 removal increases ethylbenzene conversion by up to 80% per pass, maintaining the same styrene selectivity as for conventional processes.

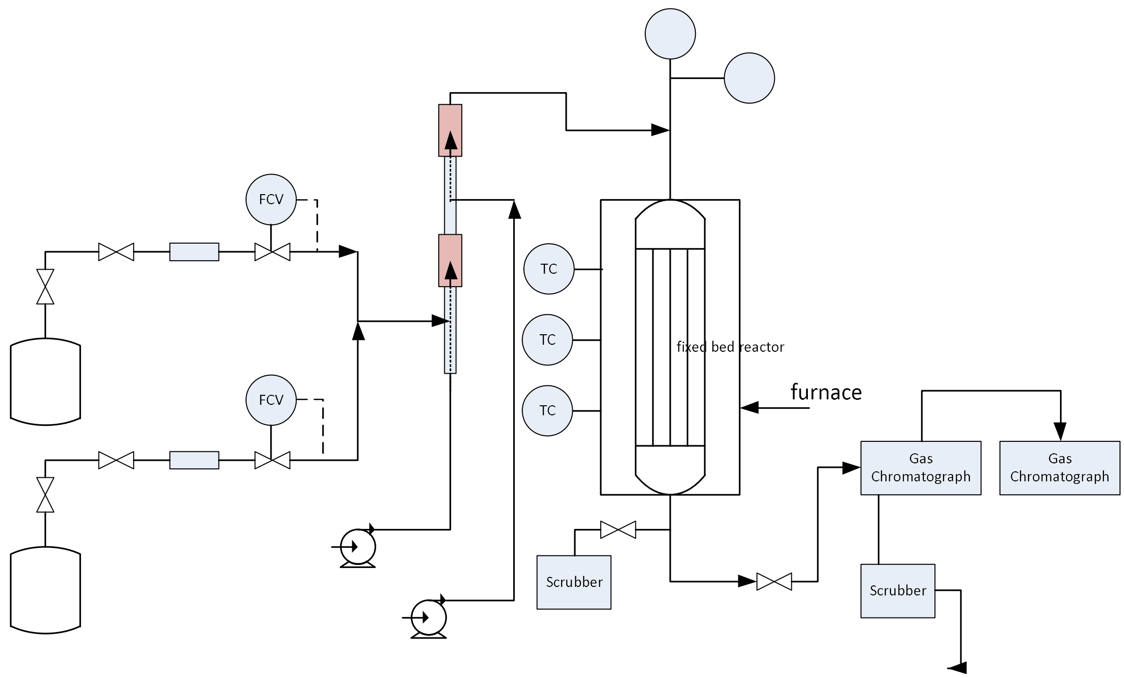

Figure 10. Experimental fixed-bed set-up for the kinetic study of ethylbenzene dehydrogenation

Explanation :

(1) mass flow control valve;
(2) liquid syringe pump;
(3) mixer & preheater;
(4) furnace;
(5) fixed-bed reactor;
(6) scrubber;
(7) gas chromatographs (TCD& FID);
(8) thermowell;
(9) temperature controller.

v. Lummus/UOP Smart Styrene Monomer Process

The Lummus/UOP Smart SM process combines oxidative reheat technology with adiabatic dehydrogenation technology to produce styrene monomer (SM) from ethyl benzene. It uses specially designed UOP reactors to achieve the oxidation and dehydrogenation reactions.

In the oxidative reheat section of the reactor, hydrogen is oxidized to supply the heat for the dehydrogenation reactions. This eliminates the costly interstage reheater and reduces superheated steam requirements. As hydrogen is consumed in the oxidation step, the dehydrogena- tion reaction equilibrium is shifted forward through the reduction in hydrogen partial pressure. This results in EB conversion of more than 80%. For existing SM producers, revamping to the Smart SM process is a cost-effective route to increased capacity.

The Lummus/UOP Smart SM process features:

- Styrene monomer purity of 99.85 wt-% minimum
- High per pass EB conversion (over 80%) for increased throughput
- Reduced superheated steam requirements
- No interstage heater

To provide the increased EB requirements of a revamped SM unit, UOP also offers the Lummus/UOP EBOneTM process for $AlCl_3$ ethylbenzene (EB) units. This commercially proven process uses the EBZ-500TM zeolitic catalyst to provide significantly lower production cost. Revamping your complex using the Lummus/UOP Smart SM process combined with the Lummus/UOP EBOne process provides the most cost-effective option for increasing capacity and improving the profitability of your styrene complex.

The feedstock, ethylbenzene, is catalytically dehydrogenated to styrene in the presence of steam in a fixed-bed, radial flow reactor system. The dehydrogenation reaction is favored by low pressures and is generally conducted under deep vacuum. Endothermic heat of reaction in the Smart SM reactor is supplied by oxidative reheat through the combustion of hydrogen with a stream of oxygen. Toluene, benzene, and some light compounds are formed as by-products. Reactor effluent waste heat is recovered through heat exchange with combined feed, and by generating steam utilized in the process.

The off gas stream is compressed, processed through the off gas recovery section, and used as fuel in the steam superheater. The condensates from the condenser and off gas recovery section flow into the separator, where hydrocarbon and water phases separate. The dehydrogenated mixture is fractionated to recover the styrene monomer product, recycle ethylbenzene, and benzene and toluene byproducts. Inhibitors are added to prevent styrene polymerization in the process equipment.

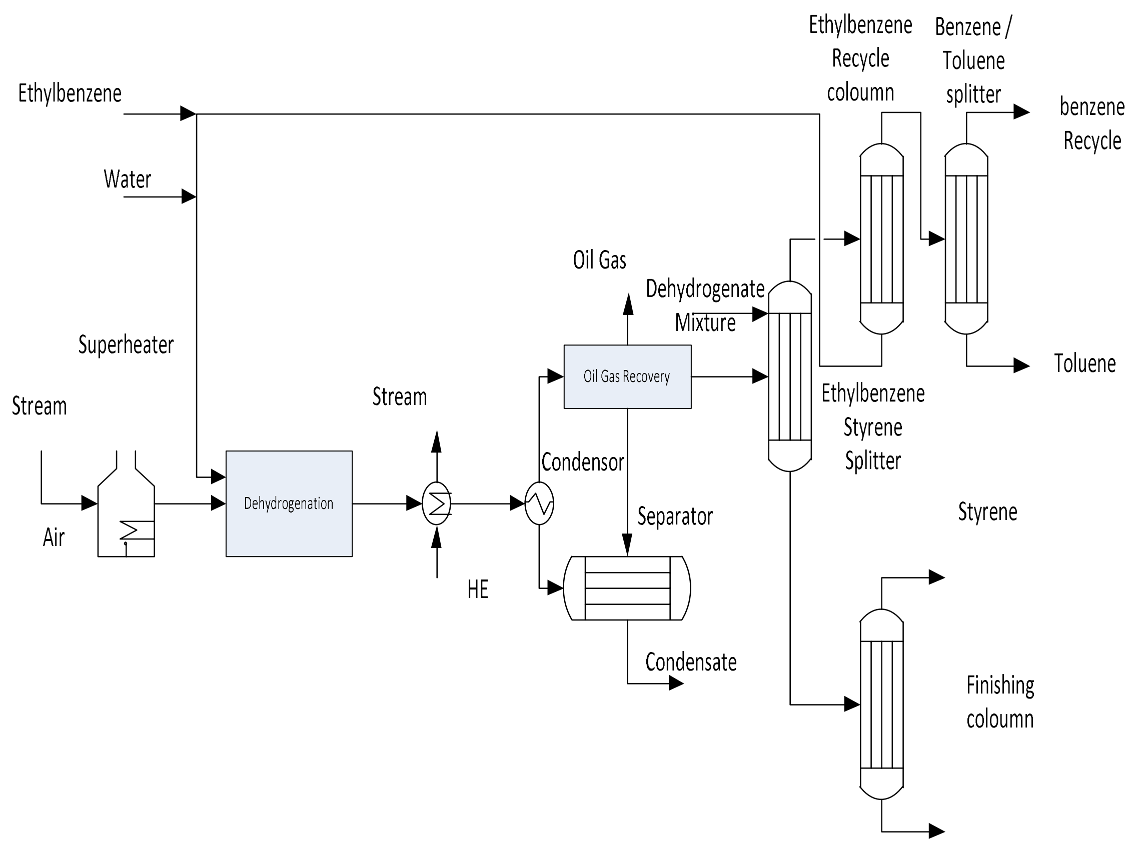

Figure 11. Lummus/UOP Smart SM Process

vi. Fina/Badger Styrene Process

The Fina/Badger styrene process has evolved through many generations.

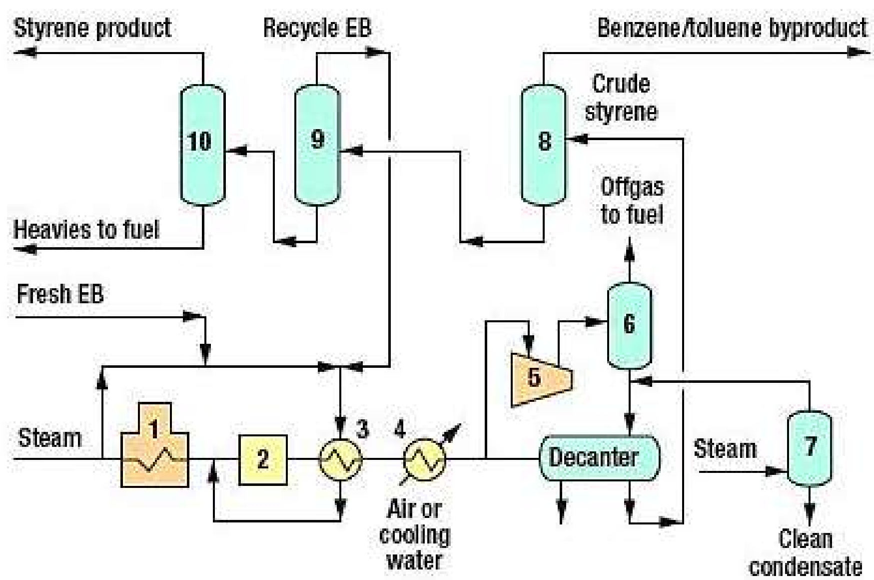

Figure 12. The Fina/Badger styrene process

EB is dehydrogenated to styrene over potassium promoted iron-oxide catalyst in the presence of steam. The endothermic reaction is done under vacuum conditions and high temperature. At 1.0 weight ratio of steam to EB feed and a moderate EB conversion, reaction selectivity to styrene is over 97%. Byproducts, benzene and toluene, are recovered via distillation with the benzene fraction being recycled to the EB unit. Vaporized fresh and recycle EB are mixed with superheated steam (1) and fed to a multi-stage adiabatic reactor system (2). Between dehydrogenation stages, heat is added to drive the EB conversion to economic levels, typically between 60% and 70%.

Reactor effluent is cooled in a series of exchangers (3) to recover waste heat and to condense (4) the hydrocarbons and steam. Uncondensed offgas—primarily hydrogen—is compressed (5) and then directed to an absorber system (6) for recovery of trace aromatics. Following aromatics recovery, the hydrogen-rich offgas is consumed as fuel by process heaters. Condensed hydrocarbons and crude styrene are sent to the distillation section, while process condensate is stripped (7) to remove dissolved aromatics and gases. The clean process condensate is returned as boiler feedwater to offsite steam boilers.

The distillation train first separates the benzene/toluene byproduct from main crude styrene stream (8). Unconverted EB is separated from styrene (9) and recycled to the reaction section. Various heat recovery schemes are used to conserve energy from the EB/SM column system. In the final purification step (10), trace C9 components and heavies are separated from the finished SM. To minimize polymerization in distillation equipment, a dinitrophenolic type inhibitor is co-fed with the crude feed from the reaction section. Typical SM purity ranges between 99.90% and 99.95%.

The Fina=Badger distillation section consists of three distillation columns. All the columns are designed to operate under vacuum to minimize temperature and polymer formation. The first column in the sequence splits the benzene and toluene byproducts from the unconverted EB and styrene product. The benzene and toluene mixture is typically sent to an integrated EB plant where it is further fractionated. In this case, the benzene by-product is ultimately consumed in the EB unit and the toluene becomes a by-product stream from the EB plant.

The EB recycle column separates the unconverted EB for recycle to the dehydrogenation reactors. Recent EB recovery columns use high efficiency packing to obtain minimum pressure drop through the column. This allows the column bottoms' temperature to be maintained below 100C. This is an important aspect of the design as styrene polymerization becomes significant at temperatures higher than approximately 100C

The EB recovery column bottoms' stream is fed to a finishing column where the styrene is purified by the removal of any heavy residue. Tertiary-butyl catechol is injected into the overhead of the finishing column to prevent polymerization. Tertiary-butyl catechol is widely used to prevent styrene polymerization during storage.

DEFINITION

Acrylonitrile butadiene styrene (ABS) - (chemical formula $(C_8H_8)_x\cdot(C_4H_6)_y\cdot(C_3H_3N)_z$) is a common thermoplastic polymer. Its glass transition temperature is approximately 105 °C (221 °F). ABS is amorphous and therefore has no true melting point.

Aromatics – Six carbon atoms form a ring, all bonds are unsaturated.

Amorphous thermoplastics - usually hard materials such as glass which, in conditions not filled, are transparent and rigid. This type of plastic material does not have sharp melting points, but does soften to melt over a wide temperature range.

Boiling point - of a substance is the temperature at which the vapor pressure of a liquid equals the pressure surrounding the liquid[1][2] and the liquid changes into a vapor.

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).

Catalyst - A material which will increase or decrease the speed of a chemical reaction without changing its own chemical identity

Catalytic polymerization - Polymerization of monomers to form high-molecular-weight molecules in the presence of catalysts.

Coke - A carbonaceous solid material made by the destructive heating of high-molecular-weight petroleum-refining residues.

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

Density - is a measure of mass per unit of volume.Density is a measure of mass per volume. The average density of an object equals its total mass divided by its total volume.

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.

Dust Contamination - It is easy to generate static electricity on plastics, which attracts dust, or dirt, very quickly.

Dynamic viscosity - is an alternative name for the viscosity or coeffi- cient of viscosity of a fluid. The usual symbol is η but μ is sometimes used.

Filaments - Used for brushes, ropes, twine, etc.

Flow meter (or flowmeter) - is an instrument used to measure linear, nonlinear, volumetric or mass flow rate of a liquid or a gas.

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

Hydrogen - is a chemical element in the periodic table that has the symbol H and atomic number 1. Hydrogen is the most abundant element with a percentage of approximately 75% of the total mass of the elements of the universe.

Heat Duty - The total heat absorbed by the process fluid

Initiation - involves the acquisition of active sites by monomers. This can occur spontaneously by absorption of heat, light (ultraviolet), or high energy irradiation. But most often, the initiation of free radical polymerization is caused by the addition of small amounts of compounds called initiators.

Liquid redistributors - Equipment in packing column to collect liquid that has migrated to the column walls and redistribute it evenly over the packing and also out any mal-distribution

Light key – The lighter (more volatile) of the two key components. Light key is collected at the distillate. All non-key components lighter than the light key are known as the light components.

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 – 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. $\alpha = P_2/P_1$

Magnesium - chloride is a magnesium salt consisting of two chlorine atoms bound to one magnesium atom. This compound can also be referred to as chloromagnesite is a colorless crystalline solid compound.

Mal-distribution – Fault distribution of vapor liquid in packing column. Maldistribution can affect in efficiency column.

Nets - Used for packaging, soil stabilization, etc.

Overheating - If overheated, even when no air present, plastics may decompose or degrade. Often gases are produced which can be dangerous.

Oxidation - This occurs when plastics are heated in contact with oxygen. They will oxidize or combine with the oxygen. The first sign of this is a change in color and then a change in properties.

Plastic Film - This is usually used for packaging or sealed into bags.

Plastic Insulated Wire and Cable - Used in the home and industry for appliances, for electric power distribution, communications etc.

Plastic Pipe - Used for gas, water, drains, etc.

Plastic Tubing – Used for hose and tubing for automobiles, laboratories, etc.

Polymer - is a large molecule, or macromolecule, composed of many repeated subunits

Polystyrene (PS) - is a synthetic aromatic hydrocarbon polymer made from the monomer styrene.[5] Polystyrene can be solid or foamed. General-purpose polystyrene is clear, hard, and rather brittle. It is an inexpensive resin per unit weight. It is a rather poor barrier to oxygen and water vapour and has a relatively low melting point.

Profile - Used for tracks, windows, doors, home siding, gaskets, etc
.
Propagation - the initiated monomer described above adds other monomers usually thousands of monomer molecules in rapid succession. This involves the addition of a free radical to the double bond of a monomer, with regeneration of another radical.

Pressure drop - A function of vapor and liquid rates as well as the packing shape and size.

Random packing - Packing of specific geometrical shapes which are dumped into the tower and orient themselves randomly

Reactor – A vessel where main catalytic cracking reaction achieved

Structure Packing - Crimped layers or corrugated sheets which is stacked in the column.

Styrene - also known as ethenylbenzene, vinylbenzene, and phenylethene, is an organic compound with the chemical formula C6H5CH=CH2. This derivative of benzene is a colorless oily liquid that evaporates easily and has a sweet smell, although high concentrations have a less pleasant odor. Styrene is the precursor to polystyrene and several copolymers.

Styrene-butadiene or styrene-butadiene rubber (SBR) - describe families of synthetic rubbers derived from styrene and butadiene (the version developed by Goodyear is called Neolite). These materials have good abrasion resistance and good aging stability when protected by additives.

Synthetic polymers - are derived from petroleum oil, and made by scientists and engineers. Examples of synthetic polymers include nylon, polyethylene, polyester, Teflon, and epoxy.

Space time - the time required to process one reactor volume of feed at specific condition

Space velocity - the number of reactor volumes of feed at specific condition which can be treated in a unit time

Termination - the growth activity of a polymer chain radical is destroyed by reaction with another free radical in the system to produce polymer molecule(s). Termination can occur by the reaction of the polymer radical with initiator radicals. This type of termination process is unproductive and can be controlled by maintaining a low rate for initiation.

Titanium - tetrachloride is a chemical compound with the molecular formula $TiCl_4$,whose structure consists of one titanium atom and four chloride atomic bonds. Titanium tetrachloride in IUPAC can also be called tetrachlorotitanium.

Viscosity - is a measure of a fluid's resistance to flow. It describes the internal friction of a moving fluid.

Water Contamination - This is caused by the material absorbing water or by condensation.

Vapor pressure – The pressure exerted by the vapor phase that is in equilibrium with the liquid phase in a closed system. For moderate temperature ranges, the vapor pressure at a given temperature can be estimated using the Antoine equation.

NOMENCLATURE

ΔHr_A	Heat of reaction (kJ/mol)
C_A	Initial Concentration of A (mol/m³)
D	Diameter of Reactor (m)
E	Efficiency (%)
F_{AO}	Initial molar flow rate of EB (mol/s)
H_R	Heat Generated Per Unit Volume of Reactor (kJ/m³s)
L_R	Length of Reactor (m)
M_{EB}	Molar flow rate ethyl benzene in the feed (mol/s)
M_{ST}	Molar flow rate styrene in the feed (mol/s)
N_a	Actual stages (Stages)
N_m	Minimum stages (Stages)
Q	Total heat generated (kJ/s)
R	Reflux ratio,
R_{min}	minimum reflux ratio
S_V	Space velocity (/s)
t	Space time (min)
V_{A0}	Initial volumetric flow rate (m³/s)
V_R	Volume of reactor (m³)
X_A	Fractional conversion,
X_D	Light key in distilat
X_F	Light key in feed
α	Average Relative volatility,

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