REVAMPED DESIGN OF CSTR AND SCRUBBING COLUMN OF SBA MANUFACTURING PLANT

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Abstract- This article focuses on the equipment design for production of Secondary Butyl Alcohol (SBA). SBA is an aliphatic alcohol with medium boiling range, has a characteristics odour and partly miscible with water. It is used as an intermediate for production of Methyl Ethyl Ketone (MEK). SBA is particularly used in lacquers with alkyl resin basis as it reduces the viscosity and improves the fluid behaviour, SBA finds its application in the manufacture of pharma industries, as a solvent in paint and lacquers industry, manufacture of Second Butyl Acetate nitro cellulose, etc., The following equipments were designed for varied flow rate: Continuous stirred tank reactor (tank flow) and Scrubbing Column.The chemical reaction Engineering and the Mass Transfer concepts were used for these equipments design.

Keywords: SBA, CSTR, Scrubbing Column.

1. INTRODUCTION

This chapter covers the equipment design and sizing of the packed scrubber column. The scrubber design is concerned with determining SBA also named as secondary butyl alcohol is one of the earliest petrochemicals. SBA is produced is large scale, but in few companies around the world since more than years. It is an aliphatic alcohol in the medium boiling range, has a characteristic odour and partly miscible with water. SBA is almost entirely (over 90%) intermediate for the production of MEK as it is the case for this new solvent plant. SBA is particularly suitable for the lacquers on alkyl resin basis as it reduces the viscosity and improves the behaviour.

The manufacturing of SBA involves the several operations such are: acid Blending, esterification, washing, neutralisation, stripping, hydrolysis, compression and distillation. These operationsinclude the various types of equipments. Among which, the Reactor, Scrubbing Column, and Distillation Column plays very important role (i.e)., why the CSTR and the Scrubbing Column were effectively revamped/scaled up by using some basic Chemical Reaction Engineering and Mass Transfer concepts in this article. This revamp was done for the 2/3rd of flow rate of input.

2.1. DESIGN OF REACTOR (CSTR)

This chapter covers the equipment design based on the modified input flow rates (i.e)., 2/3rd of inlet flow rates. The esterification reaction exists in the two series of CSTRs in SBA manufacturing plants as follows:

$$CH_3CH{=}CHCH_{3(l)} + H_2SO_{4(l)} \longrightarrow C_4H_9\text{-}SO_4\text{-}OSO_3H_{(l)}$$

$$C_4H_9\text{-}OSO_3H_{(l)} + CH_3CH{=}CHCH_{3(l)} \longrightarrow C_4H_9\text{-}SO_4\text{-}C_4H_{9(l)}$$

The material balance for the input and output of reactor as follows:

Basis:

20,000 tons of SBA/yr $\longrightarrow$ 2777.77 kg/hr $\longrightarrow$ 37.52 kgmol/hr

Table 1: Material balance for input of Reactor

Reactant	Mole %	Molar flow Rate (kmol /hr)	Weight %	Mass flow rate (kg/hr)

Butene	50	23.44	26.66	1312.64
Acid rich ester	50	23.44	73.33	3609.72
Total		46.90		4922.36

Table 2:Material balance for output of Reactor

Products	**Mole %**	**Molar flow rate (kmol/hr)**	**Weight%**	**Mass flow rate (kg/hr)**
Unreacted butene	29.40	13.72	8.64	425.1
Butane	26.29	12.272	8.13	400.76
Polymer	4.13	1.872	2.20	108.284
Ester	40.01	18.76	80.08	3939.6
Sulphuric acid	2.64	1.232	0.94	46.28
Total		47.80		4919.26

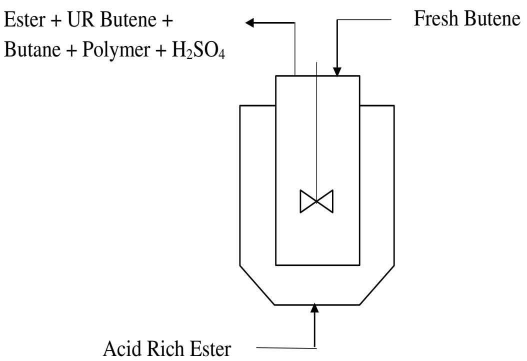

Fig: 1- Continuous Stirred Tank Reactor

DESIGN CALCULATION:

Volume of the reactor:

Rate of esterification reaction = (-) 163.14 mol L^{-1} S^{-1}

Performance equation for tank flow model reactor

F(X) = r V_b --------(1)

Where,

F = Total feed rate, mass / time.

X = Conversion of reactant, mass of reactant / feed

r = Constant rate of reaction, (mass of reactant converted) / (unit volume* unit time)

V_b = Volume of the reactor

X = 0.40

V_b = (**4919.26***0.40) / (163.14)

$V_{b=}$ 12.06 m^3

Volume = πr^2 H -------(2)

H /D ratio = 1.9 -------(3)

Substituting (3) in (2) we get: D = 2 m

H = 3.84 m

Diameter of agitator (blade)

D_a /D = 1/3

D_a= 0.667 m

Where,

D_a is the diameter of the agitator.

E is the distance of the blade from the bottom of the reactor.

E/D = 1/3

E = 0.667 m

Where, J is the baffle width.

J/D = 1/12

J = 0.167 m

Where, W is the blade width

$W/D_a = 1/5$

$W = 0.1334$ m

Where, L_b is the blade length

$L_b / D_a = 1/4$

$L_b = 0.1667$ m

Cooling jacket:

Markowitz has given the following rules for selecting the jacket type:

For < 1.89 m^3 use the simple jacket.

For > 1.89 m^3 use the dimple or half pipe coil.

Hence dimple or half pipe coil is used here.

$Q = U_J A_J (T_J - T_R)$

Where,

U_J = Overall Heat transfer coefficient for jacket

A_J = Area of the cooling jacket

T_J = Average Temperature of the cooling jacket

T_R = Temperature of the reactor

$T_J = (T_{j1} + T_{j2}) / 2$

Where,

T_J = Average temperature of the cooling jacket

T_{j1} = Inlet temperature of the cooling water

T_{j2} = Outlet temperature of the cooling water

$T_J = (30+40) / 2$

$U_J = 50 – 80$ Btu / h-^{0}F-ft^2

Assumed $U_J = 58.5$ Btu / h-^{0}F-ft^2 = 454.24 W /m^{2}K

From chemical process engineering Design and economics by Harry Silla

(Table 7.6 Approximation STR Heat-Transfer coefficient source Ref. 7.33a)

$A_J = f(V_r)$

$Q_J = -7631.233$ KJ /hr

$Q_J = 454.24 * A_J * (-10)$

$Q_J = - 7631.233 = 454.24 * A_J * (-10)$

$A_J = 1.68$ m^2

DESIGN SUMMARY:

Table 3: Design Summary of the Re-vamped CSTR

Height of the reactor	3.84 m
Volume of the reactor	12.06 m^3
Diameter of agitator (blade)	0.667 m
Diameter of the reactor	2 m
Conversion	40%
Width of blade	0.1334 m
Length of blade	0.1667 m
Width of baffle	0.167 m
Area of cooling jacket	1.68 m^2

2.2. DESIGN OF SCRUBBING COLUMN

This chapter covers the equipment design and sizing of the packed scrubber column. The scrubber design is concerned with determining the height of the packed tower, the diameter the type of packing and the required column thickness.

The absorbing liquid is dispersed over the packing material, which provides a large surface area for gas-liquid contact. The gas steam enters the bottom of the tower and flows upward through the packing material and exits from the top after passing through a mist eliminator. Liquid is introduced at the top of the packed bed by spray or weirs and flow downward over the packing.

Gas stream data:

Gas inlet flow rate = 2209.59 kg/hr

Gas inlet flow rate = 0.6137 kg/s

Gas pressure at entry = 1.024 atm

Gas temperature at entry = 107°C

Gas temperature at entry = 106.85°C

Component to be scrubbed from gas steam = Sulphuric acid (H_2SO_4)

Component flow rate = 21.975 kg/hr

Scrubbing solution data:

Liquid inlet flow rate = 2454 kg/hr

Liquid inlet flow rate = 0.6817 kg/s

Liquid density = 1100 kg/m^3

Liquid viscosity, μ_L = 0.00033 Ns/m^2

We know that,

Mass flow rate of gas = 0.92067 kg/s

Volumetric flow rate of the gas = 0.7215 kg/s

Gas density calculation:

Gas density is the ratio of mass flow rate to the volumetric flow rate of the gas.

$$\text{Gas density} = \frac{\text{Mass flow rate of the gas}}{\text{Volumetric flow rate of the gas}}$$

Therefore,

$$\text{Gas density} = \frac{0.6137}{0.4810}$$

Gas density = 1.276

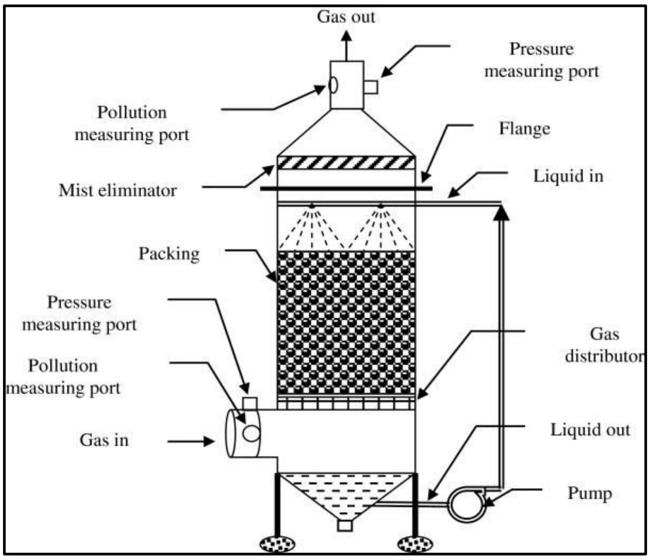

Fig 2: Wet Packed Scrubber

Packing Media Selection:

The main purpose of the packing media is to give large surface are for mass transfer. However, the specific packing selected depends on the corrosiveness of the contaminants and scrubbing liquid, the size of the absorber, the static pressure drop and the cost. There are 3 common types of packing material.

1. Mesh, 2. Ring, 3. Saddles

The principle requirement of a tower packing is

- It must be chemically inert to the fluids in the tower.
- It must be strong without excessive weight.
- It must contain adequate passage for both streams without excessive liquid hold up or pressure drop.
- It must provide good contact between liquid and gas.
- It must be reasonable in cost.
- The packing is ceramic in nature (SiO_2+Al_2O_3+Fe_2O_3).

For our model of packed scrubber, we are choosing a conventional yet reliable INTALOX SADDLE – random packing of size 57mm or

Reason for selecting intalox saddle:

- They are resistant to acid.
- Resistant to heat and corrosion.

- They are stable at high operating temperature and pressure.
- They have a good mechanical strength.
- They provide a large area for gas-liquid contact per unit area.
- It has an open structure and high bed porosity.

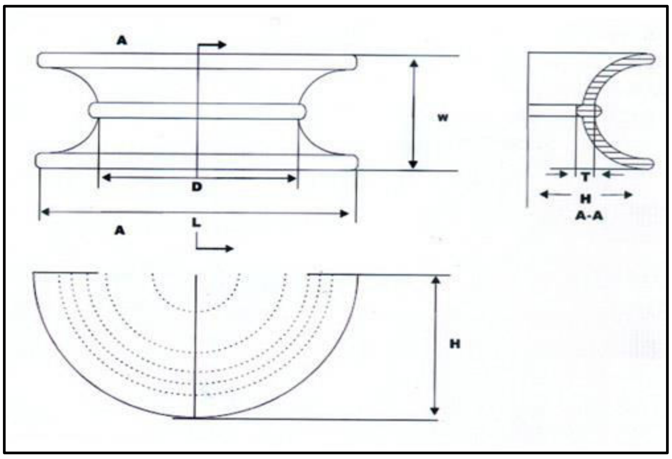

Fig 3: Intalox Saddle Dimension

Table 4: Specifications of intalox saddle

Packing factor	78
Mass	934 kg/m^3
Surface Area	292.5 m^2/m^3
Voidage	76 %

DESIGN CALCULATION:

Gas velocity is the main parameter affecting the size of packed column. For estimating flooding velocity and minimum column diameter, generalized flooding velocity and pressure drop correlation is used. One version of flooding velocity and pressure drop relationship for a packed tower in Sherwood relation.

Liquid flow rate = 0.6828 kg/s

Gas flow rate = 0.61374 kg/s

Column diameter formula

$$\frac{L}{G}\sqrt{\frac{\rho(gas)}{\rho(liquid)}} = \frac{0.6828}{0.61374}\sqrt{\frac{1.30}{1100}}$$

$$\frac{L}{G}\sqrt{\frac{\rho(gas)}{\rho(liquid)}} = 0.038246$$

Using the generalized pressure drop correlation chart for packed towers,

By using SHERWOOD CO-RELATION, we know that

For absorbers and strippers = 24-72 mm water/meter packing

The value of 0.038246 is taken as abscissa of the pressure drop co-relation chart

Let us choose 63mm of water/meter packing, we get value of 2.31 in the ordinate axis.

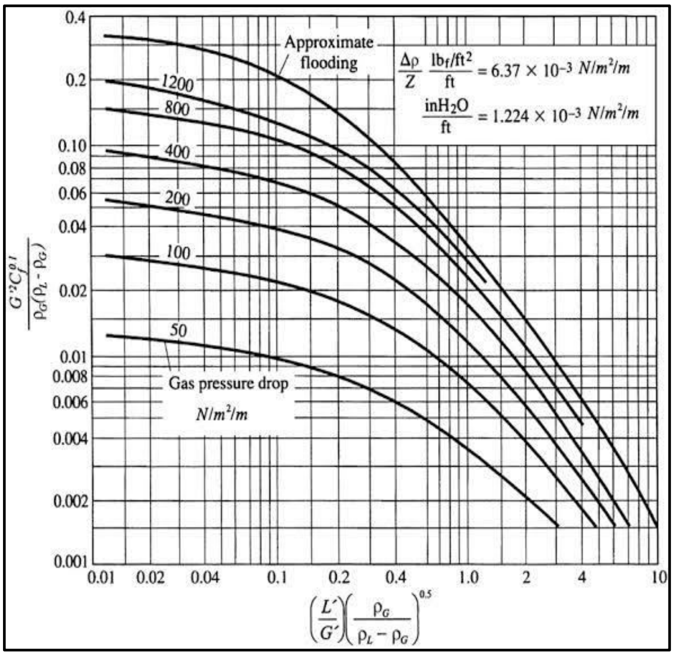

Fig 4: Sherwood Pressure Co-relation Chart

$$\frac{C}{\rho v(\rho L-\rho v)} G^2 F v^{0.1} = 2.31$$

Where,

G^2 = gas flow rate across the column

C = Conversion factor

F = Packing factor

v = Liquid viscosity

ρ_L = Liquid density

ρ_v = Gas density

$$\mathbf{G^2 = \frac{2.31*1.30(1100-1.30)}{10.764*78*0.215}}$$

G^2 = 18.2779

G = 4.27527 kg/m

Column area determination:

Column area required = $\frac{Gas\ flow\ rate}{Gas\ flow\ rate\ across\ the\ column}$

Column area required (A_C) = $\frac{0.61374}{4.27527}$ = 0.14355 m^2

Diameter of the packed column:

Diameter of the packed column = $\sqrt{\frac{4x\ column\ area}{\pi}}$

Diameter of the packed column = $\sqrt{(1.2738 * 0.14355)}$

Diameter of the packed column = 0.4275 m = 1.40265 ft (or) 42.75 cm

Height of the Scrubber column:

From the material balance equation, we know that

Y_1 = Mole fraction of Sulphuric acid gas entering = 0.00717

Y_2 = Mole fraction of Sulphuric acid gas leaving = 0.0000717

Hence,

$\frac{Y1}{Y2} = \frac{0.00717}{0.0000717} = 100$

From the material balance equation,

$G_S(y_1\text{-}y_2) = L_S(x_1\text{-}x_2)$

$(y_1\text{-}y_2) = \frac{Ls}{Gs}(x_1\text{-}x_2)$

The above equation is in form,

Y = mX + 0

$m = \frac{Ls}{Gs} = \frac{2458}{2199.02} = 1.1177$

On solving the above equation, we get

$m\frac{Gs}{Ls} = 0.9$

$\frac{Y1}{Y2} = 100$

By using above values N_{OG} value was calculated from the graph plotted N_{OG} as a function of $\frac{Y1}{Y2}$.

From Coulson & Richardson Chemical Engineering Volume 2, We can calculate the value of N_{OG}, by using below graph,

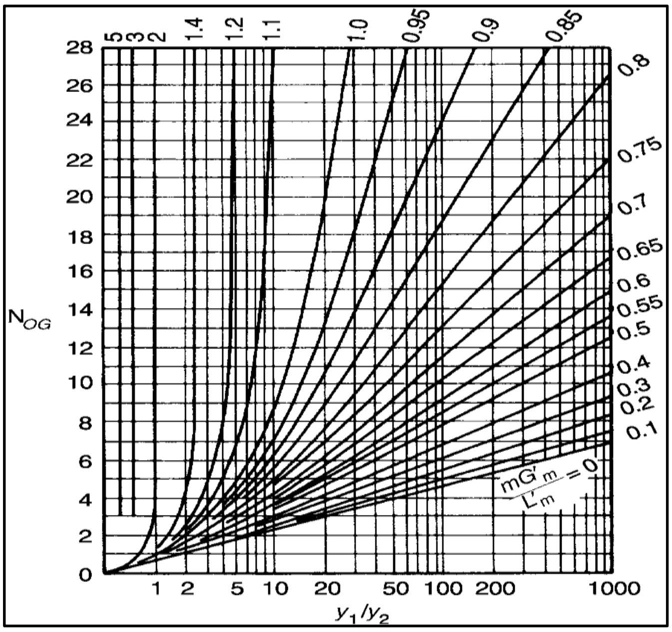

Fig 5: Relationship between N_{OG} and N_T

The mathematical relationship between number of transfer units (N_{OG}) & theoretical stages (N_T)

$$\mathbf{N_{OG} = N_T\frac{\ln A}{A-1}}$$

Where,

A = Absorption factor = 0.9

From the graph, we identified

$N_{OG} = 40.5$

$$\mathbf{N_{OG} = N_T\frac{\ln 0.9}{0.9-1}}$$

$N_T(1.053) = 40.5$

Therefore, the total no. of transfer units, N_T = 39 (dimensionless)

Height equivalent theoretical plates (HETP):

HETP offers a simple method for designing packed towers. The no. of theoretical trays required to effect a specified change in solute concentration multiplies by the packed height equivalent to one theoretical plate gives the packing height.

HETP varies with the height and size of packing, flow rate of gas and liquid as well as for every system with concentration.

Z = HETP * N_T

The HETP of packed column can be calculated by Nortan's co-relation

ln (HETP) = n - 0.187lnσ + 0.213lnμ

ln (HETP) = 2.0853 - 0.187ln (111) + 0.213ln (0.495)

HETP = 0.645 m

The value of n in the height equivalent to theoretical plate can be determined based on the size of internal packing used.

Table 5: Values of n for prediction of HETP

TOWER PACKING	**VALUE OF n**
#25 IMTP* packing	1.13080
#40 IMTP* packing	1.31850
#50 IMTP* packing	1.56860
1 in pall ring	1.13080
$1\frac{1}{2}$ in pall ring	1.35820
2 in pall ring	1.65840
1 in intalox* saddle	1.13080
$1\frac{1}{2}$ in intalox* saddle	1.39020
2 in intalox* saddle	1.72330

Total height of the packed scrubber column is given by

Z = N_T * HETP

Z = 39 * 0.645

Z = 25m (approx.)

Column thickness:

Known Datas:

Working pressure = 1.02 atm = 14.99 psi

Design pressure = 1.2 * working pressure

Design pressure = 17.988 psi

Maximum allowable stress (carbon steel) = 17100 psi

Joint efficiency = 90% = 0.9

Radius of the column = 0.455

Column thickness = t = $\frac{\text{Pri}}{2fE-0.6P}$ + C

Column thickness = t = $\frac{321.5445}{(30780-10.788)}$ + 1.6

Column thickness = t = 2.409 inches (or) 60mm

Design Summary of Scrubber Column

Table: Design Summary of the Scrubbing Column

SPECIFICATIONS	**VALUES**
Diameter of the column	0.4275 m (or) 42.75 cm
Height of the column	25 m
Column area	0.14355 m^2
Column material	Carbon Steel
Column thickness	60 mm
Packing material	Random dumped packing
Packing type	Intalox Saddle (ceramic) 1.5' inch

3. CONCLUSION

The CSTR and Scrubbing Column of SBA manufacturing Plant was effectively revamped for the $2/3^{rd}$ of inlet flow rate with the help basic chemical reaction engineering and mass transfer concepts. This revamped design will increase the rate of esterification in CSTR as well as the separation and gas-liquid contact in the scrubbing column. The above calculations were performed for the required conversion and scrubber efficiency.

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