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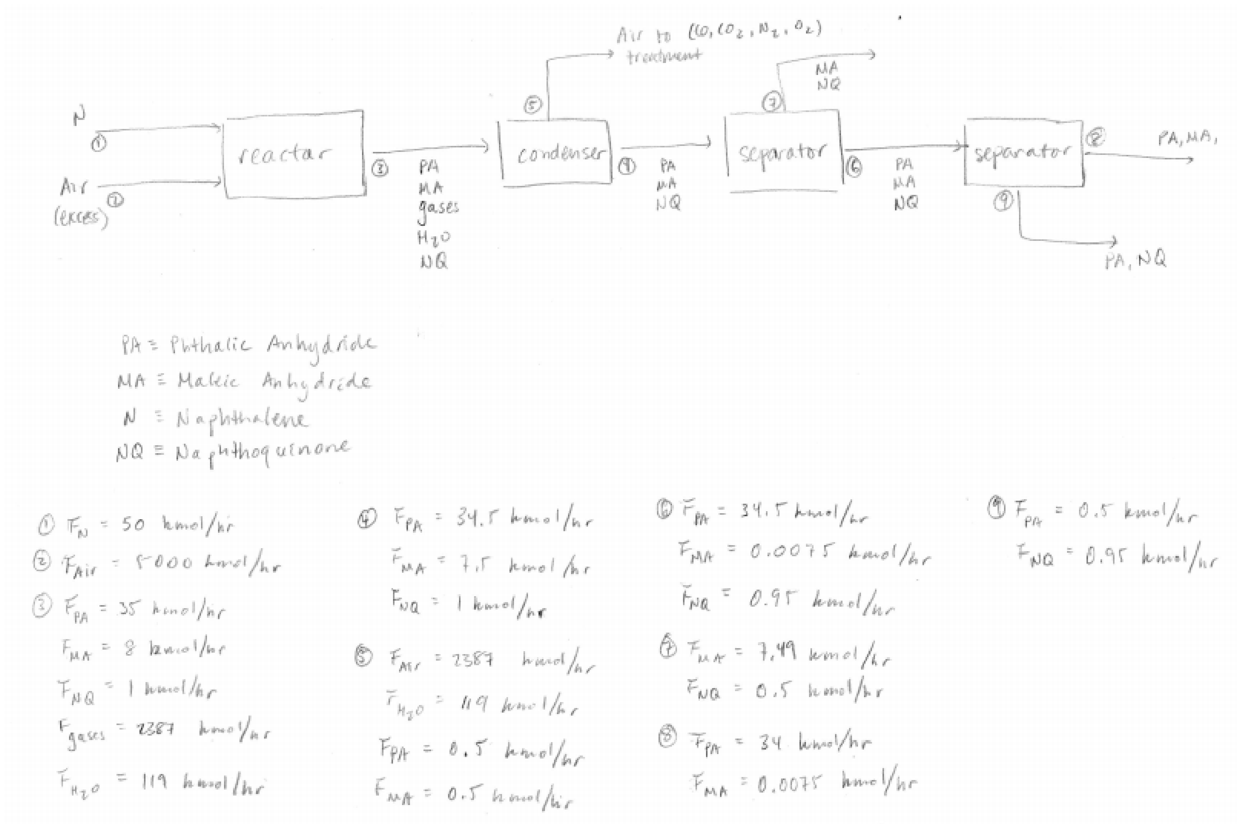
Project: PROJECT 3. Scale-Down of Phthalic Anhydride Production at TBWS Unit 700

Necessary project information has been provided from “Analysis, Synthesis, and Design of Chemical Processes[1]”.

I Abstract

The current process at this facility produces phthalic anhydride through the reaction of naphthalene and oxygen. This process takes feeds of naphthalene and excess air, and when reacted not only produces phthalic anhydride, but also byproducts of maleic anhydride and naphthoquinone. Naphthalene is heated and mixed with air, then sent to a fluidized-bed reactor. The resulting products are then condensed, and sent to an initial column to remove the maleic anhydride. The bottoms from the first column are then processed in a second column to separate the phthalic anhydride from the rest of the byproduct. Currently the facility produces 80,000 metric tons/year of phthalic anhydride, but due to a large loss of customers this needs to be scaled down by 50% of the current capacity to 40,000 metric tons/year. This scale-down must last at least another year until a new phthalic anhydride production process, projected to regain customers, is developed. It is desired to achieve this scale-down without a shutdown, as one is not scheduled for another 6 months. The goal of this project is thus to determine the maximum possible scale-down (up to 50%) that can be achieved immediately without a shutdown. Additionally, we will provide any recommendations on modifications that would be needed to reach a full 50% downsize, as well as a cost analysis on the new process. It should be noted that running the current process at full scale until the scheduled shut down, then shutting down permanently is not an acceptable solution by the company.

II Block-Flow Diagram



III Reaction Kinetics

The reactions involved in the process are detailed below.

$$C_{10}H_8 + \frac{9}{2}O_2 \rightarrow C_8H_4O_3 + 2H_2O + 2CO_2 \; [1]$$

naphthalene + oxygen → phthalic anhydride + carbon dioxide

$$C_{10}H_8 + 6O_2 \rightarrow 2C_4H_2O_3 + H_2O + 2CO_2 \; [2]$$

naphthalene + oxygen → maleic anhydride + water + carbon dioxide

$$C_{10}H_8 + 6O_2 \rightarrow 2C_4H_2O_3 + 2H_2O + 2CO_2 \; [3]$$

naphthalene + oxygen → napthoquinone + water

The process also includes the complete and incomplete combustion of naphthalene. They are assumed as the following:

Complete Combustion

$$C_{10}H_8 + 12O_2 \rightarrow 10CO_2 + 4H_2O \, [4]$$

naphthalene + oxygen → carbon dioxide + water

Incomplete Combustion: Carbon Formation

$$C_{10}H_8 + 2O_2 \rightarrow 4H_2O + 10C$$

naphthalene + oxygen → water + carbon

Incomplete Combustion: Carbon Monoxide Formation

$$C_{10}H_8 + 7O_2 \rightarrow 4H_2O + 10CO$$

naphthalene + oxygen → water + carbon monoxide

The combustion reactions are assumed to be irreversible.

An incomplete combustion of naphthalene where carbon and carbon monoxide are formed simultaneously does not exist.

Rate constants are not given for any of the reactions. However, the stream tables indicate a 100% single pass conversion of naphthalene in reference to all products with the dominating product as phthalic anhydride (desired) which takes up 70% of the naphthalene feed. This indicates that the rate constant of the primary reaction of the desired product dominates. The formation of maleic anhydride and naphthoquinone take up another 16% and 2% respectively of the naphthalene feed, indicating that the combustion reactions combined take up the remaining 12% of the naphthalene feed. Overall it can be concluded that reaction 1 is roughly 7 times faster than the combustion reactions, 4 times faster than reaction 2, and 35 times faster than reaction 3.

For the simulation the exact rate kinetics are not necessary as this process is a scale-down. It is assumed that the reaction and conditions of the reactor have already been optimized because equipment is not changed. The relative rates are assumed as constant as the plant is scaled down.

IV Thermodynamics Package and Extra Information

The suggested thermodynamics package from ASPEN plus is NTRL. This was suggested by the software for this particular chemistry, but we reserve the freedom to change the method as our understanding of the process develops.

The following information may need to be gathered for the simulation:

1. Raw material costs and product sell costs
2. Equipment costs (most likely estimated using CAPCOST)

3. Utility costs
4. Rate constant data may become necessary

V Cost Estimate

The cost estimate that was acquired in CAPCOST was done so on the assumption that the fluidized bed reactor can be modeled as a low pressure steam heat exchanger and that the switch condenser can be modeled as a refrigeration cycle heat exchanger. With these two assumptions, a fixed capital investment minus land value was determined. Scaling a plant down to 50% is essentially a remodel of the existing plant and a remodel can be thought of as building a new plant for some scalar value of the original investment. For this particular project it seemed appropriate to make that scalar ½. Therefore, it is our opinion that an accurate order of magnitude approximation of this project is one half the cost of the capital investment which is $12,750000. Following is a cost analysis of the plant.

Name	Total Module Cost	Grass Roots Cost	Utility Used	Efficiency	Actual Usage	Annual Utility Cost
C-701	$ 5,100,000	$ 7,260,000	NA			
E-701	$ 558,670	$ 780,000	Medium Thermal Source		11400 MJ/h	$ 1,233,300
E-702	$ 442,000	$ 614,000	Medium Thermal Source		21500 MJ/h	$ 2,326,000
E-703	$ 1,216,000	$ 1,690,000	Low Thermal Source		36900 MJ/h	$ 3,786,000
E-704	$ 100,000	$ 150,000	Cooling Water		0 MJ/h	$ -
E-705	$ 117,000	$ 162,000	High-Pressure Steam		0 MJ/h	$ -
E-706	$ 107,000	$ 153,000	Cooling Water		0 MJ/h	$ -
E-707	$ 238,000	$ 330,000	High-Pressure Steam		0 MJ/h	$ -
E-708	$ 12,801,000	$ 17,800,000	Refrigeration (5°C)		215000 MJ/h	$ 7,930,000
E-709	$ 1,100,000	$ 1,590,000	Refrigeration (5°C)		0 MJ/h	$ -
H-701	$ 1,840,000	$ 2,620,000	Natural Gas	0.9	10390 MJ/h	$ 959,700
P-701	$ 32,000	$ 43,000	Electricity	0.7	1.86 kilowatts	$ 935
P-702	$ 113,000	$ 151,000	Electricity	0.7	77.1 kilowatts	$ 38,800
P-703	$ 290,000	$ 362,000	Electricity	0.7	200 kilowatts	$ 101,000
P-704	$ 31,400	$ 42,300	Electricity	0.7	0.714 kilowatts	$ 360
P-705	$ 39,400	$ 53,000	Electricity	0.7	6.29 kilowatts	$ 3,160
P-706	$ 31,400	$ 42,300	Electricity	0.7	1.14 kilowatts	$ 575
T-701	$ 53,900	$ 77,000	NA			
T-702	$ 1,250,000	$ 1,780,000	NA			
V-701	$ 11,700	$ 16,600	NA			
V-702	$ 34,000	$ 48,500	NA			
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Totals	**$ 25,500,000**	**$ 35,800,000**				**$ 16,380,000**

Add Equipment

Edit Equipment

Remove All Equipment

Unit Number	700
CEPCI	541.7

User Added Equipment

Compressors	Compressor Type	Power (kilowatts)	# Spares	MOC	Purchased Equipment Cost	Bare Module Cost
C-701	Centrifugal	5670	0	Carbon Steel	$ 1,580,000	$ 4,320,000

Exchangers	Exchanger Type	Shell Pressure (barg)	Tube Pressure (barg)	MOC	Area (square meters)	Purchased Equipment Cost	Bare Module Cost
E-701	Floating Head	41	3.1	Carbon Steel / Carbon Steel	695	$ 132,000	$ 473,000
E-702	Floating Head	41	1.91	Carbon Steel / Carbon Steel	539	$ 105,000	$ 374,000
E-703	Floating Head	40	2	Carbon Steel / Carbon Steel	1520	$ 288,000	$ 1,030,000
E-704	Floating Head	0.16	0.15	Carbon Steel / Carbon Steel	5.52	$ 27,100	$ 89,200
E-705	Floating Head	42.4	0.3	Carbon Steel / Carbon Steel	50	$ 27,500	$ 98,800
E-706	Floating Head	5.16	0.3	Carbon Steel / Carbon Steel	51	$ 27,700	$ 91,000
E-707	Floating Head	42.4	0.3	Carbon Steel / Carbon Steel	243	$ 56,200	$ 202,000
E-708	Floating Head	40	2.25	Carbon Steel / Carbon Steel	15900	$ 3,040,000	$ 10,800,000
E-709	Floating Head	1	1.7	Carbon Steel / Carbon Steel	1520	$ 288,000	$ 949,000

Fired Heaters	Type	Heat Duty (MJ/h)	Steam Superheat (°C)	MOC	Pressure (barg)	Purchased Equipment Cost	Bare Module Cost
H-701	Process Heater	9350		Carbon Steel	2.35	$ 733,000	$ 1,560,000

Pumps (with drives)	Pump Type	Power (kilowatts)	# Spares	MOC	Discharge Pressure (barg)	Purchased Equipment Cost	Bare Module Cost
P-701	Centrifugal	1.3	1	Carbon Steel	2.35	$ 6,810	$ 27,100
P-702	Centrifugal	54	1	Carbon Steel	2	$ 24,000	$ 95,500
P-703	Centrifugal	140	1	Carbon Steel	41	$ 44,500	$ 246,000
P-704	Centrifugal	0.5	1	Carbon Steel	0.12	$ 6,690	$ 26,600
P-705	Centrifugal	4.4	1	Carbon Steel	0.05	$ 8,380	$ 33,400
P-706	Centrifugal	0.8	1	Carbon Steel	0.3	$ 6,690	$ 26,600

Towers	Tower Description	Height (meters)	Diameter (meters)	Tower MOC	Demister MOC	Pressure (barg)	Purchased Equipment Cost	Bare Module Cost
T-701	Empty Vertical Vessel	11	0.84	Carbon Steel		0.3	$ 11,200	$ 45,700
T-702	Empty Vertical Vessel	21.5	4.2	Carbon Steel		0.3	$ 260,000	$ 1,060,000

Vessels	Orientation	Length/Height (meters)	Diameter (meters)	MOC	Demister MOC	Pressure (barg)	Purchased Equipment Cost	Bare Module Cost
V-701	Horizontal	1.5	0.5	Carbon Steel		0.3	$ 3,280	$ 9,880
V-702	Horizontal	3.75	1.25	Carbon Steel		0.3	$ 9,580	$ 28,800

Total Bare Module Cost $ 21,586,580

References

1. Turton, Richard, et al. *Analysis, Synthesis, and Design of Chemical Processes*. Fourth ed., Prentice Hall, 2012