Mechanical engineering design of IPA distillation column

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Abstract. Extractive distillation is one of the popular methods being leveraged to separate isopropyl alcohol (IPA) from water. This project demonstrates the mechanical design data for second distillation column in continuous flow process of propan-2-ol production. Moreover, a 3 dimensional view of the sieve tray (rising vapour and liquid flow) are illustrated.

1. Introduction
Many choices confront on engineer with the selecting the control scheme for a column ¹, ². The first thing comprises configuration of the top and bottom control loops, which will give the knowledge of the product compositions. Once the way of strategy is decided, the control strategies for the rest become easier to choose.

The idea of relative gain provides a measure of the pairing that can be caused between control loops. Consequently, the relative gain analysis must be well-studied in the first step in evaluating the composition control strategy. The following conceptions are general rules to reject some possible control interactions.

- The condenser loop level must not be controlled with reboiler heat.
- Bottom level loop must not be controlled with top operating flow.
- Bottoms level loop must not be controlled with a reboiler heat.
- The condenser level must not be controlled by bottom product flow
- If the number of plates higher than 20 stages (in this distillation column have 23), so the bottom composition must not be controlled with a reflux flow.
- Overhead compositions must not be controlled with bottoms product flow.

The decision on monitoring the product composition should indicate the controlling top or bottom composition. In distillation column the pressure and then level of the vapour/liquid must be ordered before the control of composition.

1.1 Pressure control
Pressure control – required because the change in pressure will effect on relative volatility and the separation will cause troubles. The temperature difference across the reboiler and condenser will have to be organized as well. Additional reason of using the pressure controllers is to control the ability to work at the minimum column pressure, within the system restrictions. Within the pressure decrease the
temperature needed to process (reducing the input heat required for separation process) will also change [3], which save money. A flow controller in the feed input can maintain a continuous flow rate. In some cases, the feed pump of distillation unit instead of electrically driven pump the steam-driven pump is used. With continuous feed inlet the control of the plant gets easier to operate [4]. With different feed rates and different feed compositions, cascade controls are approved, but of the feed composition and rate are constant (like in this case) then resetting the major control loop manually is sometimes sufficient. In other cases, the flow manager is organized as the cascade slave of the level controller. From the thermal condition of the feed, the amount of needed heat can be determined, so that heat must be added to the column by reboiler [5]. In most of the cases it is more efficient to preheat the feed, so the reboiler will need to use less energy, [6] but in this project as, the distillate product temperature (25°C) is close to the feed inlet temperature (23.5°C), so no preheating will be done on the feed. Besides, the feed comes directly from 1st distillation column.

2. Results and discussion

Some estimations were assumed (table 1).

| Table 1. Estimations       |          |
|----------------------------|----------|
| Design pressure (p)        | 1 bar    |
| Nozzle ID                  | 254 cm   |
| Corrosion Allowance (c)    | 2 cm     |
| Allowed stress (f)         | 4.75 mPa |
| Joint Efficiency(j)        | 0.8      |
| Mechanical design (m)      | 0.036    |
| Number of stages           | 7        |
| Minimum reflux ratio R_MIN | 3.38     |
| Actual number of stages    | 23       |
| Shell Outside diameter (m) | 2.395    |

Shell thickness calculation

\[ Ts = \frac{p \times D_s}{f_j - 0.6p} + c \implies \]

\[ Ts = \frac{0.101325 \times 1.88}{4.75 \times 0.8 - 0.6 \times 0.101325} + 0.002m = 20.05 \text{mm} \]

Torrispherical head calculation

\[ Th = \frac{pR_i \times \sqrt{W}}{2(\sqrt{r_i} - 0.2p)} + c \]

To find out \( W \implies \)

\[ W = \frac{1}{4} \times (3 + \frac{R_i}{\sqrt{r_i}}) \]

For Torrispherical head \( \frac{R_i}{r_i} = \frac{1}{0.06} = 1.6 \implies \)

\[ W = 0.25 \times (3 + \sqrt{16.6} = 1.77 \implies \]
\[ Th = \frac{0.101325 \times 1.165 \times 1.77}{2 \times ((4.75 \times 0.85) - (0.2 \times 0.101325))} + 0.002m = 20.02\, mm \]

Channel cover diameter and thickness
Channel cover diameter equal to Shell Outside diameter = 2.395 m
Mechanical Design is 3.6 cm
So within equation below

\[ T_{cc} \frac{D_{cc}}{\sqrt{CIP}} \Rightarrow \]

\[ T_{cc} = \frac{2.395 \times \sqrt{0.25 \times 0.101325}}{10 \times 4.75} = 8.023\, m \Rightarrow \]

Column Height = \((N_{Actual} - 1) \times \text{Plate spacing} + \text{Mechanical Design} \Rightarrow \)

Column Height = \((23 - 1) \times 0.45 + 0.036 = 9.936\, m. \]

Reflux
Nozzle diameter = 233mm
tn=4.96mm

Overhead Vapour Outlet gas
Nozzle diameter = 233mm
tn=4.96mm

Bottom out
Nozzle Diameter = 233*0.6 = 139.8
Consequently,

\[ tn = \frac{0.101325 \times 139.8mm}{2 \times 4.75 \times 0.85 - 0.101325} + 2mm \Rightarrow tn = 3.78\, mm \]

Reboiler Return
Nozzle diameter = 139.8
tn=3.78mm

Figure 1. 3 dimensional view of the sieve tray (rising vapour, liquid flow).
The view from upper side of the sieve tray with liquid flow rate and rising vapour is illustrated in figure above (figure 1).

3. Conclusion
To sum up, after some estimations, the shell thickness and Torrispherical head were calculated almost to be the same - 20.05 mm and 20.02 mm respectively. The column height was designed to be almost 10 m within mechanical design – 0.036 m and number of plates – 23. Nozzle diameter for overhead vapour outlet was also designed to be 233 mm and bottom out 139.8 mm.

References
[1] Fruehauf P S et al. 1993 Distillation column control design using steady state models: Usefulness and limitations ISA Transactions 32 (2) 157-75
[2] Luyben W L 2006 Evaluation of criteria for selecting temperature control trays in distillation columns Journal of Process Control 16(2) 115-34
[3] Gawish A and Emad A 2008 Relative permeability curves for high pressure, high temperature reservoir conditions Electronic Scientific magazine oil and gas case 2 120-43
[4] Basu S and Debnath A 2019 Control Handbook (Academic Press, US)
[5] Maka K and Norwal G W 2013 Optimizing chlorine compression design with vapour phase nitrogen trichloride destruction Canadian Journal of Chemical Engineering 91(4) 718-24
[6] Towler G and Sinnott R 2008 Chemical Engineering Design: Principles, Practice and Economics of Plant and Process Design (Elsevier Inc)
[7] Bamatov I 2017 Development Of The Chemical Reactor Vstar For Continuous Flow Reactions Chechen State University Journal 2(6) 205-7
[8] Bamatov I, Rumyantsev E V and Bamatov D 2019 Coating of powder particles by a continuous method of reaction by using V-star chemical reactor IOP Conference Series: Materials Science and Engineering 537 062010