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Cost Estimation of Distillation Unit at *Dimethyl Ether* Plant Based on Production Capacity

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Abstract. The aim of this research is to determine the impact of production capacity in determining of distillation cost estimation on the dimethyl ether plant design. The estimation of equipment costs are determined using the CEPCI cost index. The calculation of the equipment specification was done with 4 different production capacities. The number of column height and diameter will increase when the production capacity is increased. The increase of the equipment cost is directly proportional to the increase of production capacity. The greater the production capacity, the larger the height column and diameter, so the equipment cost will increase also. The equipment cost is affected by production capacity. Based on this analysis, the cost in the year of 2024 will follow the model of $y = 9923.8x + 2E+08$, which x is the capacity.

Keyword: Cost Estimation, Design, Distillation Column

1. Introduction

Distillation can be considered as the most popular vapor-liquid separation process which is widely used in industry to separate various chemicals [1]. Distillation is a method of separating chemicals based on differences in the speed or ease of evaporation (volatility) of the material [2]. In the pre-planned dimethyl ether plant, the presence of a distillation column is a very important part of the separation process, because it is related to the purity of the product produced. Distillation in this study was used to separate the dimethyl ether product from a mixture of methanol and water [3].

The distillation column is a series of process equipment consisting of a preheater, column, condenser, accumulator, reboiler, and its supporting equipment with the configuration as shown in Figure 1. There are 4 types of flow in the distillation process [2]:

- The feed stream is the stream that enters the distillation column.
- The product stream is the stream leaving the distillation column. There are at least two kinds, namely the top product (distillate) and the bottom product.
- Internal stream is the fluid flow that occurs in the distillation column. There are two types, namely the vapor stream and the liquid stream.
- Reflux flow is some of the top product (distillate) which is returned to the distillation column through the top of the column.

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In a factory planning, the estimated cost of equipment is one of the factors needed for economic analysis in estimating the final cost of a plant to prevent non-productive construction. With these estimates, operational and capital costs can be estimated and with that profit estimates can be achieved [4]. In this study, the estimation of the price of the equipment was carried out on the distillation apparatus based on the production capacity of the dimethyl ether plant.

This research was conducted with the aim of knowing the effect of production capacity in determining the price of the distillation equipment in the dimethyl ether factory planning.

2. Research Method

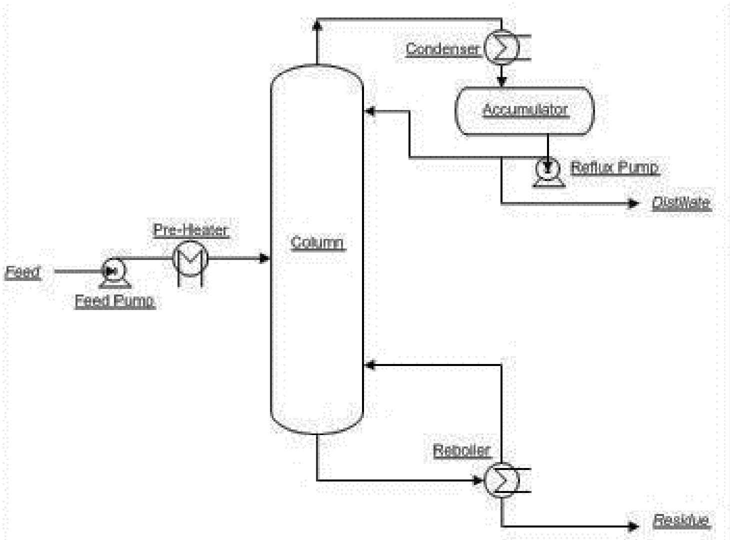

Figure 1. Distillation equipment

2.1 The working of distillation equipment

The feed in the form of a mixture of dimethyl ether and crude methanol is fed to a distillation column with a boiling point feed temperature condition. The material in the form of steam will directly rise to the top of the column and exit through the steam outlet, which is then cooled in the condenser. While the material in the form of liquid will go down through each tray. The liquid that has reached the bottom of the column is heated again with a reboiler and the dimethyl ether vapor formed will rise to the top of the distillation column. The steam that has been cooled in the condenser will then be condensed into a distillate and some of the liquid is returned to the distillation column as reflux [5]. The performance of the distillation column is determined by several factors, including [6]:

- Feed conditions; the state of the mixture and the composition of the feed affect the operating line and the number of trays in the separation. This also affects the location of the feed tray.
- Reflux conditions; a minimum tray is required under conditions of total reflux i.e. no distillate withdrawal. The separation is better if fewer trays are used to obtain the degree of separation.
- Steam flow conditions.

2.2 Design Process

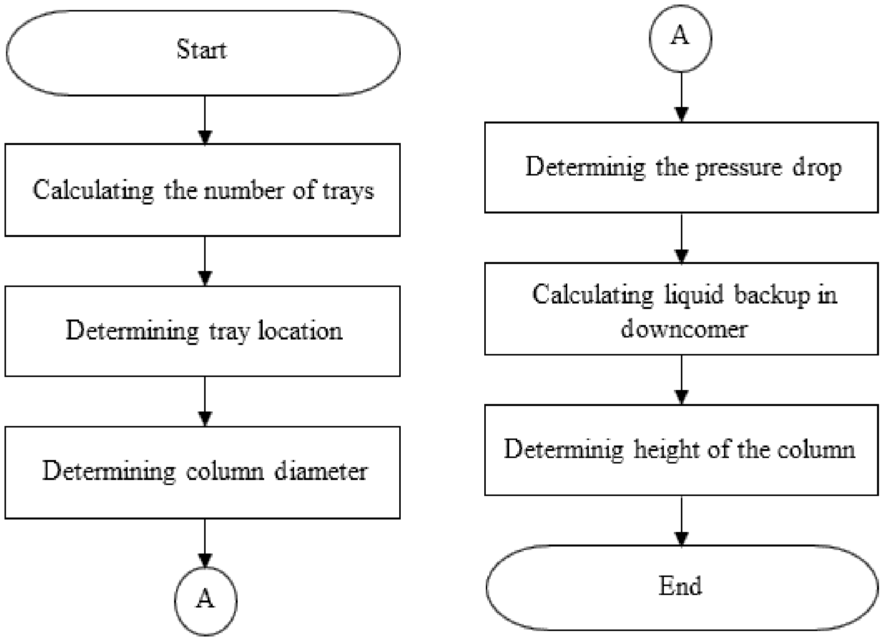

Figure 2. Distillation column design process flow chart

In the distillation column design process there are several steps, the first is to calculate the number of trays with equations [5].

$$\alpha_{average}\ (\alpha_i) = (\alpha_L\ distilat \times \alpha_L\ bottom)^{0,5} \tag{1}$$

$$N_{min} = \left(log\left[\left(\frac{X_{LK}}{X_{HK}}\right) D \times \left(\frac{X_{HK}}{X_{LK}}\right) B\right]\right) \times (log\ \alpha_{ave})^{-1} \tag{2}$$

$$X = \frac{R - R_{min}}{R+1} \tag{3}$$

$$\frac{N - N_{min}}{N+1} = 1 - exp\left(\left(\frac{1+54{,}4\ X}{11+117{,}2\ X}\right)\left(\frac{X-1}{X^{0,5}}\right)\right) \tag{4}$$

After getting the number of trays, then determine the location of the feed tray with equation [7]:

$$log\left(\frac{N_R}{N_S}\right) = 0{,}206 \times log\left[\frac{B}{D}\left(\frac{Z_{HK,F}}{Z_{LK,F}}\right)\left(\frac{X_{LK,B}}{X_{HK,D}}\right)^2\right] \tag{5}$$

Next determine the column diameter by equations [8]:

$$\rho_{V campuran} = \frac{P_{operasi} \times BM_{campuran}}{R \times T} \tag{6}$$

$$P_F = \frac{L}{V}\left(\frac{\rho_V}{\rho_L}\right)^{0,5} \tag{7}$$

$$U_{VN} = P_C\left(\frac{\rho_L - \rho_V}{\rho_V}\right)^{0,5} \tag{8}$$

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$$A_N = \frac{Q_V}{U_{VN} \times 0{,}7} \quad (9)$$

$$A = A_N + (2\ A_d) \quad (10)$$

$$D = \left(\frac{A}{\pi/4}\right)^{0{,}5} \quad (11)$$

After the diameter is obtained, then determine the pressure drop using equations [8]:

$$Q_L = \frac{L}{\rho_L} \quad (12)$$

$$h_{ow} = 0{,}48 \times F_w \left(\frac{Q_L}{l_w}\right)^{0{,}67} \quad (13)$$

$$h_\sigma = \frac{0{,}04 \times \sigma}{\rho_L \times d_h} \quad (14)$$

$$h_0 = 0{,}186 \times \frac{\rho_V}{\rho_L} \times \left(\frac{U_{VN}}{C_0}\right)^2 \quad (15)$$

$$\Delta H_T = \beta\ (h_w + h_{ow}) + h_0 + h_\sigma \quad (16)$$

Then calculate the liquid backup in downcomer, with equation [8]:

$$H_D = \left(\Delta H_T + \beta\left(h_w + h_{ow} + \frac{\Delta}{2}\right) + h_d\right) \times \frac{1}{\phi_d} \quad (17)$$

After the H_D value is obtained, the next step is to determine the column height using equations [9]:

Total height of tray = (Σ tray – 1) × (*tray spacing*) + (distance for feed inlet) (18)

Liquid hold-up height, H = = $Sf + 0{,}000049\ D^3$ (19)

Volume down cap = $\frac{\pi}{4} D^2 H$ (20)

$$P_{hidrostatic} = \rho_L \times \frac{g}{gc} \times H \quad (21)$$

$$P_{\text{design}} = 1{,}1 \times (P_{operation} + P_{hidrostatic}) \quad (22)$$

Shell thickness, $t_s = \frac{P \times ri}{f \times E - 0{,}6 \times P} + C$ (23)

Cap thickness, $t_d = \frac{0{,}885 \times P \times rc}{f \times E - 0{,}1 \times P} + C$ (24)

$$AB = \frac{ID}{2} - icr \quad (25)$$

$$BC = r - icr \quad (26)$$

$$b = r - (BC^2 - AB^2)^{0{,}5} \quad (27)$$

Cap height, $OA = td + b + sf$ (28)

$$\text{Total tower height} = \text{height for plate holder} + \text{liquid backup height} + \text{cap height} + \text{inlet feed height} + \text{liquid hold up height} + \text{inlet reflux height} \quad (29)$$

Information :

A = *Area of column*
A_N = *Net vapor flow area between plates*
C_0 = *Orifice coefficient*
D = *Tower diameter*
F_w = *Factor*
H_D = *Height of liquid backup in downcomer*
ΔH_T = *Total pressure drop*
h_d = *Equivalent head loss in downcomer*
h_0 = *Equivalent head loss through holes*
h_{ow} = *Liquid crest over weir*
h_σ = *Equivalent surface-tension head loss*
h_w = *Weir height*
N_{min} = *Total tray minimum*
P_C = *Capacity factor*
P_F = *Flow parameter*
Q_L = *Liquid load*
Q_V = *Vapor load*
U_{VN} = *Vapor velocity*
β = *Relative foam density*
ϕ_d = *Froth density, downcomer*

2.3 Approximate Equipment Price

After the specification of the tool is done, the estimated price of the tool can be calculated. To calculate the price of a distillation device, data on column height, diameter, number of actual trays, and types of construction materials are required. Furthermore, with the following equations, the initial value of the distillation column [10] will be obtained:

$$C_{BM} = C_p \times F_{BM} \quad (30)$$

$$C_{BM} = C_p \times F_{BM} \times N_{act} \times f_q \quad (31)$$

The price of equipment in the year the factory was established is determined using the CEPCI (Chemical Engineering Plant Cost Index) price index, where the price index is a value given at a time indicating the price or value at a certain time [3]. The initial price index in this study was obtained from literature data in 1982, which was 315 [10]. As for the price index in 2024, which is the year the dimethyl ether plant is planned to be established, the price index is set at 600.05. Obtained from table data CEPCI Annual Index [11] which was then calculated using the least square method [12]. Furthermore, as a comparison, the price index in 2026 is calculated, which is worth 605.51.

CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957–59 = 100)	Jan. '19 Prelim.	Dec. '18 Final	Jan. '18 Final
CE Index	619.2	615.9	576.4
Equipment	757.5	751.2	697.4
Heat exchangers & tanks	677.3	667.3	606.1
Process machinery	734.3	731.2	697.0
Pipe, valves & fittings	978.9	979.9	910.2
Process instruments	416.1	420.2	415.9
Pumps & compressors	1060.6	1037.3	1001.0
Electrical equipment	554.7	553.7	531.2
Structural supports & misc.	841.7	827.2	736.1
Construction labor	334.1	339.5	328.7
Buildings	601.5	600.1	570.5
Engineering & supervision	316.9	316.3	308.7

Annual Index:
2011 = 585.7
2012 = 584.6
2013 = 567.3
2014 = 576.1
2015 = 556.8
2016 = 541.7
2017 = 567.5
2018 = 603.1

Figure 3. CEPCI Annual Index [11]

From the results of the calculation of the initial price of the distillation column, then a calculation is carried out to get an estimate of the price in the desired year, using equation [12]:

$$\text{Price in year A} = \frac{\text{index price in year A}}{\text{index price in year B}} \times \text{price in year B} \qquad (32)$$

For the price of the distillation column in the market today, it is known to be in the price range of Rp. 218.667.600 to Rp. 29.155.680.000 [13].

3. Results and Disscussions

The results of the estimation of the price of the distillation column equipment based on the production capacity of the dimethyl ether plant.

Table 1. Estimated price of distillation column in 2024 and 2026 based on production capacity

Production Capacity	Estimated Price in 2024	Estimated Price in 2026
10.000 ton/year	Rp 250.685.471	Rp 252.966.780
13.973 ton/year	Rp 325.569.208	Rp 328.531.980
20.000 ton/year	Rp 371.140.293	Rp 374.517.775
25.000 ton/year	Rp 406.950.384	Rp 410.653.748

Based on Table 1, it is known that the greater the production capacity, the greater the estimated price for the distillation column.

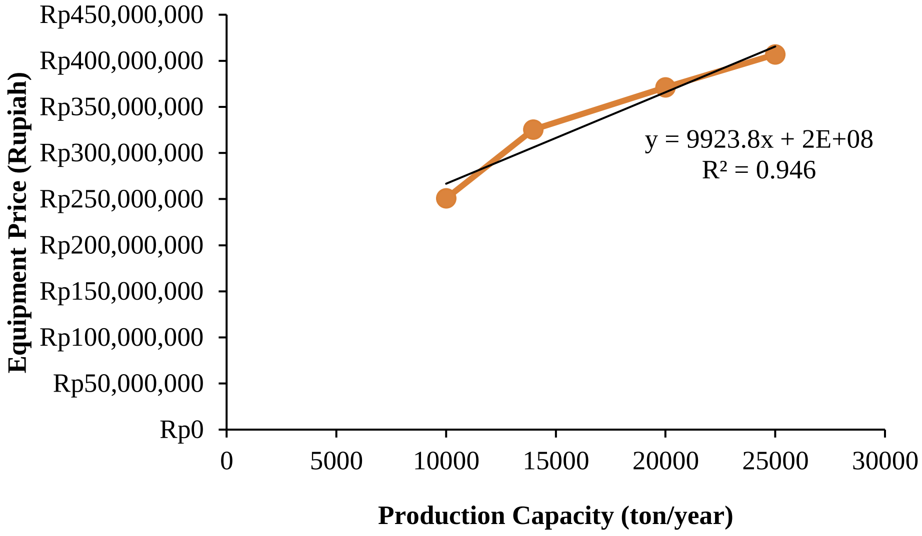

Figure 4. The relation between production capacity and equipment price in 2024

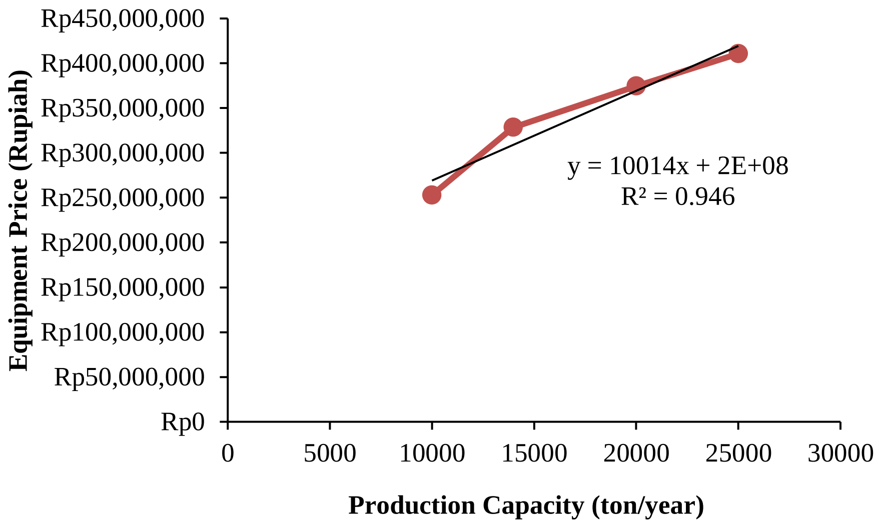

Figure 5. The relation between production capacity and equipment price in 2026

Figure 4 shows that the increase in equipment prices in 2024 is directly proportional to the increase in production capacity. The same thing is also seen in Figure 5, where the increase in equipment prices in 2026 is proportional to the increase in production capacity. Based on the graph in the literature [10], it is known that in determining the price of the distillation column, it is influenced by the height of the column and the diameter of the tray. Where the greater the capacity, the column height and tray diameter will increase. Thus, the estimated value of the tool price also increases.

4. Conclusion

Based on the graph of the calculation results of the estimated price of the distillation column in 2024 and 2026, it shows an increase in line with the increase in production capacity. When compared with the prices on the market today, the results of the calculation of the estimated price of the distillation column equipment based on the pre-planned production capacity of the dimethyl ether plant are appropriate.

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