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Modeling and optimization of distillation to produce bioethanol

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Abstract

Distillation is the most widely used separation operation in chemical industries; the great consumption of energy is the major disadvantage of this process that is unable to reach a high level of purity of bioethanol. The objective of this study is to model and to optimize the distillation column, by testing the effect of impurities. A parametric study of sensitivity of the feeding tray position of the column and the reflux ratio was carried out to optimize the operating conditions and improve the production of bioethanol. The results of this study show that acetaldehyde has more effect on the separation of binary water/ethanol in comparison with acetic acid and glycerol. In addition, working with optimal operating conditions values increase the ethanol production to about 2.88 %.

Keywords: Molasses; minor components; distillation column; modeling; optimization; bioethanol.

1. Introduction

Bioethanol production as a source of renewable energy from the byproducts of the sugar industry such as molasses is produced by the fermentation process, followed by the distillation step that requires a significant energy. This energy has been estimated at a value equal to 50 % of the energy needs of a distillery. This high consumption generates both high production costs and greenhouse emissions [1]. Another constraint is added that is produced in the high purity ethanol by removing impurities. The particularity of the studied industrial wine it contains dozens of minor compounds making it difficult to model behavior during simulation. Most research studies focus on energy

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consumption, dehydration techniques and alternative control strategies to separate the ethanol–water binary mixture, but few studies that have considered these minor components and especially evaluate the change of their fractions that depend to the kind of the raw material. Therefore it is necessary to study and control the various parameters that can affect the distillation column for the optimal bioethanol production, with high purity and less energy consumption while respecting environment. The distillation column is an industrial process multivariate and highly nonlinear mainly due to the mutual interaction of several phenomena and combination of technology components that implement laws. The simulation of this type of mixture as wine makes the system complex to study, but the results will more accurately with the real conditions. The application of the interactions analysis methods of a distillation column requires the search for his mathematical model, so a modeling step is necessary to allow the simulation study [2], and also ensure that bioethanol production meets the standards [3].

The aim of our study is the modeling and optimization of a distillation column to produce ethanol from wine by controlling the components such as acetic acid, acetaldehyde and glycerol. The developed model was compared and validated against the experimental data. A sensitivity approach of the impurities fractions existing in the wine, reflux ratio, and feeding tray position was used to control the quality of bioethanol and reboiler and condenser duties.

Nomenclature

Ace-ac	acetic acid
Acet	acetaldehyde
c	condenser
D	molar flow rate of distillate (mol/s)
d	distillate
Eth	ethanol
F	molar flow rate of feed (mol/s)
f	feed
Gly	glycerol
h	molar enthalpy (J/mol)
L	liquid
P	pressure (Pa)
P^S	vapor pressure (Pa)
Q	power (Watt)
R	molar flow rate of residue (mol/s)
r	residue
reb	reboiler
V	vapor
x	molar fraction in liquid phase
y	molar fraction in vapor phase

2. Principle of distillation column

The distillation column is shown in Fig. 1. The feed molar flow rate F, with a molar fraction x_f is introduced at the temperature T_f. The feed separates the column into two parts, the rectifying section, and the stripping section. For fractions, the most volatile compound was taken as reference. Vapor V_1 escaping the first tray is condensed at the head of the column. Part of the flow of liquid L_0 constituting reflux is fed back to the head of the column. The other part called distillate is collected at a molar flow rate D and a molar fraction x_d. The duty of the condenser is Q_c. The liquid descending the column is depleted of ethanol and intersecting the steam amount that it is enriched in ethanol. The liquid L'_1 arriving in the reboiler is partially vaporized, providing a duty Q_{reb} to the reboiler. The residue R is recovered in the reboiler with a molar fraction x_{reb}. The column consists of a succession of trays on which the exchanges between phases are established. The equations for modeling the distillation column are the mass and heat balance, the equilibrium and the summation equations, these equations are described below [2,4]: