Production of Ammonia

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Cost Estimation

Source for all calculation : Sinnot, P & Towler, G., Chemical Engeneering Design, Coulson & Richardson's Chemical Engineering Series, Vol. 6, 5th edition, Chapter 6 and 10, Elsevier, Amsterdam, 2009.

Equipment Type and energy consumption

Equipment	Type	Energy Consumption (-) / Generation (+) (kW)
COOL-3	Cooler	10428.9
COOL-5	Cooler	5195.35
COOL-1	Cooler	5014.82
Ammonia reactor	Plug-Flow Reactor (PFR)	3406.99
COOL-2	Cooler	3151.09
HTS (High T shift reactor)	Plug-Flow Reactor (PFR)	1800.11
COOL-4	Cooler	1270.97
LTS(Low T shift reactor)	Plug-Flow Reactor (PFR)	195.082
Absorption column	CAPE-OPEN Unit Operation	4.31364
PSA	Compound Separator	0.957365
Flash sep	Gas-Liquid Separator	0.069004
MIX-3	Stream Mixer	1.6248E-08
Flash	Gas-Liquid Separator	0
Ammonia storage	Tank	-2.27374E-12
MIX-2	Stream Mixer	-7.42148E-10
MIX-1	Stream Mixer	-0.000123341
HEATER	Heater	-1689.52
Compressor	Compressor	-3206.33
Steam reformer	Plug-Flow Reactor (PFR)	-12052.8

The purchased equipment cost on a US Gulf Coast basis can be calculated by given equation:

$$C_e = a + b^S$$

Where e a and b are cost constants, S is the size parameter and n is the exponent for that type of equipment The values for a, b and n are given in table 6.6 in Sinnot & Towler.

All the values were calculated on a US Gulf coast basis from January 2007. At this year the CE index (CEPCI) was 509.7. To approximate the price in 2022 , all purchased equipment cost had to be multiplied by the ratio of cost in year 2016 and cost in year 2007 as given in equation

$$I_{2022,2007} = 806.9/509.7$$

$$= 1.583$$

Compressor

Cost for one compressor is given by

$$C_e = 490000 + 16800(W)^{0.6}$$

Where W is sizing factor , duty [kW] of the compressor,

from simulation W = 3206.52 kW

$$C_e = 490000 + 16800(3206.52)^{0.6} = \text{Rs. } 2622699.43$$

Material cost factor of stainless steel 304 is 1.3 and multiply it with CE index ratio $I_{2022,2007}$

$$C_e = 26622699.43 * 1.3 * 1.583$$

$$= \text{Rs. } 5397253.159$$

Reactors

For estimating the cost of the reactors,

$$C_e = 53000 + 28000(V)^{0.8}$$

where V is the reactor volume. It can be calculated by

$$V = \hat{V}\tau / \varphi$$

where $\hat{V}$ is the volume flow into the reactor, τ the residence time and the void fraction, φ.

We can get value of $\hat{V}$ and τ from simulation model , φ was assumed to be 0.45 for every case.

1. **HTS(High T shift Reactor) :**

$$V = (6251.44 * 0.00319927)/ 0.45$$

$$= 44.44\ m^3$$

$$C_e = 53000 + 28000(44.44)^{0.8}$$

$$= \$\ 635609.11$$

2. **LTS(Low T shift Reactor) :**

$$V = (4420.01 * 0.00339366)/ 0.45$$

$$= 33.34\ m^3$$

$$C_e = 53000 + 28000(33.34)^{0.8}$$

$$= \$\ 515946.18$$

3. Ammonia Reactor :

$$V = (311.348 * 0.0963553) / 0.45$$

$$= 66.67 \text{ m}^3$$

$$C_e = 53000 + 28000(66.67)^{0.8}$$

$$= \$ 858939.41$$

Total reactor cost = (cost of HTS + cost of LTS + Ammonia reactor) * material factor * $I_{2022,2007}$

= $ 337919813.9

= Rs. 27597894305.22

4. Reformer :

The high alloy reformer tubes are expensive and account for a large part of the reformer costs, the volume of the reformer tubes was estimated for the sizing parameter.

$$V = 41.03 \text{ m}^3$$

$$C_e = 53000 + 28000(41.03)^{\wedge}0.8$$

$$= \$\ 599561.76$$

Material we are using is inconel , material factor of inconel is 1.7.

$$C_e = \$\ 599561.76 * \text{material factor} * I_{2022,2007}$$

$$= \$\ 599561.76 * 1.7 * 1.583$$

$$= \$\ 1613480.652$$

$$= \text{Rs. } 131772884.17$$

Heat Exchanger

We have 5 coolers and 1 heater as heat exchanger.

For estimating the cost of the exchnagers,

$$C_e = 24000 + 46A^{1,2}$$

where A is the heat transfer Area. It can be calculated by

$$Q = UA\Delta T_{AM}$$

Where Q [W] is the duty of the cooler/heater and U [W/m²K] is the coefficient of the heat transfer.

U is assumed to be 400 W/m²K, which is a typical value for industrial heat exchangers at these conditions

1. **Cooler 1 :**

$$A = 5016230/(400*1033.07)$$

$$= 12.14\ m^2$$

$$C_e = 24000 + 46(12.14)^{1'2}$$

$$= \$\ 24920.06$$

2. **Cooler 2 :**

$$A = 3151120/(400*592.12)$$

$$= 13.3\ m^2$$

$$C_e = 24000 + 46(13.3)^{1'2}$$

$$= \$\ 25026.55$$

3. Cooler 3 :

$$A = 10428500/(400*408.15)$$

$$= 63.87\ m^2$$

$$C_e = 24000 + 46(63.87)^{1'2}$$

$$= \$\ 30747.053$$

4. Cooler 4 :

$$A = 1270970/(400*772.39)$$

$$= 4.11\ m^2$$

$$C_e = 24000 + 46(4.11)^{1'2}$$

$$= \$\ 24250.82$$

5. **Cooler 5 :**

$$A = 5195340/(400*445.65)$$

$$= 29.15\ m^2$$

$$C_e = 24000 + 46(29.15)^{1’2}$$

$$= \$\ 26632.23$$

6. **Heater :**

$$A = 1689520/(400*343.15)$$

$$= 12.31\ m^2$$

$$C_e = 24000 + 46(12.31)^{1’2}$$

$$= \$\ 24935.55$$

Total C_e = (cost of cooler 1+cooler 2 +cooler 3 + cooler 4 + cooler 5 + heater) * 1.3 *$I_{2022,2007}$

= 156512.26 * 1.3 * 1.583

= $ 322086.58

= Rs. 26304794.88

Separators

We have 3 Separator, Flash, Flash sep and PSA

For estimating the cost of the separatos,

$$C_e = 15000 + 68^* (m_{shell}^{0'85})$$

where m_{shell} is the shell mass of the separators. It can be calculated by

$$m_{shell} = \pi D_v h \, t_w \rho$$

where tw is the wall thickness(> 2.5mm) ,ρ is the density of the metal which is 8030 kg/m3 for stainless steel 304.

And D_V, minimum vessel diameter = $\sqrt{[4\,(\hat{V}/u\pi)]}$

here u , settling velocity = $0.007\sqrt{[(\rho L - \rho V)/\rho V]}$

h , total height of separator = $h_L + D_V/2 + D_V + 0.4$

here $h_L = V_L/(D_V^2 * \pi) * 4$

$V_L = \hat{V}(10*60)$ [assume hold on time 10 min]

Where ρL = density of liquid

ρV = density of vapor

h_L = liquid volume held in vessel

$\hat{V}$ = volumetric flow

1. Flash :

$$U = 0.007\sqrt{[988.916 - 5.95)/ 5.95]} = 0.09$$

$$D_V = \sqrt{[4\,(1788.23/0.09*3.14)]} = 2.65$$

$$V_L = 1788.23(10*60)/3600 = 298.03$$

$$h_L = 298.038 / (2.65^2 * 3.14) * 4 = 54.036$$

$$h = 54.036 + 2.65/2 + 2.65 + 0.4 = 58.411$$

$$m_{shell} = 3.14*2.65*58.411*0.0027*8030 = 10543.13$$

$$C_e = 15000 + 68* (10543.13^{0'85})$$

$$= \$\ 127430.61$$

2. Flash sep :

$$U = 0.007\sqrt{[742.93 - 76.9908)/ 76.9908]} = 0.023$$

$$D_V = \sqrt{[4 (67.5764/0.023*3.14*3600))]} = 1.0238$$

$$V_L = 67.5764(10*60)/3600 = 11.26$$

$$h_L = 11.26/ (1.023^2 * 3.14) * 4 = 13.67 \text{ m}$$

$$h = 13.67 + 1.023/2 + 1.023 + 0.4 = 15.605$$

$$m_{shell} = 3.14 * 1.023 * 15.605 * 0.0027 * 8030 = 953.26$$

$$C_e = 15000 + 68* (953.26^{0'85})$$

$$= \$ 31439$$

3. PSA :

$$U = 0.007\sqrt{[10482 - 1.2725)/ 1.2725]} = 0.0212$$

$$D_V = \sqrt{[4 (61257.91/0.0212*3.14*3600))]} = 4.581$$

$$V_L = 61257.91(10*60)/3600$$

$$h_L = V_L / (4.581^2 * 3.14) * 4 = 12.73$$

$$h = 12.73 + 4.581/2 + 4.581 + 0.4 = 20$$

$$m_{shell} = 3.14 * 4.581 * 20 * 0.0027 * 8030 = 6239.13$$

$$C_e = 15000 + 68* (6239.13^{0'85})$$

$$= \$ 88893.82$$

Total C_e = (cost of Flash + cost of flash sep + cost of PSA) * 1.3 *$I_{2022,2007}$

= 247763.53 * 1.3 * 1.583

= $ 509872.57

= Rs. 41641267.30

Absorber

Assuming 0.5 m between the stages, gave a height of the absorbers to be 9.5 m. The diameter was assumed to be 1.5 m . Total no. of stages 15.

For estimating the cost of the sieve trays,

$$C_e = 110 + 380\, D^{9/5}$$

where D is diameter .

For estimating the rest of cost Absorber,

$$Ce = 15000 + 68\, (m\char`^0.85)$$

$$m = V_{total} * \rho$$

V_{cyl} , Volume of the pressure vessel cylinder = $(\pi * D^2 * h)/4$

t_w, hold up time = $(p_{design} * D)/(2SE - 1.2 * p_{design})$

V_{wall} , Volume of wall = $V_{cyl} - (\pi * (D-2t_w)^2 * h)/4$

$V_{top+bottom}$, Volume of the top and bottom = $(\pi * D^2 * t_w * 2)/4$

V_{total} , Total volume = $V_{top+bottom} + V_{wall}$

Design pressure, p_{design} , of the vessel is 10 % of the operating pressure .SE is the shear stress for stainless steel 304 which is 89 N^2/mm^2

For sieve trays ,

$$C_e = 110 + 380\,(1.5)^{9/5} = 229.018$$

For rest of the absorber,

$$V_{cyl} = (3.14 * 1.5^2 * 9.5)/4 = 16.78$$

$$t_w = (p_{design} * 1.5)/(2*89 - 1.2*p_{design}) = 1.248$$

$$V_{wall} = 9.61418$$

$$V_{top+bottom} = 4.41$$

$$V_{total} = 24.02$$

$$m = 24.02 * 8030 = 112620.558$$

$$C_e = 15000 + 68\,(112620.558\hat{\ }0.85) = 1352777.651$$

Total cost = (cost of trays + rest of the costs) * 1.3 * $I_{2022,2007}$

= $ 2784352.424

= Rs. 227397923.25

Total fixed Cost

Major equipment, total purchase cost	C_e value	Comment
f_{er}	0,3	Equipment erection
f	0,8	Piping
f_i	0,3	Intrumentation and control
f_{el}	0,2	Electrial
f_c	0,3	Civil
f_s	0,2	Structures and buildings
f_l	0,1	Lagging and paint
OS	0,3	Offsites
D&E	0,3	Design and Engeneering
X	0,1	Contigency

Total Fixed cost

Total fixed capital cost = C_{FC} = C(1 + OS)(1 + D&E + X)

Where $C = C_{SS} + C_{NI}$

C_{SS} for all the equipment in material 304 stainless steel

$$C_{SS} = \sum C_{e,i,SS} F$$

$$F = [(1 + fp)fm + (fer + fel + fi + fc + fs + fl)]$$

C_{NI} costs of the reformer,

$$C_{NI} = \sum C_{e,i,NI} F$$

$$F = [(1 + fp) + (fer + fel + fi + fc + fs + fl)/fm]$$

For equipments of material 304 stainless steel, [fm = 1.3]

$$F = [(1 + 0.8)1.3 + (0.3 + 0.3 + 0.2 + 0.3 + 0.2 + 0.1)] = 3.2$$

$$C_{SS} = 741179643.6 * 3.2$$

$$= 2371774859$$

For reformer, [fm = 1.7]

$$F = [(1 + 0.8) + (0.3 + 0.3 + 0.2 + 0.3 + 0.2 + 0.1)/1.7] = 2.6$$

$$C_{NI} = 24306393.91$$

Total fixed capital cost , CFC = (2371774859+24306393.91)(1+0.3) + (1 + 0.3 + 0.1)

= Rs. 3114905630

Steam

We have 2 streams of steam named steam and extra steam.

Cost of steam coal in gujarat = Rs.10886.22/ton

For Extra steam , mass flow = 16.53 ton/h

Cost = 16.53 * 10886.22 = Rs. 179949.22

For Steam , mass flow = 3.97 ton/h

Cost = 3.97 * 10886.22 = Rs. 43196.52

Total cost = Rs. 223145.738/h

Compressor work

Compressor duty , W = 3206.33 kW

Cost of electricity in Gujarat = Rs. 4.57 /kW

Total cost of electricity = 4.57 * 3206.33

= Rs. 14652.928

Methane

Mass flow , m = 3600 kg/h

Cost of methane in Gujarat = Rs. 180.7858/kg

Total cost of electricity = 3600 * 180.7858

= Rs. 650828.86

Total variable cost

Total variable cost = Cost of methane + cost of steam + cost of compressor work

= Rs. 888627.5261

Above cost for one hour of work, calculate for one year,

If plant is operating for 15 hours/ day and total of 330 days/ year

Total variable cost per Annum = 888627.5261 * 15* 330

= Rs. 4398706254