Economic Optimization of Unit 700 and T-702

Supplier Company ABC

To: Dr. Walton

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Subject: Economic Optimization of Unit 700 and T-702

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Mill: ACME Chemicals

Executive Summary

RH Consulting, Inc was contracted by ACME Chemicals to do an analysis of their unit 700 design for production of ethylene oxide production in Shandong Province, People's Republic of China. RH Consulting was tasked with conducting a variety of analysis including capital cost, operating cost, profitability, T-702 optimization, safety assessment, global issues, and potential heuristic optimizations. Profitability analysis determined that it was highly probable that the project would be successful, even with deviations in supply/demand. Monte Carolo simulations (MCS) were performed over a variety of discounted and non-discounted profitability metrics. Some key metrics from the MCS concluded that there was an 82.8% probability of ending with 164-362 million for a cumulative cash position, 82.9% probability that the range of return on investment would be between 48-105%, 79.9% probability that the discounted cash flow rate of return would end in the range of 41-80%, and additionally a 71.7% probability that the net present value would end in the range of 99.5-182 million. Due to the profitability analysis, subsequent capital cost analysis and operating cost analysis were deemed to be in the range of acceptability. Capital cost analysis found a module cost (dollars millions) of 36.15, grass roots cost of 43.26, equipment cost of 14.49, and lang factor cost (a lang factor of 4.74) to be 68.7. Due to the payback period having an 86.1% probability to be between 1.8-2.7 years out of a 10-year plant life, the capital cost is strongly supported by the profitability metrics, making it highly favorable and a financially sound decision. The cost of manufacturing was found to be 156 million with revenue being 205 million. The projected net profit pre-tax margin was measured at 23.9%, again strongly supporting the construction of the facility. Optimization of T-702 was also of key importance. It was found that T-702, which was operating at 90 trays and a reflux of 12.96 was extremely excessive. You could achieve the same separation efficiency with a 13-tray column operating with a reflux of 1. Allowing for a significantly smaller piece of equipment, that is significantly cheaper to build and maintain. However, the most important part was the reduction of reflux ratio from 13 to 1. The reduction in reflux ratio would save the company approximately 15 million dollars in energy a year alone. Safety concerns were also of importance and due to the temperatures exceeding 200 degrees and pressures reaching 22 bar, it is pivotal to have a proper safety plan and systems to prevent incidents. Preventative safety such as pressure relief values, redundant controllers, variety of sensors with alarms, and a quench line if the highly exothermic reaction starts to run away. Potential heuristic optimizations were to be inspected. A potential cost savings measure could be to use carbon steel rather than stainless steel due to the weakly acidic process fluid, that may not warrant the cost of the more expensive stainless steel. Finally, global issues were to be conducted since the facility is located overseas in China. It is recommended that a significant cost premium is assessed to putting the facility in China. Even measures to assess whether the facility can run profitably domestically in North America. Although the facility

seems to be highly favored in China, if conflict was to break out between United States and China over Taiwan, this could result in complete loss of the facility. If conflict was to break out prior to the projected payback period, this would result in a net loss to the company that could be in the tens of millions of dollars.

Capital Cost Analysis

Capital cost analysis was performed utilizing an excel macro enabled workbook that calculated the bare module cost of all equipment in the year 2001. The equipment was then scaled using a 2022 CEPCI value of 816. Table 1 summarizes the total cost of all the equipment in Unit 700. Figure 1 in Appendix A gives a detailed breakdown of the specifications of each equipment and its subsequent contributions in Table 1. Figure 1 shows that the greatest contribution of the bare module cost was T-701, T-702, and R-701, making up 25.3%, 23.8%, and 19.4%, respectively.

Table 1: Capital cost metrics for Unit 700

Totals	Cost
Module Cost	**$ 36,150,000**
Grass Roots Cost	**$ 43,260,000**
Equipment Cost	**$ 14,493,600**
Lang Factor Cost (4.74)	**$ 68,700,000**

Operating Cost Analysis

Capital cost analysis was performed utilizing an excel macro enabled workbook. Table 2 shows the cost associated with raw materials and products. Rather than paying 38 million dollars are year for dumping the water produced by the ethylene oxide reaction, we believe this water can be dumped at no cost because it is 99.997% water and 0.003% ethylene oxide. Generating significant savings over the course of 10 years. If water treatment was still a concern, it would be recommended to add another separation unit to further treat the water so it could be dumped at no cost, which would be more financially effective than paying 38 million dollars a year for 10 years.

Table 2: Annual revenue from products and cost of raw materials

Material Name	Classification	Price ($/kg)	Flowrate (kg/h)	Annual Cost
Oxygen	Raw Material	$ -	11304.90	$ -
Ethylene	Raw Material	$ 1.49	9348.90	$ 115,768,700
Carbon Dioxide	Non-Hazardous Waste	$ 0.04	6688.00	$ 2,003,671
Ethylene Oxide	Product	$ (1.69)	14636.00	$ (205,477,936)
Water	Product	$ -	128665.00	$ -

Figure 2 provides a detailed breakdown of all assumptions used in generation of the cost to operate the facility. Important values (millions) from Figure 2 include working capital of 15.2, fixed capital investment of 36.15, revenue from sales of 205, and a cost of manufacturing (COMD) of 157. Since the facility is in Shandong Province, the operator labor was significantly reduced from 58,000$ per operator to 4200$. This savings in operator salary allowed the company to save an estimated 13.8x on salaries to operators than if the facility was domestic. With revenue being 205 and COMD being 156, there is a healthy buffer of 48 million leftovers per year to allocate towards payback of initial investment, expansion of new projects, or fluctuations in supply and demand of markets.

Profitability Analysis

Profitability analysis was performed utilizing an excel macro enabled workbook that performed Monte Carlo simulations (MCS) over a variety of discounted and non-discounted profitability metrics. Figure 3 in Appendix A shows the possible variations used in generation of the Monte Carlo Simulations. Figure 4 is a MCS of net present value (NPV). Figure 4 shows an extremely likely outcome of ending with a positive NPV. Figure 4 shows 11/1000 trials had a negative NPV while 717/1000 trials were likely to end in the range of 99.5-182 million. Figure 5 is the discounted payback period MCS (DPBP). Figure 5 ranged from 1.8 to 10 years to payback the initial investment. 861/1000 trials had a payback period between 1.8-2.7 years, illustrating that it would be extremely likely to recuperate capital within the first 3 years, out of the 10-year plant life. Figure 6 is a MCS of cumulative cash position (CCP). Figure 6 illustrates 0/1000 outcomes that could end with a negative CCP. Out of 1000 trials, 828 of them would end in a range of 164-362 million in cash by the end of the project. Figure 7 is a MCS of return on investment (ROI). Figure 7 again has 0 outcomes where the ROI would be negative. 829/1000 outcomes resulted in very strong returns between 48-105%. Figure 8 is a MCS of the discounted cash flow ROI (DCFROI). Even when discounted, Figure 8 has 0 trials where the DCFROI is less than 11%. Out of 1000 trials in figure 8, 799 ended in the range of 41-80% return on investment on a discounted basis. Both discounted and non-discounted profitability metrics show that it is highly probable that the project is viable and will earn a strong return on investment while paying back its initial investment in less than 1/3 of the expected project life.

Tower Optimization Analysis

The optimization of T-702 was performed by simulating the column in the chemical process simulator, Aspen. The base case column was first simulated, which had 90 trays, a reflux of 12.96, and a feed tray of 18. The base case design was quickly found to be extremely excessive, as it ran a reflux ~13 times higher than other columns, while having ~6.5 times more trays and still resulted in the same purity. Figure 9 varies tray size and reflux ratio to determine profit. Profit was measured by determining the value of ethylene oxide flow and subtracting the cost of the condenser and reboiler duty and subtracting the COMD that was measured in the excel macro capital cost workbook.

Table 3: Optimal column design for each tray size and base case

number of trays	feed stage	reflux ratio	condenser duty (GJ/h)	reboiler duty (GJ/h)	etox flow (kmol/h)	Profit (million_dollars/yr)
3	3	6	-56.5336825	67.5197583	302.515596	30.6725
4	3	3	-31.5853785	44.3395957	320.020197	45.7518
5	3	2	-23.4593739	36.5921835	324.0056319	49.5759
6	3	1	-15.6325465	28.7795645	324.1708125	50.9201
7	5	1	-15.6634038	28.8825343	324.9547714	51.4148
8	4	1	-15.6914877	28.9863935	325.79284	51.9446
9	4	1	-15.6967756	29.0047112	325.9368807	52.0357
10	5	1	-15.704194	29.0331454	326.1674225	52.1815
11	5	1	-15.7058101	29.0373072	326.1985384	52.2011
12	5	1	-15.7056472	29.0377605	326.2035061	52.2043
13	5	1	-15.7061084	29.0380735	326.2042691	52.2047
14	5	1	-15.7057307	29.0378971	326.204385	52.2048
90	18	12.96	-109.632578	122.964275	326.204406	37.3399

Economic Optimization of Unit 700 and T-702

Table 3 is the optimal design for each tray count, collected from over 100 different variations of T-702. Figure 9 and Table 3 show that identical flow rates can be achieved running low reflux in a 10-14 tray column and achieve the same purity and flow rate of the high reflux, 90 tray base case column. Running a 14 tray, feed on tray 5, and reflux of 1 saved approximately 15 million dollars over the base case due to the large savings in energy by running a lower reflux. The 15 million dollars savings is likely understated, as the cost of a 14-tray column with 1-foot spacings would also be significantly less than its 90-tray counterpart. Figure 11 and Figure 12 show little impact on profit going beyond tray 13, as the slope in profit vs tray size began to stagnate after tray 10.

Safety Concerns

Producing Ethylene Oxide involves high-temperature and high-pressure conditions, exceeding 200 degrees Celsius and reaching 22 bars. Due to the risk of explosions, a thorough safety approach is crucial. Preventive measures include using pressure relief valves, redundant controllers, and a variety of sensors with alarms. These measures not only protect personnel but also ensure the overall operation's integrity. The reaction is highly exothermic, posing a risk of a runaway scenario. To quickly address this, there's a standby quench gas line ready to suppress any escalating reaction and prevent catastrophic consequences. Due to Ethylene Oxide's flammability and instability, operator competence is vital. All personnel, including delivery staff, undergo comprehensive training to operate equipment safely and ensure secure operations.

Global Issues Awareness

The location for the proposed facility is in Shandong Province, the People's Republic of China. While production in China would be favorable for the company in comparison to the USA, ranging from labor, materials, energy, logistics, regulations. However, the risk of operating in China to save money, may not be worth it if operating in the United States can still be viable. If operations were to be conducted in China, a large premium should be attached to the project to adjust for the risk. The main risk being if China decided to invade Taiwan as Russia did with Ukraine. The issue of Taiwan between China and America has been one of the largest Geopolitical conversations of 2023. If China were to invade Taiwan, the United States has pledged direct military intervention. If the United States and China were to enter a military conflict, this would likely result in any contracts the company had in China, largely unenforceable, products could be difficult to export, and even a total loss of facility by government seizure. Therefore, an analysis should be conducted to see if a location in North America could also be viable, as operating in China could be a complete loss if a conflict was to occur.

Heuristic Optimizations

Ethylene oxide is an epoxide that is very weakly acidic. Almost all the materials of construction for unit 700 are stainless steel. Since the process fluid is weakly acidic, it may be possible to have a less expensive material of construction like carbon steel. Additionally, an electric drive is being used for C-701. Since high pressure steam is being used for multiple other unit operations in unit 700, it may be worthwhile to use a steam turbine as a source of power for the compressor. Steam turbines are also frequently used as spares in case of power failure, so this would be an extra layer of redundancy. Improvement of thermal insulation around heated and cooled processes can be beneficial to reduce overall utility consumption. Thermal insulations such as ceramic linings or mixtures of asbestos and diatomaceous earth for higher temperature insulation, especially around the heat exchangers and R-701

Sincerely,

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Appendix A.

User Added Equipment

Compressors	Compressor Type	Power (kilowatts)	# Spares	MOC	Purchased Equipment Cost	Bare Module Cost	Base Equipment Cost	Base Bare Module Cost
C-701	Centrifugal	1840	0	Carbon Steel	$ 889,000	$ 2,440,000	$ 889,000	$ 2,440,000

Drives	Drive Type	Power (kilowatts)	# Spares	Purchased Equipment Cost	Bare Module Cost	Base Equipment Cost	Base Bare Module Cost
D-701	Electric - Explosion Proof	1940	1	$ 626,000	$ 939,000	$ 626,000	$ 939,000

Exchangers	Exchanger Type	Shell Pressure (barg)	Tube Pressure (barg)	MOC	Area (square meters)	Purchased Equipment Cost	Bare Module Cost	Base Equipment Cost	Base Bare Module Cost
E-701	Floating Head	23	23	Stainless Steel / Stainless Steel	574	$ 495,000	$ 1,090,000	$ 167,000	$ 548,000
E-702	Floating Head	23	23	Stainless Steel / Stainless Steel	502	$ 440,000	$ 971,000	$ 148,000	$ 487,000
E-703	Floating Head	6	6	Stainless Steel / Stainless Steel	700	$ 548,000	$ 1,240,000	$ 201,000	$ 660,000
E-704	Floating Head	6	6	Stainless Steel / Stainless Steel	1050	$ 843,000	$ 1,900,000	$ 308,000	$ 1,010,000
E-705	Floating Head	6	6	Stainless Steel / Stainless Steel	265	$ 245,000	$ 554,000	$ 89,700	$ 295,000

Pump	Type	Power (kilowatts)	# Spares	MOC	Discharge Pressure (barg)	Purchased Equipment Cost	Bare Module Cost	Base Equipment Cost	Base Bare Module Cost
P-701	Centrifugal	15.2	1	Stainless Steel	4.9	$ 43,600	$ 94,900	$ 19,100	$ 61,900

Reactors	Type	Volume (cubic meters)	Purchased Equipment Cost	Bare Module Cost	Base Equipment Cost	Base Bare Module Cost
R-701	Autoclave	129	$ 1,490,000	$ 5,960,000	$ 1,490,000	$ 5,960,000

Towers	Tower Description	Height (meters)	Diameter (meters)	Tower MOC	Demister MOC	Pressure (barg)	Purchased Equipment Cost	Bare Module Cost	Base Equipment Cost	Base Bare Module Cost
T-701	14 meters of 304 Stainless	18.6	3	Stainless Steel		23	$ 4,210,000	$ 7,750,000	$ 228,000	$ 765,000
T-702	12 Stainless Steel Valve Trays	6.23	4	Stainless Steel		23	$ 4,440,000	$ 7,290,000	$ 579,000	$ 920,000

Vessels	Orientation	Length/Height (meters)	Diameter (meters)	MOC	Demister MOC	Pressure (barg)	Purchased Equipment Cost	Bare Module Cost	Base Equipment Cost	Base Bare Module Cost
V-701	Horizontal	8.52	2.13	Stainles Steel		6	$ 224,000	$ 404,000	$ 42,400	$ 128,000
						Totals	**$ 14,493,600**	**$ 30,632,900**	**$ 4,787,200**	**$ 14,213,900**

Figure 1: Equipment and equipment cost of Unit 700

Economic Optimization of Unit 700 and T-702

Economic Options

Cost of Land	$	-
Taxation Rate		30%
Annual Interest Rate		10%
Salvage Value		0
Working Capital	$	15,200,000
FCI_L	$	36,150,000
Total Module Factor		1.18
Grass Roots Factor		0.50

Economic Information Calculated From Given Information

Revenue From Sales	$	205,477,936
C_{RM} (Raw Materials Costs)	$	115,768,700
C_{UT} (Cost of Utilities)	$	6,370,000
C_{WT} (Waste Treatment Costs)	$	-
C_{OL} (Cost of Operating Labor)	$	58,800

Factors Used in Calculation of Cost of Manufacturing (COM_d)

Comd = 0.18*FCIL + 2.76*COL + 1.23*(CUT + CWT + CRM)

Multiplying factor for FCIL		0.18
Multiplying factor for C_{OL}		2.76
Facotrs for C_{UT}, C_{WT}, and C_{RM}		1.23
COM_d	$	156,899,889

Factors Used in Calculation of Working Capital

Working Capital = $A{*}C_{RM} + B{*}FCI_L + C{*}C_{OL}$

A	0.10
B	0.10
C	0.10

Project Life (Years after Startup)	10

Construction period	1

Figure 2: Detailed breakdown of operating cost metrics

Probable Variation of Key Parameters over Plant Life

	Lower Limit	Upper Limit	Base Value
FCIL	-20%	30%	$ 36,150,000
Price of Product	-20%	5%	$ 205,477,936
Working Capital	0%	0%	$ 15,200,000
Income Tax Rate*	0%	0%	30%
Interest Rate*	0%	0%	10%
Raw Material Price	-10%	10%	$ 115,768,700
Salvage Value	0%	0%	0

Figure 3: Variable inputs and variability for Monte Carlo simulation

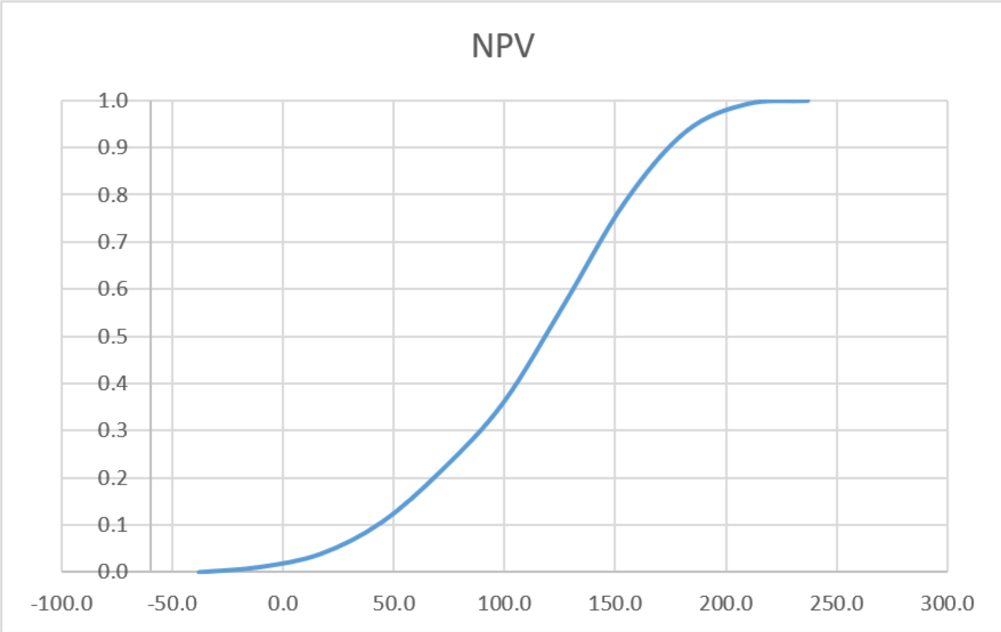

Figure 4: Monte Carlo Simulation, net present value

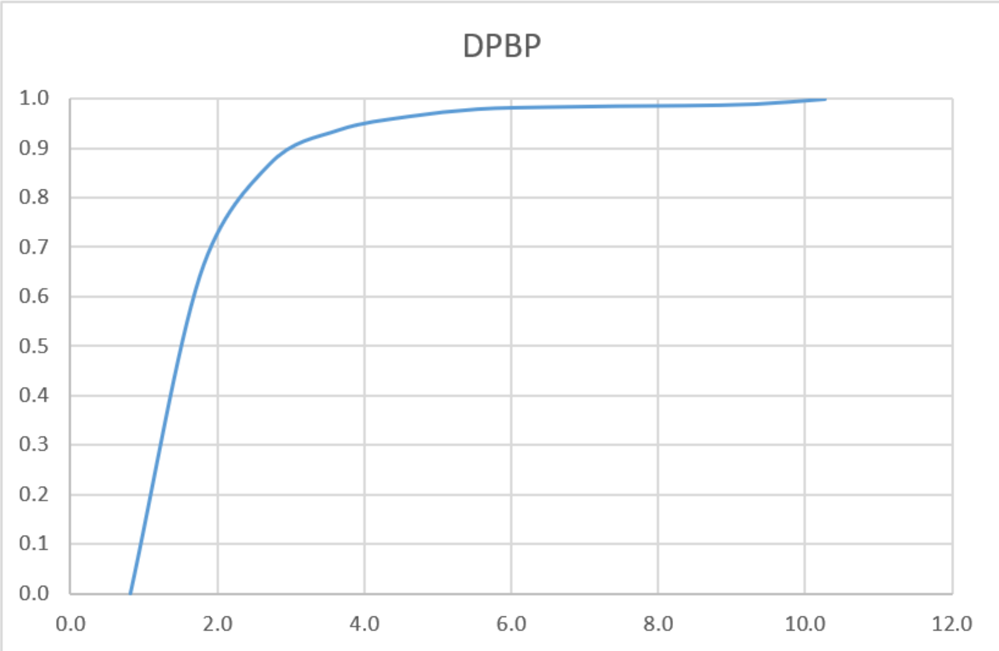

Figure 5: Monte Carlo simulation, discounted payback period

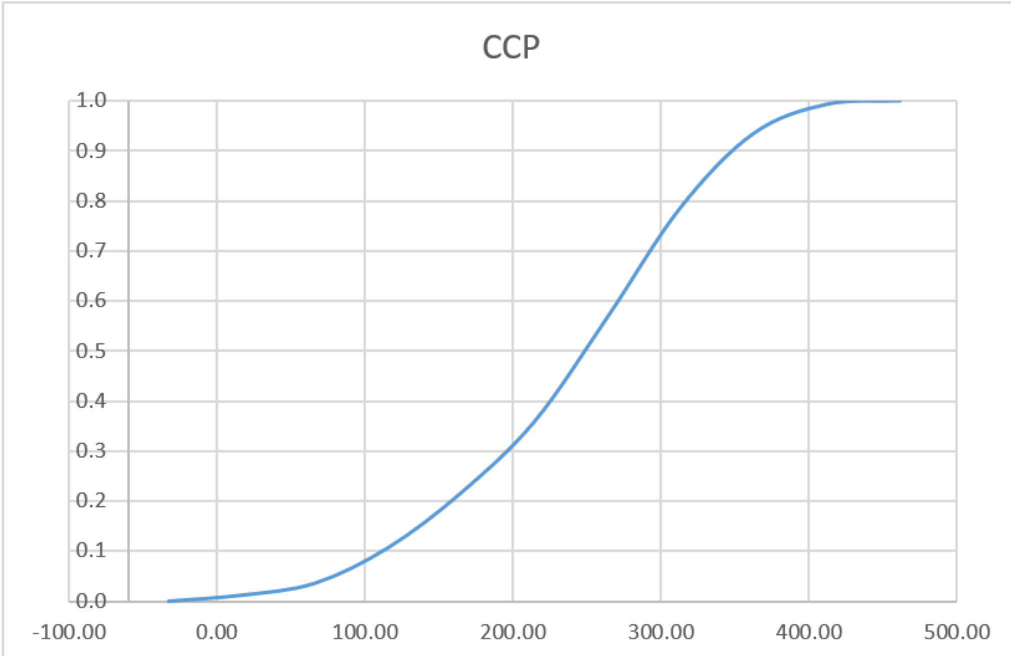

Figure 6: Monte Carlo simulation, cumulative cash position

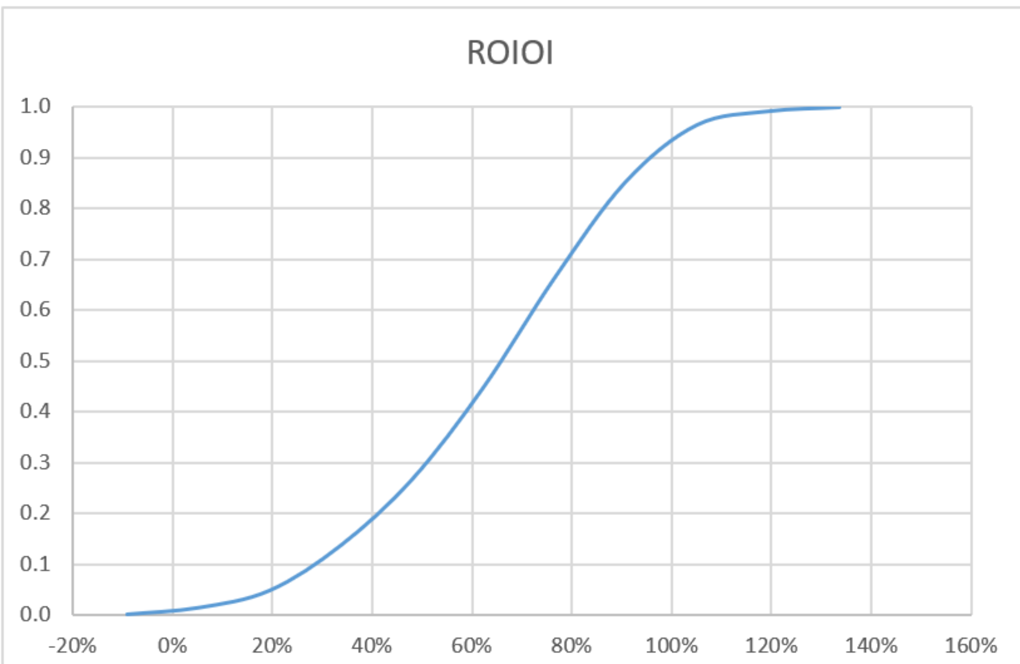

Figure 7: Monte Carlo simulation, return on investment.

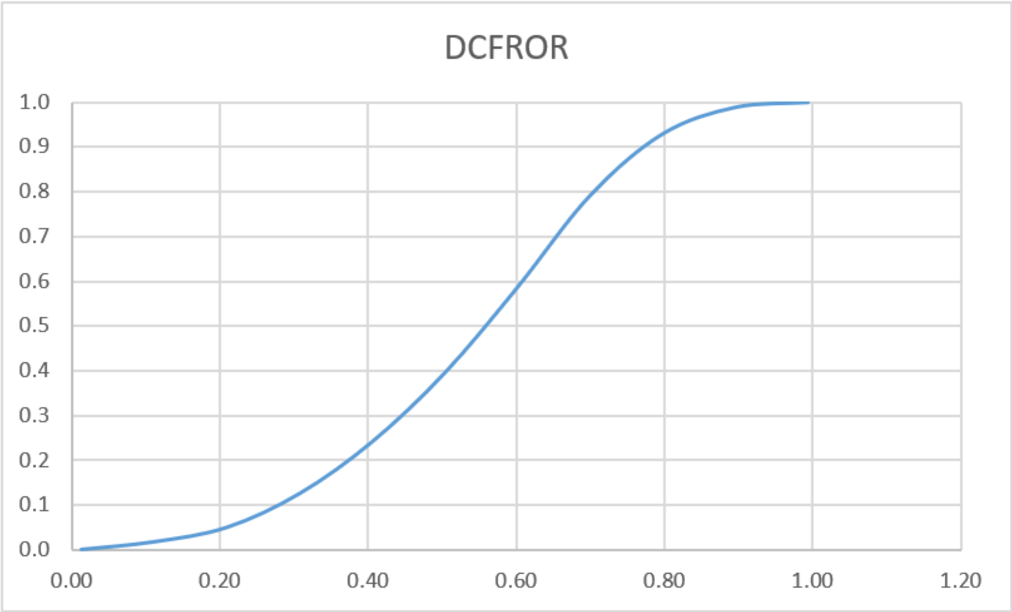

Figure 8: Monte Carlo Simulation, discounted cash flow rate of return

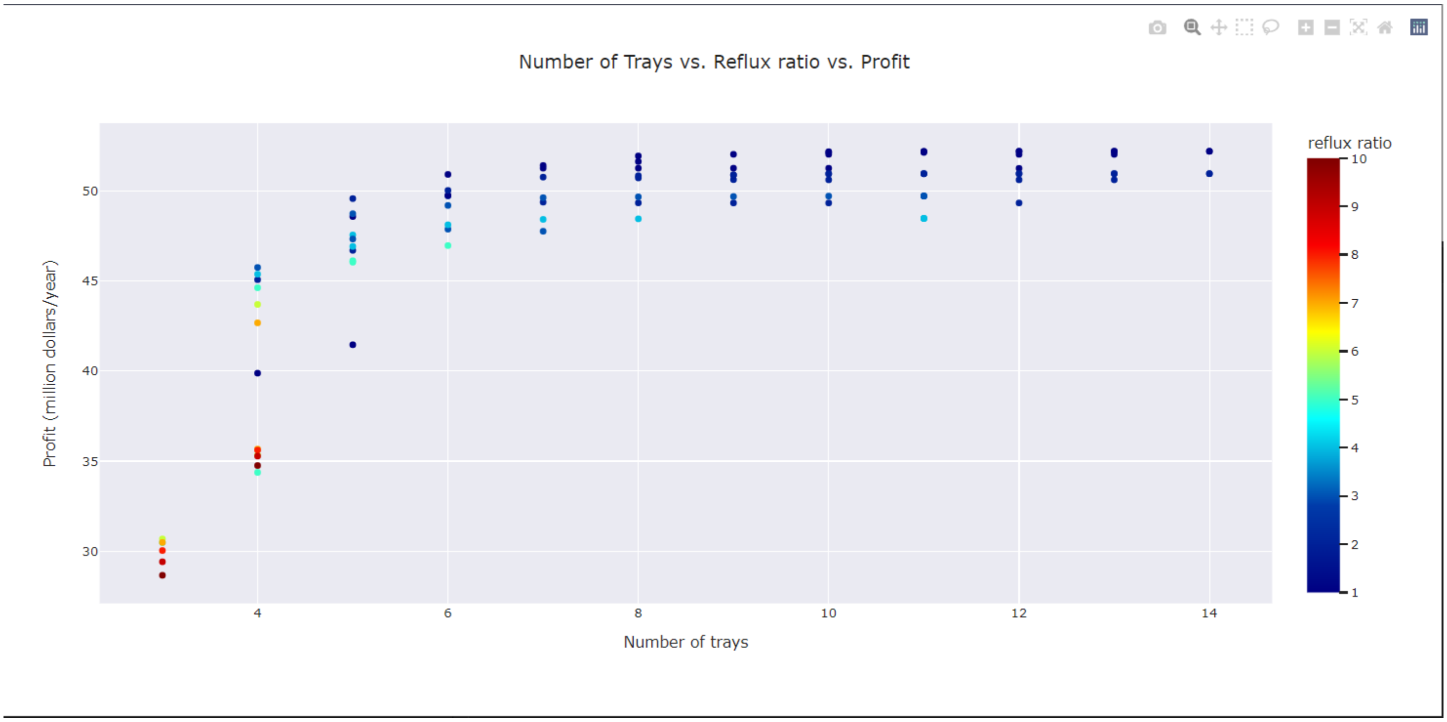

Figure 10: Trays and Reflux ratio impact on Profit

Economic Optimization of Unit 700 and T-702

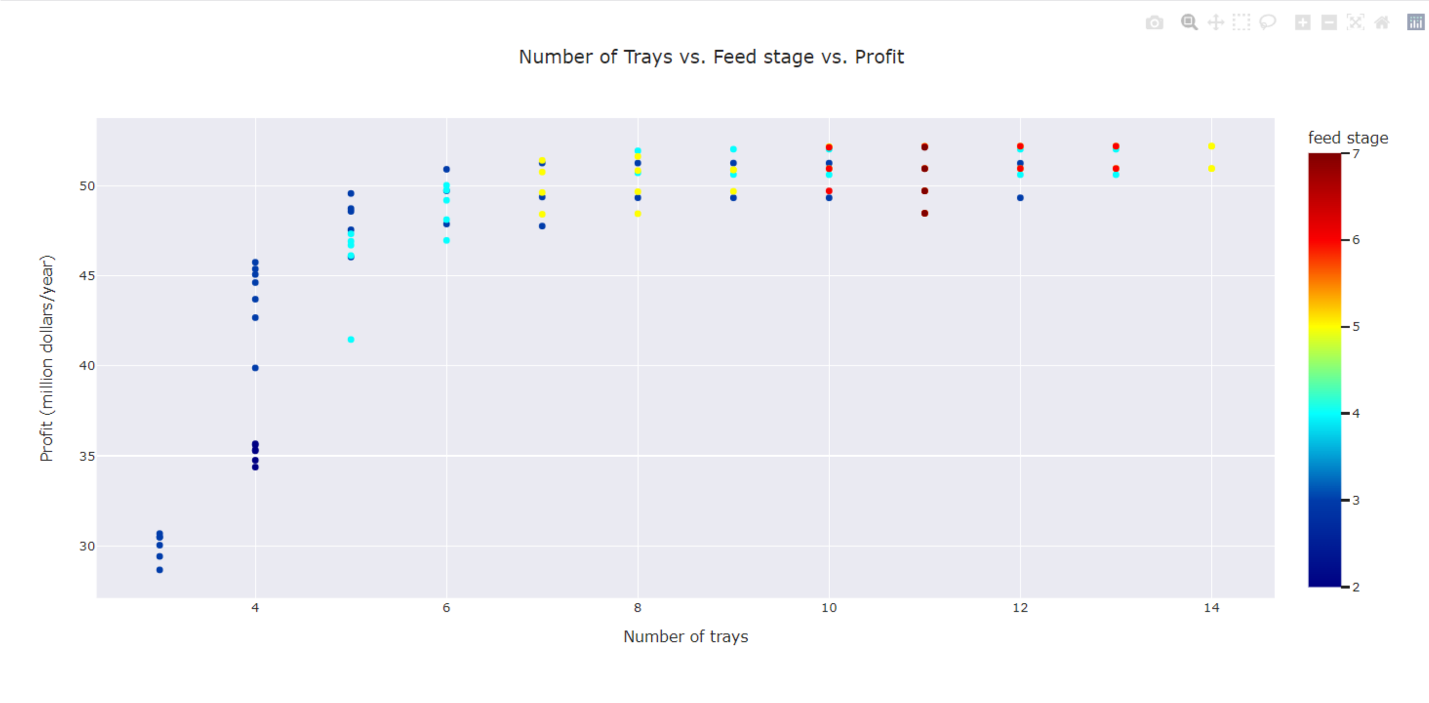

Figure 9: Trays and feed trays impact on Profit

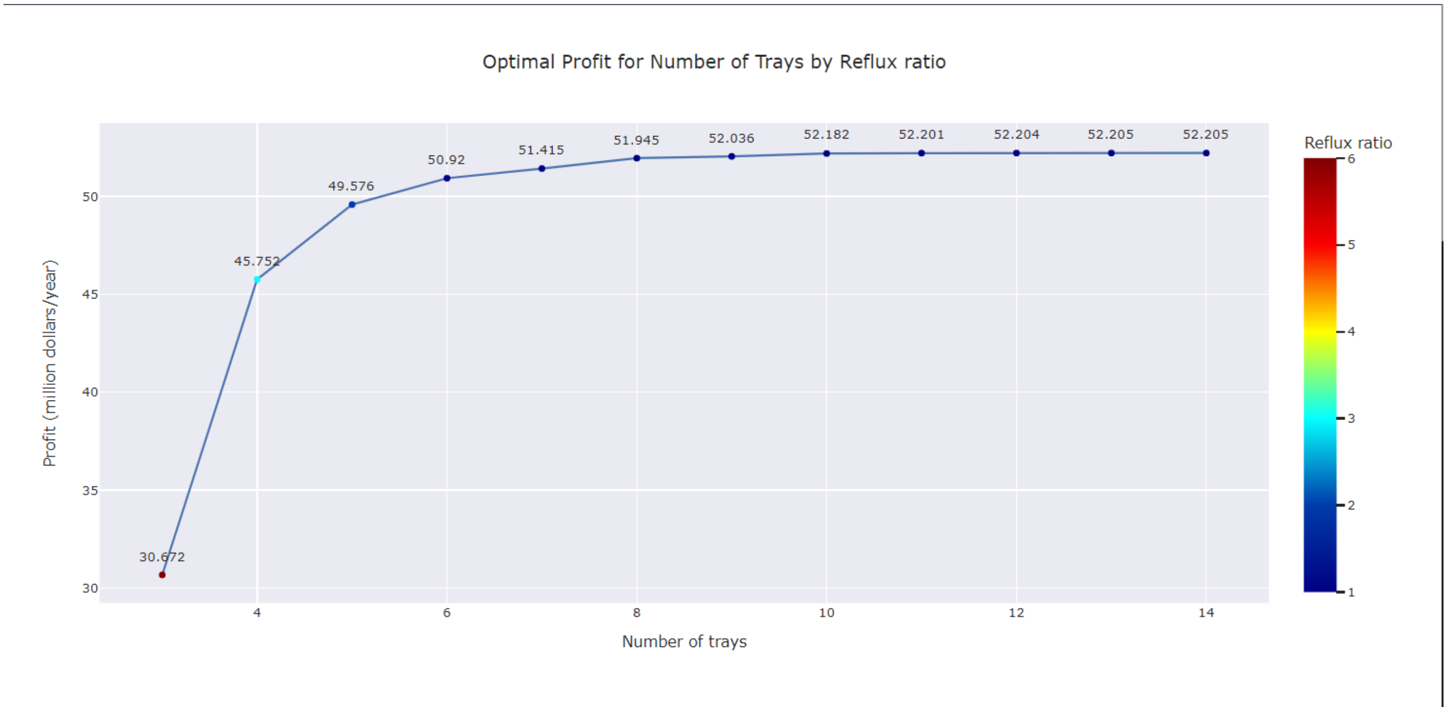

Figure 11: Optimal Profit for each number of trays by reflux ratio

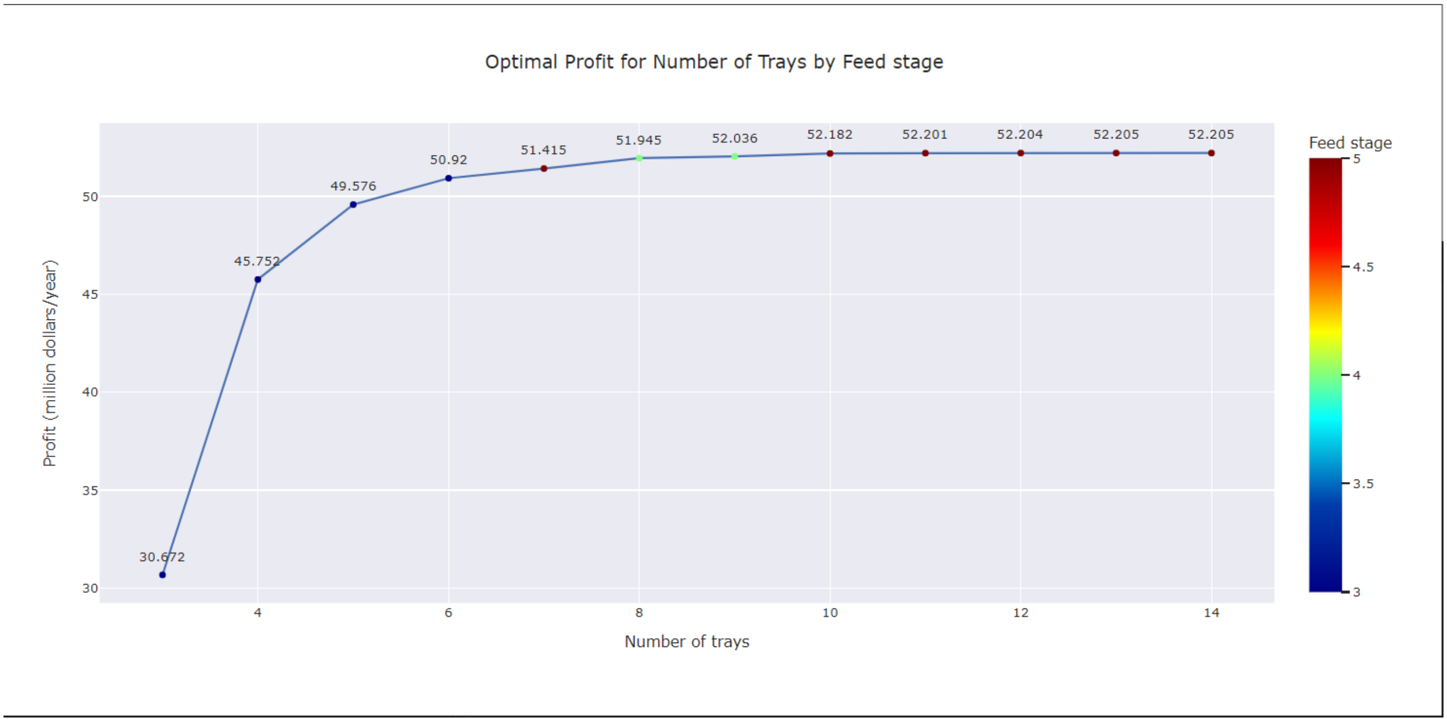

Figure 12: Optimal Profit for each number of trays by feed tray

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