Process Analysis and Plant Design for Manufacturing of Nitric Acid

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Abstract

The primary objective is to design a chemical plant for the production of nitric acid by ammonia oxidation process. Firstly, the description about the need of process design and which process to choose among the available for the production. Next step is performing material and energy balance for all equipment. Further, designing of all major equipment of the plant has to be done, followed by utilities and finally, the economic feasibility of the project has to be checked.

Keywords - *Ammonia oxidation process, plant design, material balance, energy balance, distillation column, reactor, oxidation tower, absorption column, cost estimation*.

I. INTRODUCTION

Process design includes all the engineering aspects involved in the development of industrial plant, from plant layout to economic evaluation while the synthesis is a step in designing where the engineers select the component parts and how to inter-connect them to create a flow sheet. A process is a method by which the product is manufactured from the raw materials. Process engineer job is to select appropriate steps for the manufacturing of products as per the required specification.

Chemical plant designing involves chemical technology, unit operations, instrumentation and control, specialized equipment, safety, materials of construction etc. Chemical technology is the branch of chemical engineering dealing with chemical changes and physical methods involved in industrial processes. It is thus necessary to supplement knowledge of unit operations with chemical technology to have a complete knowledge of the plant.s

Capacity of plant is decided based on demand and investment. In order to arrive at consumption figures of raw materials and energy, preliminary stoichiometric calculations are needed to have a rough amount of material and energy consumption.

Mainly there are three methods to prepare nitric acid but we choose Ostwald's process or also known as ammonia oxidation process above all due to its advantages such as increased quality of nitric acid compared to other two process and a low operating cost. Chile saltpetre method was first method which commercially produced nitric acid with raw material as sodium nitrate processed from Chile saltpetre. This method was used nearly in the world war1 timeline, also up to date this method is obsolete since 1920 because of the yield percentage obtained from the process. Other option is to use electric arc process but it consumes enormous amount of energy. Among this process, the probability of reverse dissociation is the most because of high temperature and its yield is less.

II. METHODOLOGY

Initial step involves catalytic ammonia oxidation with atmospheric oxygen to produce nitrogen monoxide. Here compressed air is mixed with anhydrous ammonia, fed to a shell and tube heat exchanger, also, the catalyst bed is in the form of 60-80 mesh wire gauge consisting of 10 to 30 sheets of catalyst. The catalyst involved in the reaction is Platinum (10%)-Rhodium (90%). Oxidation of nitrogen monoxide takes place in presence of air which gives nitrogen dioxide and dinitrogen tetra oxide at 40-50 ^{0}C in the next step. Further the product of earlier step goes into derivatives into nitric acid by spraying water from top of the column. The product obtained from absorption system is 57 to 60% concentrated. To increase its concentration

level the product is recirculated to absorption system.

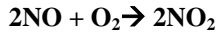## III. MATERIAL BALANCE

A. *Reactor*
Reactions occurring in reactor are;
1) $4NH_3 + 5O_2 \rightarrow 4NO + 6H_2$
2) $4NH_3 + 3O_2 \rightarrow 2N_2 + 6H_2$
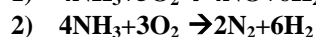
Components	Input (Kg)	Output (Kg)	X_i
NH_3	1124.38	-	0
O_2	2730.24	105.92	0.00825
N_2	8987.16	9005.64	0.7013
NO	-	1944.6	0.1514
H_2O	-	1785.78	0.1391
Total	12841.78	12841.94	1

B. Tail gas heater and heat recovery boiler

Reaction occurring are;

$$2NO + O_2 \rightarrow 2NO_2$$

Components	Input (Kg)	Output (Kg)	X_i
NO	1944.6	1746.3	0.136
NO_2	-	304.06	0.024
H_2O	1785.78	1785.78	0.139
O_2	105.95	-	0
N_2	9005.64	9005.64	0.701
Total	12841.94	12841.78	1

C. Cooler or Condenser

Reaction occurring in the equipment is;

$$3NO_2 + H_2O \rightarrow 2HNO_3 + NO$$
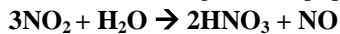
Components	Input (Kg)	Output (Kg)	X_i
NO_2	304.06	256.22	0.01995
NO	1746.3	1754.7	0.1366
H_2O	1785.78	1790.82	0.1395
N_2	9005.64	9005.64	0.7012
HNO_3	-	35.38	0.00275
Total	12842.76	12842.76	0.9999

D. Oxidation tower

Reaction occurring in oxidation tower;

$$NO_2 + 2HNO_3 \rightarrow 3NO_2 + H_2O$$
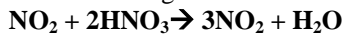
Component	Input (kg)	Output (kg)	X_i
NO	1754.7	175047	0.0054
N_2	9005.64	9005.64	0.2767
HNO_3	13076.02	6443.26	0.198
H_2O	8717.34	9664.88	0.297
NO_2	-	7260.64	0.223
Total	32550.7	32549.89	1.00

E. Compressor

Reaction taking place in compressor is;

$$2NO + O_2 \rightarrow 2NO_2$$
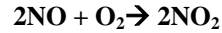
Component	Input (kg)	Output (kg)
NO	175.47	-
NO_2	7414.28	7683.38
O_2	1583.04	1490.08
N_2	14218.4	14218.4
Total	23391.19	23391.86

F. Distillation Column

Material balance of distillation column

Component	Input	Output	
	A (kg)	B (kg)	C(kg)
HNO_3	7894.77	4166.67	3728.1
H_2O	1973.69	219.29	1754.4
Total	9868.46	4385.96	5482.5
		9868.46	

IV. ENERGY BALANCE

A. For reactor

Reactions occurring in it are;

1) $4NH_3 + 5O_2 \rightarrow 4NO + 6H_2$, $\Delta H_{298k} = -54.1$ kcal/mol
2) $4NH_3 + 3O_2 \rightarrow 2N_2 + 6H_2$, $\Delta H_{298k} = -75.7$ kcal/mol

Heat of reactant	Heat of product	Heat of reaction	Heat accumulat-ion
616424	3398564	-3607975	-824486

B. Compressor

Two stage Compressor is used

Stage	Inlet temp(°C)	Outlet temp(°C)
Stage 1	48	216.9
Stage 2	50	218.98

C. Oxidation Tower

Following reaction takes place;

$$NO_2 + 2HNO_3 \rightarrow 3NO_2 + H_2O, \Delta H_{298k} = 34.4 \text{kcal/mol}$$
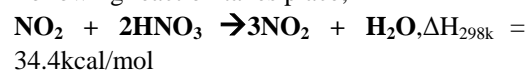
Heat of reactant	Heat of product	Heat of reaction
314744	$11347(T_2 - 25)$	1704

D. Super Azeotropic Column

The reaction taking place in it is;

$3NO_2 + H_2O \rightarrow 2HNO_3 + NO$, $\Delta H_{298k} = -80.178 kJ/mol$
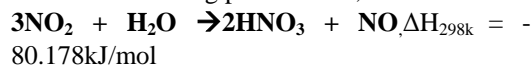
Heat of reactant	Heat of product	Heat of reaction
5.925×10^6	9.36×10^5	-2.733×10^6

V. EQUIPMENT DESIGN & MECHENICAL DESIGN

This part includes designing of all major equipment for producing nitric acid by Ostwald's process. Selection of reactor mainly depends on three parameters; type of reaction, process condition and mode of catalyst exposure. Fixed bed reactor is best suited for the reaction taking place in the process, also, the selection of 90% Pt with 10% Rh as catalyst is best suited. The shape of catalyst used is made of fine wire moulded in form of gauze.

A. Reactor;

Inlet pipe diameter = 0.719 m
Outlet pipe diameter = 0.968 m
Diameter of region where gauge is present = 1.387 m
Height of reactor = 1.5023 m
Volume of reactor = 1.4711 m^3
Material of construction is Stainless Steel
Wall thickness = 5.1 mm
Total head thickness = 3.2 mm
The next standard thickness is 5mm

B. Oxidation Tower;

Column diameter = 1 m
Total height of column = 3.85 m
Height of packing = 2.85 m
Total pressure drop across column is = 0.02426 atm
Material of construction is Stainless Steel
Total thickness = 4.9 mm
Thickness of head = 3.8 mm
The standard thickness is 5 mm

C. Absorption Column;

Actual number of trays = 10
Diameter of column at bottom = 0.84 m
Diameter at top = 0.84 m
Total height of column = 8.43 m
Material of construction is stainless steel
Total thickness of shell = 4.5 mm
Total head thickness = 4.1 mm
Next standard thickness is 5 mm

D. Distillation Column

Total height of column = 46.92 ft
Diameter of column = 2.1 ft
Material of construction is Stainless Steel
Total thickness of shell = 3.3 mm
Total head thickness = 2.68 mm
Next standard thickness is 5 mm

VI. DESIGN OF PUMPS

No.	Installation	Power(hp)
1.	Ammonia supply	0.13692
2.	Oxidation tower to absorption column	1.958
3.	Absorption column to Oxidation column	2.655
4.	Distillation column to storage	0.534
5.	Distillation column to Super Azeotropic column	0.668
6.	Super Azeotropic column to Bleaching column	1.22
7.	Bleaching column to Distillation column	1.2

VII. COST ESTIMATION

A. Cost of Equipment's

Sr. No.	Equipment	Cost (Rs.)
1.	Absorption Column	16,46,580
2.	Reactor	13,48,591,520
3.	Oxidation Column	20,27,614
4.	Distillation Column	20,21,760
5.	Tail Gas Heater	25,07,421

	&Heat Recovery Boiler	
6.	Cooler& Condenser	5,70,765
7.	Compressor	7,57,708
8.	Super Azeotropic Column	13,33,320
9.	Bleaching Column	14,61,929
10.	Pump	8,51,250
	Total	13,61,769,867

B. Total Direct Capital Investment

Item	Assumed % of E	Cost (Rs.)
Equipment	E	13,61,769,867
Equipment Installation	47%	6,40,031,837
Instrumentation	12%	1,63,412,384
Piping	66%	8,98,768,112
Electrical	11%	1,49,794,685
Building	18%	2,45,118,576
Yard Improvement	10%	1,36,176,986
Service Facility	70%	9,53,238,906
Land	60%	8,17,061,920
Total Direct Cost		53,65,373,276

C. Total Indirect Capital Investment

Item	Percentage %	Cost (Rs.)
Eng.& Supervision	33	4,49,384,056
Construction	41	5,58,325,645
Contingency & Contractors Fee		9,45,654,735
Total		10,07,709,701

D. Direct Product Cost

Sr. No.	Item	Cost (Rs,)
1.	Raw Material	4,45,255,000
2.	Operating Labour (0.15% of Total Production Cost)	12,64,260,335
3.	Direct Supervision & Clerical Labour (15% of OL)	1,89,639,050
4.	Utilities (15% of TPC)	12,64,260,335
5.	Maintenance & Repair (6% of FCI)	4,39,742,725
6.	Operating Supplies (15% of MR)	65,961,408
	Total	36,39,118,854

E. Fixed Charges

Sr. No.	Item	Cost (Rs.)
1.	Depreciation (5% of TCI)	4,21,420,111
2.	Local Taxes (2% of FCI)	1,45,470,908
3.	Insurance (1% of FCI)	73,290,454
4.	Plant overhead cost [0.6(OL+MR)]	10,22,401,836
5.	Administration (25% of OL)	3,16,065,083
6.	Distributing & Selling (10% of TPC)	7,32,904,542
7.	R & D (5% of FCI)	3,66,452,271
8.	Financing (8% of FCI)	5,86,323,633
	Total	36,65,438,839

Total product cost = Direct product cost + Total
Fixed cost = Rs. 73,04,557,693
Daily production of HNO_3 = 1,00,000 kg
Cost of HNO_3 per kg= Rs.40
Daily income= Rs. 40,00,000
Payback Period $= \frac{Total\ Product\ Cost}{Daily\ Selling}$ = 1826 days

Hence, payback period is 5.5 years

VIII. CONCLUSION

In the end it can be concluded that Ostwald's process is best suitable for us to manufacture nitric acid of desired quality based on the availability of raw materials. This project can be implemented in industry for producing nitric acid and is helpful for others those are aiming to prepare the same product as we did. Moreover, the amount which we invested will be returned to us i.e. payback period is 5.5 years. After this time the production will earn us profitability.

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