Journal of the Taiwan Institute of Chemical Engineers 65 (2016) 8–21

Contents lists available at ScienceDirect

Journal of the Taiwan Institute of Chemical Engineers

journal homepage: www.elsevier.com/locate/jtice

A new configuration in the tail-end acetylene hydrogenation reactor to enhance catalyst lifetime and performance

Ourmazd Dehghani Khold, Mahboubeh Parhoudeh, Mohammad Reza Rahimpour*, Sona Raeissi

Department of Chemical Engineering, School of Chemical and Petroleum Engineering, Shiraz University, Shiraz 71345, Iran

ARTICLE INFO

Article history:
Received 7 September 2015
Revised 14 February 2016
Accepted 20 April 2016
Available online 27 May 2016

Keywords:
Acetylene hydrogenation
Ethylene production
Catalyst regeneration
Tail-end reactor

ABSTRACT

Due to importance of acetylene removal from ethylene rich stream in polymerization units in order to prevent formation of highly explosive compounds, presenting any strategies improving the process efficiency has attracted researchers and industries interests. Proposing novel configurations in the reaction-regeneration cycles with lower energy consumption and enhanced catalyst lifetime leading to profits for the polymerization units is of a great interest. In this regard, a new configuration for the tail-end acetylene hydrogenation reactor of a commercial olefin plant was proposed in the present study. Based on the proposed configuration, a new protocol is applied to the process for utilizing total capacity of active catalysts in each fixed bed. A mathematical model based on component and energy balance was developed and validated to evaluate the operability of the proposed configuration. Operation of different runs in the new protocol was compared with the conventional configuration. The obtained results revealed that the new configuration is managed to decrease the volume of the regenerated catalyst in a 4-year period of operation. A 33.3% decrease in the volume of the regenerated catalyst was observed. Such an achievement was obtained without reducing acetylene conversion and ethylene yield.

1. Introduction

1.1. Ethylene and acetylene

Ethylene, which is a colorless, nonpolar and highly flammable gas, could be used as a raw material for diverse organic compounds. Polyethylene, polyvinyl chloride (PVC), ethyl benzene and polyesters are generally produced from ethylene and its derivatives due to low production costs. Besides, its reaction with other low cost accessible material such as oxygen and water leads to production of beneficial chemicals. The major application of ethylene monomers is in polymerization units in which ethylene is converted to polyethylene [1]. Ethylene is mainly produced by thermal cracking of various feedstocks such as ethane and naphtha. However propane, butane and gas oil are other alternatives for ethylene production. Ethane and naphtha cracking for ethylene production is carried out in gas and liquid furnaces, respectively. Due to increasing growth in ethylene supply and demand, any enhancement in the process of ethylene production may lead to remarkable profits for the petrochemical industries [2,3].

Acetylene is an undesired side product in ethylene manufacturing process. Depending on the feed and cracking conditions, about 0.5–2.5 ton acetylene is produced per 100 ton of ethylene. Acetylene is a contamination for catalyst of the polymerization unit. Maximum acetylene content for catalyst of the polymerization cannot exceed 1 ppm; otherwise, it leads to formation of metal acetylides, which are highly explosive. Hence, acetylene has to be eliminated from ethylene to assure an acetylene free stream for the polymerization unit [4,5].

An olefin plant in a domestic petrochemical complex uses thermal cracking of alkanes such as ethane, propane, butane, naphtha and gas oil to produce 1324,000 ton of ethylene per year [6]. Both gas and liquid crackers are applied to produce ethylene using ethane and naphtha as a feedstock, respectively [6–8]. Typical analysis of both liquid and gas furnace output streams in this plant are shown in Table 1. As clear, ethylene percentage in output stream of the gas furnace is considerably higher than that of the liquid furnace. Besides, more acetylene is produced in the liquid furnace.

1.2. Hydrogenation techniques

Generally, acetylene is eliminated through two different strategies, removal from the main stream and hydrogenation. The former is not cost effective; therefor it is unfavorable for large-scale applications. Conventionally, catalytic hydrogenation in an adiabatic fixed bed reactor is running the art of acetylene elimination from ethylene. Defects in the performance of an acetylene hydrogenation reactor may lead to remarkable extra charges [5,7–10].

* Corresponding author. Tel.:+98 711 2303071; fax: +98 711 6287294.
E-mail address: rahimpor@shirazu.ac.ir (M.R. Rahimpour).

http://dx.doi.org/10.1016/j.jtice.2016.04.027
1876-1070/

Nomenclature

a	catalyst activity [dimensionless]
A_C	cross section [m^2]
C_{pg}	specific heat of the gas at constant pressure [J/mol K]
C_t	total concentration [mol/m^3]
CR	crossover probability constant [dimensionless]
$E_{a,i}$	activation energy [J/mol]
F	DE-step size [dimensionless]
F_t	total molar flow rate [mol/s]
H	hydrogen [dimensionless]
k_d	deactivation rate constant [day^{-1}]
k_i	reaction rate constant [bar^{-1}] or [kmol/kgCat s bar^2]
N_P	number of population [dimensionless]
P_i	partial pressure of component i [Pa]
r_i	rate of reaction of component i [mol/kgCat s]
t	time [s]
T	temperature [K]
y_i	mole fraction of component i [dimensionless]
z	axial reactor coordinate [m]

Greek letters

ΔH_i	enthalpy of formation of component i [J/mol]
ε_B	bed porosity [dimensionless]
η	catalyst effectiveness factor [dimensionless]
ρ_B	density of catalytic bed [kg/m^3]

Subscripts

1	bed 1 (lead bed)
2	bed 2 (guard bed)
i	numerator for component/day
In	inlet
j	numerator for reaction
Out	outlet

Table 1
A typical analysis of both liquid and gas furnace output streams in the domestic petrochemical plant[a].

Component	Gas furnaces (wt%)	Liquid furnaces (wt%)
Acetylene	0.34	0.86
Ethylene	50.75	34.11

[a] Sample method: gas chromatography ASTM D2504 test method for non-condensable gases in C2 and lighter hydrocarbon products and ASTM D6159 for other components by gas chromatography in olefin plant laboratory.

There are diverse configurations for the acetylene hydrogenation reactor in an industrial olefin plant, including; raw gas catalytic reactor, front-end reactor, and tail-end reactor, among which, tail-end and front-end configurations cover 64% and 29% of all operating plants, respectively [5]. A schematic diagram of an industrial olefin plant is sketched in Fig. 1. As shown, the acetylene hydrogenation reactor could be devised in three different locations in each configuration.

The specified location 1 in Fig. 1 shows the raw gas catalytic hydrogenation reactor suggested for acetylene hydrogenation in the

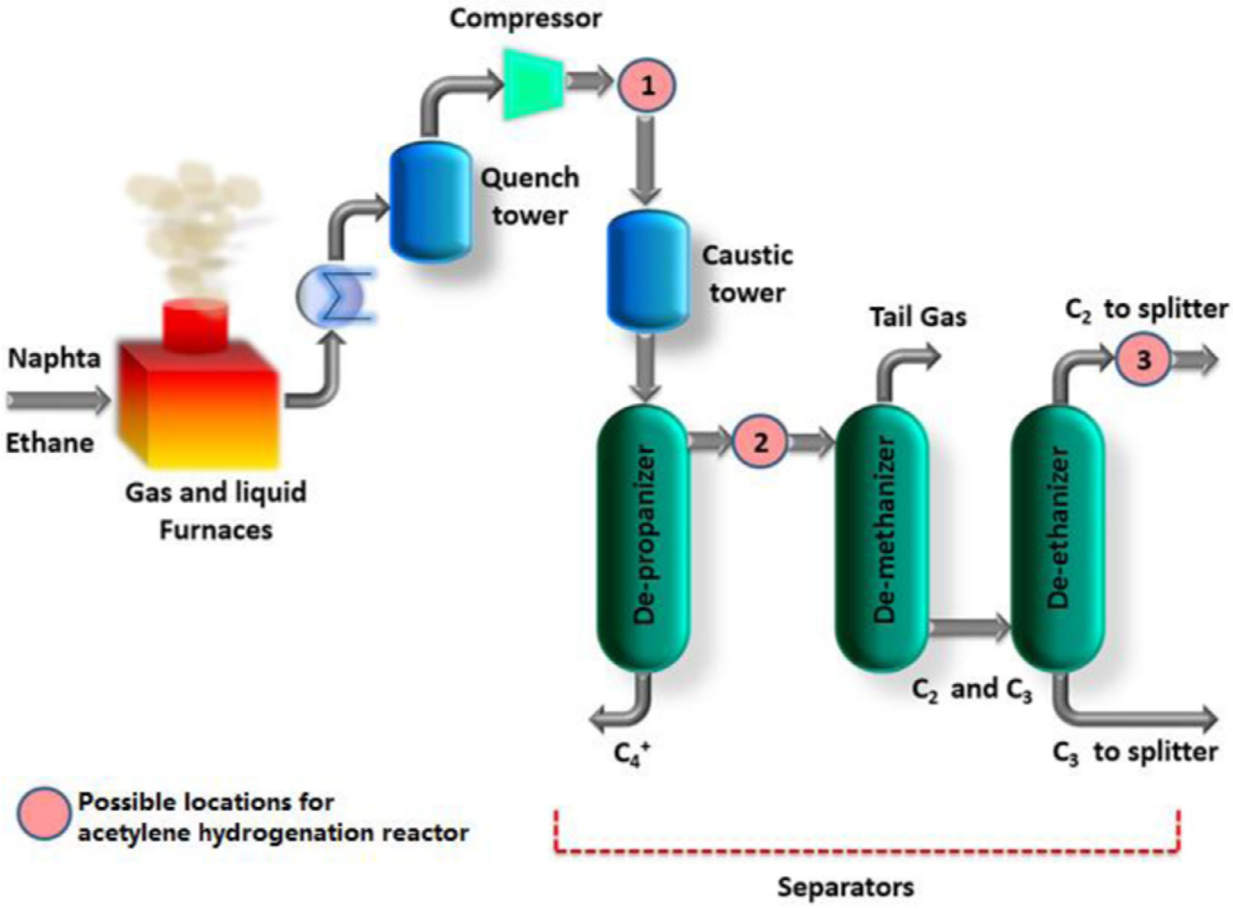

Fig. 1. Schematic diagram of an olefin plant.