Contents lists available at ScienceDirect

Chemical Engineering Research and Design

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

Estimation of the number of trays for natural gas triethylene glycol dehydration column

Branislav M. Jaćimović[a], *Srbislav B. Genić*[a], *Dimitrije R. Djordjević*[b], *Nikola J. Budimir*[a], *Marko S. Jarić*[a,*]

[a] *Faculty of Mechanical Engineering, University of Belgrade, Kraljice Marije 16, 11000 Belgrade, Serbia*
[b] *Termoliv, Knjaza Miloša bb, 31210 Pozega, Serbia*

ABSTRACT

The paper deals with the tray-to-tray method for determining the required number of trays in columns with intensive entrainment of liquid when the operating line of the “dry working regime” is not straight and with a small concentration of diffusing component in gas. Presented calculations show that the number of transfer units for gas and liquid should be calculated using the AIChE method accompanied with longitudinal mixing according to Gilbert properly transformed for case of diffusion through stagnant film. The suggested method can be applied for TEG dehydration absorbers–columns for dehydration of natural gas using triethylene glycol with system factor $SF = 0.5$.

Keywords: Computation; Diffusion; Unit operations; Absorption; Dehydration; Natural gas

1. Introduction

Intensive entrainment of liquid in trayed columns occurs in cases when liquid flow across the tray is relatively small compared to gas flow. This phenomenon is known as excessive entrainment and belongs to spray regime in trayed columns (Kister, 1992). Columns for dehydration of natural gas using triethylene glycol (TEG), operate usually in such working regime. Over viewing the literary sources which deal with this problem it can be shown that column efficiency values are somewhere in between $E_O = 0.25/0.40$ (Oi, 1999), and according to Campbell (1972), recommended column efficiency is $E_O = 0.25$. The same column efficiency is recommended by Manning and Thompson (2008), with additional recommendation that one additional tray should be added to the calculated number of trays for safety reasons. In accordance with Oi (2003, 1999), these recommended values of efficiency are not reliable because they are gained on the basis of unreliable equilibrium data. Improved calculus of equilibrium data, given in Oi (1999), leads to the conclusion that column efficiency is within $E_O = 0.40/0.50$, and Murphree efficiency between $E_{MG} = 0.55/0.70$. These conclusions derive from experimental data for one absorber and nine working regimes. The same author concludes (Oi, 2003), based on greater amount of experimental data (three absorption columns – 24 working regimes), that column efficiency is $E_O = 0.31/0.62$, while tray efficiency is $E_{MG} = 0.51/0.76$. In his work, Oi (2003) recommends AIChE method of calculation (Bubble Tray Design Manual, 1958) as reliable enough for calculation of TEG absorbers. By analyzing calculation procedure given in Oi (2003), we came to a conclusion that it is necessary to give a critical review, and to propose a new and reliable procedure for the calculation of tray and column efficiencies of TEG absorber. As an example of new procedure we have used data from one working regime partially given in Oi (2003), while the other data (nonexistent in article), were obtained through personal correspondence with author Lars Erik Oi. Special attention in new procedure needs be payed on tray variables (length and width of the liquid path), operating line and tray and column efficiency (including the effect of entrainment), etc.

* Corresponding author. Tel.: +381 63 435779; fax: +381 11 3370364.
E-mail address: mjaric@mas.bg.ac.rs (M.S. Jarić).
Received 14 April 2010; Received in revised form 30 July 2010; Accepted 24 August 2010
0263-8762/$ – see front matter © 2010 The Institution of Chemical Engineers. Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.cherd.2010.08.012

2. Input data for a column at the offshore platform Gullfaks C in the North Sea

The column (inside diameter $D_c = 2.35$ m) consists of $N = 6$ bubble cup trays, and dehydration of natural gas is done using triethylene glycol (TEG). Working conditions are such that intensive entrainment of liquid appears during the process (far more intensive than normal for trayed columns):

- $M_A = 18$ kg/kmol, molecular weight of water – component A;
- $M_B = 150.17$ kg/kmol, molecular weight of TEG – component B;
- $p = 63$ bar, total pressure in the column;
- $t_{G,in} = 22.5\,^\circ$C, gas temperature at column inlet;
- $y_{in} = y_7 = 538 \times 10^{-6}$ kmol A/kmol G = 538 mol ppm, mole fraction of water (A) in gas at column inlet;
- $t_{G,out,dew} = -23^\circ$C, dew point temperature of gas at column outlet;
- $y_{out} = y_1 = 27 \times 10^{-6}$ kmol A/kmol G = 27 mol ppm, mole fraction of water (A) in gas at column outlet;
- $\rho_G = 69$ kg/m^3, gas density;
- $\tilde{x}_{in} = 0.4\%$ kg/kg L, mass fraction of water (A) in liquid at column inlet;
- $\tilde{x}_{out} = 7\%$ kg A/kg L, mass fraction of water (A) in liquid at column outlet;
- $x_{in} = x_0 = 0.0324$ kmol A/kmol L, mole fraction of water (A) in liquid at column inlet;
- $x_{out} = x_6 = 0.3857$ kmol A/kmol L, mole fraction of water (A) in liquid at column outlet;
- $\rho_L = 1120$ kg/m^3, liquid density;
- $G_{inert} = 8500$ kmol G/h, gas mole flow rate of inert phase;
- $L_{inert} = 7.3$ kmol L/h, liquid mole flow rate of inert phase;
- $m = 0.00034$, slope of the equilibrium line (mole fractions).

Remark indexes associated to mole fractions correspond to tray fluid outlet streams. Trays are numbered from the top to bottom, as defined in Treybal (1981), Jacimovic and Genic (2007), Jacimovic and Genic (2008).

Mass balance for the component A, which is transferred from gas into liquid is

$$\dot{N}_{A,G} = G_{inert}\left(\frac{y_{in}}{1-y_{in}} - \frac{y_{out}}{1-y_{out}}\right) = 4.3459\ \text{kmol A/h} \quad (1)$$

$$\dot{N}_{A,L} = L_{inert}\left(\frac{x_{out}}{1-x_{out}} - \frac{x_{in}}{1-x_{in}}\right) = 4.3420\ \text{kmol A/h} \quad (2)$$

Mass balance error for component A is 0.09%, so it can be concluded that measured data is of good quality for the given working regime.

3. Calculus for the working regime according to Oi (2003)

For a column of the inside diameter $D_c = 2.35$ m Oi (2003) has taken the length of free path of liquid across the tray is $Z_L = 1$ m and the effective width of the tray (the effective width of liquid flow) $B_{ef} = 0.94$ m. The author has estimated the fractional entrainment $\psi_e = 0.3$, that is entrainment $e(G/L) = (\psi_e/1 - \psi_e) = 0.4286$. He also used AIChE method (Bubble Tray Design Manual, 1958) for determination of the number of transfer units in gas and in liquid, as well as axial mixing coefficient. Based on this data he has calculated the apparent tray efficiency and the column efficiency. Complete reconstruction of the calculation results from Oi (2003), are given in Table 2 – column A.

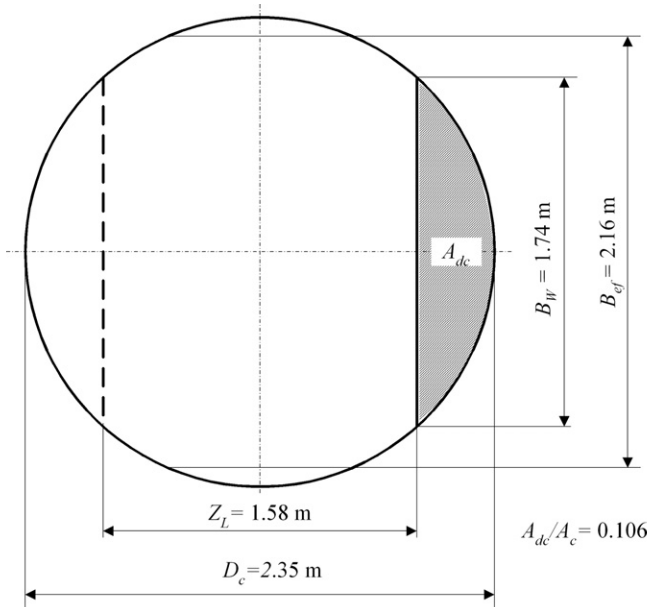

Fig. 1 – Tray cross-section.

Oi (2003) stated that the measured tray efficiency is $E_{MG,meas} = 60$ %, and that the tray efficiency calculated using AIChE procedure is $E_{MG,est} = 62$ %, based on which column efficiency $E_{O,est} = 51$ %. Terms $E_{MG,meas}$ and $E_{MG,est}$ used in Oi (2003), are actually apparent tray efficiencies $E_{a,Colb}$, as defined by Colburn (Jacimovic, 2000).

We have several remarks on the calculations presented in Oi (2003), mainly concerning the tray geometry and its influence on AICHE tray efficiency calculation procedure. Real tray cross-section (outlet weir width, effective tray width and length of liquid flow path across the tray) is presented in Fig. 1.

Gullfaks column inside diameter is $D_c = 2.35$ m (cross-sectional area of the column is $A_c = 4.335$ m^2). Volume flow rate of gas, according to input data are $\dot{V}_{Gin} = 1972$ m^3/h at the column inlet and $\dot{V}_{Gout} = 1971$ m^3/h at the column outlet.

Mean gas flow rate is

$$\dot{V}_{Gav} = \frac{\dot{V}_{Gin} + \dot{V}_{Gout}}{2} = \frac{1972 + 1971}{2} = 1971.5\ \text{m}^3/\text{h} = 0.5476\ \text{m}^3/\text{s} \quad (3)$$

Characteristic gas velocities are:

- gas velocity based on total cross-sectional area:

$$w_{Gc} = \frac{\dot{V}_{Gav}}{A_c} = \frac{0.5476}{4.335} = 0.126\ \text{m/s} \quad (4)$$

- gas velocity based on active bubbling area according to Oi (2003) $w_{GB} = 0.16$ m/s

$$w_{GB} = \frac{w_{Gc}}{1 - 2\varphi_{dc}} = \frac{0.126}{1 - 2\varphi_{dc}} = 0.16\ \text{m/s} \quad (5)$$

Remark 1. The length of liquid path is greater than that taken in Oi (2003).