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ECONOMIC FEASIBILITY OF A METHANOL TO DIMETHYL ETHER PRODUCTION PROCESS TO AVOID CONTRACT FAILURE SHORTFALLS FROM THE COVID-19 PANDEMIC

By

Harrison Patrick McKinnis, Jacob Philip Noll, and Robert George Wasson

A thesis submitted to the faculty of The University of Mississippi in partial fulfillment of the requirements of the Sally McDonnell Barksdale Honors College.

Oxford, MS

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Approved By

Advisor: Dr. Adam Smith

Reader: Professor David Carroll

Reader: Professor Mike Gill

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ABSTRACT

Our team entered the 2021 AVEVA Academic Competition, where teams of undergraduate senior chemical engineering students competed across the country. The competition was composed of two parts: the base case design and the optimization of a chemical process. As part of the competition, our team is acting as the Engineering team for a fictional company that has given us this project. Due to COVID-19, our methanol producing company has lost a contract with a customer, leaving 23,000 tonnes/yr of unclaimed methanol. We have two choices with this methanol: either sell the methanol on the market at the spot price for a loss, or turn the methanol into DME and sell this instead. This leads us to the first phase of the competition: the base case design of the proposed methanol to DME process.

The base case consists of five heat exchangers, a reactor, and a distillation column. At the conclusion of this design phase, our team concluded that the methanol to DME process was viable and able to deliver DME at the required purity, as well as found the minimum equivalent annual operating cost of the distillation column used for this process. From this, our Engineering team moved on the second phase of the competition: the optimization of the methanol to DME process. In this phase, our team was tasked with finding the best combination of available equipment rentals from a Toller, all of which had fixed dimensions and operational constraints. Our team used Toller's equipment to make nine different equipment combinations, and determined that Reactor B and Column A were the best combination, giving the lowest annual operating cost of $688,000 (this value includes utilities and equipment rental fees). Using this combination, our team then performed a detailed economic analysis and considered process safety with the future set-up and running of this process. In the end, our Engineering team concluded that our company should indeed move forward with the methanol to DME process, since it can reduce profit loss from selling methanol at the contract price by approximately $4 million, turning a profit of $1 million for the company.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ABBREVIATIONS

DME	Dimethyl ether
EAOC	Equivalent annual operating cost
OC	Operating cost
CI	Capital investment
mo	Month
No.	Number
HPS	High pressure steam
MPS	Medium pressure steam
LPS	Low pressure steam
GJ	Gigajoule
kg	Kilogram
Hr	Hour
kmol	Kilomole
kW	Kilowatt
NFPA	National Fire Protection Association
EPA	Environmental Protection Agency
MARR	Minimum acceptable rate of return
NPV	Net present value
MeOH	Methanol

CHAPTER 1: INTRODUCTION TO PROCESS DESIGN AND OPTIMIZATION

This project was a design and optimization competition run by AVEVA, a chemical process simulation software developer. As described in the Executive Summary, the team was tasked with designing and optimizing a process to convert methanol to dimethyl ether and then analyzing the process economics to make a business recommendation on how to proceed. Before presenting the Executive Summary, it is important to understand the basics of chemical engineering process design and optimization.

Chemical engineering process design at its most basic level involves determining a desired product to be made from given raw materials and identifying the essential pieces of equipment required to achieve the desired production. Following this, any constraints on the process are identified such as desired rates of production; operating limitations such as temperature and pressure; and additional desired values such as ratios. These constraints also impact the size and sequence of equipment as they are placed throughout the chemical process, giving further limitations in the freedom of designing a process. Once these constraints on the process and pieces of equipment have been established, an engineering team will move forward with identifying operating conditions that will deliver the required production without violating any constraints. This first set of operating conditions is known as the base case and provides a starting point for further exploration of the process. Utilizing the base case, the required equipment can be sized using heuristics and then priced based on empirical correlations. After the equipment has been priced, an economic analysis of the process can be conducted to determine if the base case is worth further consideration. The base case design is critical part of the design process.

Process optimization begins with a completed base case design and then attempts to improve the process based on an objective function of interest such as net present value (NPV). Often the objective function is an economic variable such as minimizing a cost or maximizing a profit, although the objective function could be a number of different things. After identifying the objective function, an optimization strategy is developed based on the process. Typically, topographic optimization, or the rearrangement of process units, is considered first. After optimization, operating conditions in the process can be adjusted to further optimize the objective function. However, it is important that any constraints identified and met in the base case must be met or improved in the optimized solution.

CHAPTER 2: EXECUTIVE SUMMARY

Introduction

The sudden onset of the COVID-19 pandemic has left many companies, including some of our customers, facing economic downturns. The price of methanol has been declining for the past two years, likely attributed to a decreased demand in methanol due to low oil prices and the slowing of global trade due to the economic crisis brought upon by COVID-19. The pandemic has affected one of our methanol customers, who has chosen not to renew their methanol contract. After discussions with the business side of the company, we believe that a price rebound and the acquiring of a new contract would be possible, at the minimum, two years from now. This leaves our company with an excess production of 23,000 metric tons of methanol per year, which was worth approximately $8 million at the contract price. At the spot price, however, it is only worth $5.2 million – a significant reduction in the company's potential profits.

Our company has several options to solve this problem, and this team was tasked with analyzing options to recover lost profit and recommend the best option among taking a loss by selling the methanol at the spot price, or creating a new process to turn the unused methanol to DME and sell the DME instead. Establishing a new methanol contract is the company's long-term objective, but this has been deemed unlikely to occur in the next two years. One solution is to sell the excess methanol at the spot price;

however, the spot price is currently below the methanol's production cost and is likely to fluctuate. The contract and spot prices have been on a steady decline in the past two years. In 2018, the methanol was worth $11.5 million at the contract price versus $8.6 million at the spot price. This is in comparison to today, where it is worth $8 million at the old contract price versus $5.2 million at the spot price. This spot price is likely to continue dropping until a resurgence in the methanol market, once the pandemic passes. An alternative solution is to convert the excess methanol to dimethyl ether (DME), for which a shortage exists in the local market. Instead of selling the methanol at the spot price for $5.2 million, the company could convert it to an equivalent amount of DME, which would be worth $13.7 million.

The Engineering team is hesitant to commit capital resources for a permanent DME operation, so equipment for the DME process would be rented from the Toller and would require additional funds for equipment and operations. The Engineering team sought to determine feasibility and the economic viability of the DME process. The team gathered necessary information regarding the DME specifications required for market and equipment specifications from the Toller to produce an economically viable process that would minimize the profit loss caused by the COVID-19 pandemic. The optimal solution for the available equipment and the methods used to determine this solution are described in detail below. It was determined that this solution was a feasible and economically viable process, so the team will now move forward with production plans.

Base Case

The first phase of the project was to determine if the production of DME from methanol was feasible and economically viable by developing a simulated model of the required process. This was completed using a preliminary process flow diagram and AVEVA Process Simulation, a chemical process simulation software. The preliminary model of the DME process required several major pieces of equipment including heat exchangers, an adiabatic, catalytic, gas-phase reactor, and a DME distillation column. The adiabatic, catalytic reactor reacts two methanol molecules to form DME and water. The distillation column separates the DME from un-reacted methanol and wastewater to deliver the DME product as a 99.5 wt% DME liquid saturated at 30°C. The remaining wastewater and un-reacted methanol are sent to our pre-existing methanol and wastewater separation portion of the plant, which has extra capacity. The un-reacted methanol is recycled into the methanol to DME process, and the wastewater is removed from the system. The final DME product purity is dictated by customer specifications, and the main piece of equipment that controls the purity of the final product is the DME distillation column.

After the preliminary process was modeled in AVEVA Process Simulation, the DME distillation column was optimized while maintaining the product specifications. The equivalent annual operating cost (EAOC) of the column, including the reboiler and condense, was the objective to minimize in optimization. The EAOC is made of up two major components, annual operating cost (OC) and capital investment (CI), for the column, reboiler, and condenser. The OC depended on the utilities and the rate of utility usage for the reboiler and condenser. The CI depended on a pressure factor, material factor, and the purchase cost of the equipment. The purchase cost of the condenser and reboiler was based on heat transfer area, the tower was priced based on volume, and the trays in the tower were priced based on area. The process of optimization balanced the tradeoffs between OC and CI to achieve the lowest possible EAOC for the distillation column that was still able to meet the required DME purity specifications.

The optimization of the base case provided the Engineering team with a range of equipment specifications that could be used to deliver the DME at the desired conditions. However, there were various constraints that had to be met to provide a feasible solution. The first constraint was that the flooding on the individual trays within the column must be between thirty and eighty percent; this is used to ensure that there was adequate vapor-liquid contact throughout the column. The second additional constraint was that the reactor must have a length to diameter ratio between 3:1 and 8:1, to ensure there is sufficient space to perform the reaction. The DME distillation column was optimized by varying the number of stages, the reflux ratio, and the feed tray location. The minimum EAOC of the DME distillation column occurs in a column with seven trays with the feed located on seventh tray operating with a reflux ratio of 0.67. The seventh, or bottom, tray was determined to be the best feed tray because the feed stream quality most closely matched the quality of the bottom tray, making for the most efficient separation. The optimized base case showed that the DME production process was feasible. Additionally, while the building and purchasing of custom equipment is possible, it is desired to keep this methanol to DME process a short-term project. Thus, the Engineering team began an investigation into designing and optimizing the DME process using Toller rental equipment.

Optimization Challenges

In the next phase of the project, the engineering team re-designed the methanol to DME process to fit with the Toller's available equipment. It is important to distinguish the difference between the base case design and the next phase of design. In the base case design, the Engineering team chose the process conditions - such as the stream temperature and quality - and determined the equipment sizes required to produce these operating conditions. The opposite is true in the next stage of the design process. Here, the Engineering team had fixed equipment sizes and had to determine the operating conditions to work with these fixed pieces of equipment. From this, the equipment was the constraining factor as the Engineering team moved forward in the design and optimization of the DME process.

After discussing the base case design of the DME process with the Toller, the Toller sent following list of equipment to the Engineering team, shown in *Table 1*.

Table 1: Available Equipment from Toller

Reactors	**Length (m)**	**Diameter (m)**	**Max Op Temp (°C)**	**Max Op Pressure (bar)**	**Catalyst Volume (m^3)**	**Rental Cost ($/mo)**
Reactor A	5	1	400	12	3.93	10.0k
Reactor B	4	0.8	400	12	2.00	6.31k
Reactor C	7	1.4	400	12	10.74	20.3k
Columns	**Length (m)**	**Diameter (m)**	**Max Op Temp (°C)**	**Max Op Pressure (bar)**	**No. of Valve Trays**	**Rental Cost ($/mo)**
Column A	9	0.5	300	11	20	5.8k
Column B	10	0.6	300	7	24	7.9k
Column C	10	0.8	300	15	24	11.9k
Heat Exchangers	**Area (m^2)**	**Max – Tube P(bar)/ T(°C)**	**Max – Shell P(bar)/ T(°C)**	**Configuration Shell-pass**	**Tube-pass**	**Rental Cost ($/mo)**
Exchanger A	125	15/150	15/150	1	2	5.9k
Exchanger B	90	15/300	50/300	1	2	4.5k
Exchanger C	60	15/150	15/400	1	2	3.7k
Exchanger D	40	20/300	15/180	1	1	3.4k
Exchanger E	180	20/300	50/300	1	2	6.7k
Exchanger F	100	15/150	15/150	2	4	6.1k
Exchanger G	20	20/300	15/180	1	1	1.1k
Exchanger H	150	50/300	15/300	1	1	6.1k

As seen in *Table 1*, the available equipment varied significantly in terms of dimensions and operating conditions. The team recognized the importance in considering the maximum temperature and pressure constraints of each piece of equipment to ensure safe operation. This was particularly important in the heat exchanger network topography, or placement, throughout the chemical process. It is vital for safety concerns to ensure that at no point in the chemical process the heat exchangers come close to these maximum constraints. Another constraint the team considered was the fact that the process temperatures and outlet stream qualities were fixed by the heat exchanger areas and the utilities used. In the base case, the team had the freedom to manipulate these values by changing the heat exchanger areas, but that was no longer possible with the fixed dimensions provided by the Toller.

Optimization Strategy

With the above challenges in mind, the Engineering team developed the optimization strategy detailed below, which consists of several key tasks followed in a stepwise manner. First, the team designed a working simulation in AVEVA Process Simulation for each Toller reactor and column combination, a total of nine simulations. Second, while considering the heat exchanger network topography limitations, the team input the available Toller heat exchangers throughout the chemical process.

As an example of this consideration, refer to the reactor effluent cooler, or heat exchanger E-103, on *Figure 1*. The reactor effluent comes out at a temperature that exceeds 300 °C, and only one heat exchanger can handle temperatures greater than this, which is Exchanger C (as listed in *Table 1*). A reduction of the reactor effluent temperature was explored in order to open up possibilities for other heat exchangers, however, the desired level of purity in the product DME was able to be reached at lower temperatures. Therefore, Exchanger C must be positioned in E-103, removing it from the choice of available heat exchangers to be utilized elsewhere. For another example, see E-102 on *Figure 1*. This heat exchanger uses high pressure stream (HPS) as the utility, which is fed at a pressure of 47 bar. From Table 1, only two heat exchangers can handle a pressure of this magnitude on the shell side, which is the side the Engineering team chose the utility to be fed since it is easier to handle fouling issues from a tube-side process fluid, due to the corrosive nature of the process fluid. Thus, one of these two heat exchangers, Exchanger B or Exchanger E, had to be placed in E-102, removing one of these for consideration elsewhere in the process.

After the heat transfer requirements of the process had been fulfilled, the team moved to the third step: writing the custom economic model in AVEVA Process Simulation. This model calculated the hourly utility cost of running the chemical process. This value served as a metric for the team to focus on minimizing in the optimization of the process, since the lower the hourly utility cost, the more economically viable the process is. To verify the accuracy of the model in the software and to perform consistent quality checks on the team's work, the team also created an economic model in Microsoft Excel to ensure that both models gave the same result. In the fourth step of the optimization process, the team used the optimization function within AVEVA Process Simulation to minimize the hourly utility cost by changing the methanol feed pump pressure and the distillation column inlet pressure. At this stage in the process, these two parameters were the two remaining significant values the team had the freedom to change, as the remainder of the process parameters are fixed by the equipment sizing and utilities used, as discussed in the Optimization Challenges section.

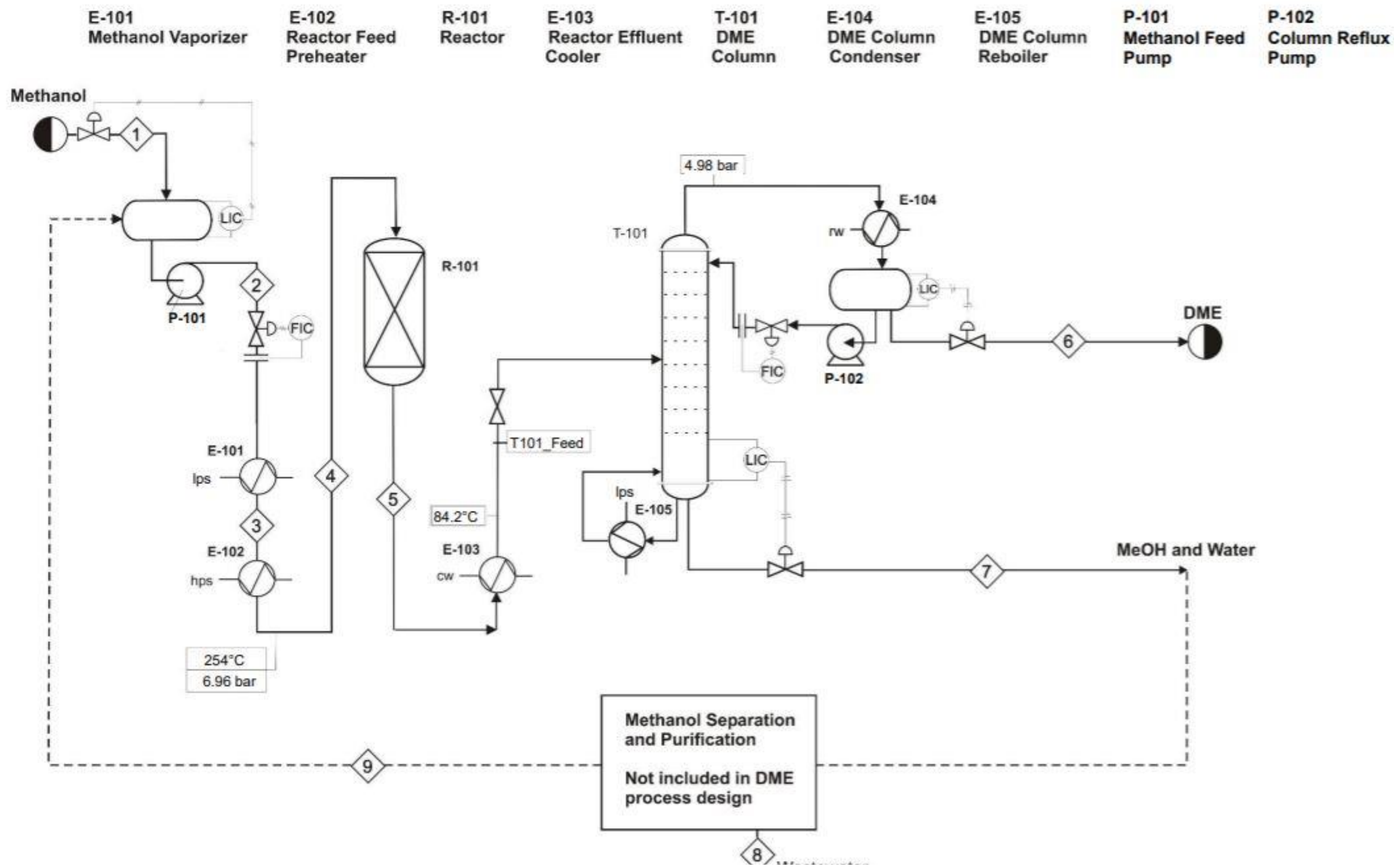

Figure 1: Process Flow Diagram for Optimized DME Solution

Once the utility cost was minimized within AVEVA, utility substitutions and process safety were considered by the Engineering team. For an example on these considerations, see the reboiler on *Figure 1*, or heat exchanger E-105. For the base case, this reboiler utilized medium pressure steam (MPS) as the utility. In some of the nine simulations, the team determined it was possible to substitute low pressure steam (LPS) for the MPS utility in the reboiler. This is beneficial for two reasons. First, LPS operates at 150°C and 4.76 bar, while MPS operates at 180°C and 10.03 bar. LPS is at a lower temperature and pressure than MPS, making it an inherently safer utility to use. The second reason as to the benefit of this substitution is that LPS is a cheaper utility to use than MPS ($9.45/1000 kg versus $9.54/1000 kg), which will lower the hourly utility cost and make the process more economically viable.

Next, the team re-evaluated the heat exchanger network after making utility substitutions, to determine if further reductions in price were possible. In reference to the reboiler example, when LPS was substituted for MPS, the team was able to use a smaller heat exchanger for the reboiler. Previously with MPS, the team had to use a larger, more expensive heat exchanger to not violate the maximum temperature constraint (as seen in *Table 1*, many of the smaller heat exchangers have a maximum temperature of 180°C or lower). With the change to LPS as the utility, the team was able to use a smaller heat exchanger, and therefore cheaper heat exchanger, since this maximum temperature was no longer in violation with a lower temperature utility. After this re-evaluation, the final step in the Engineering team's optimization strategy was to determine appropriate costs for each of the nine combinations created, in terms of the yearly utility cost and the yearly equipment rental cost. These costs have been detailed in *Tables 2 and 3* below, respectively.

Table 2: Yearly Utility Costs for the 9 Combinations

		Reactor		
		A	**B**	**C**
Column	**A**	$ 366,000	**$ 310,000**	$ 369,000
	B	$ 398,000	$ 365,000	$ 397,000
	C	$ 566,000	$ 502,000	$ 554,000

Table 3: Yearly Equipment Rental Costs for the 9 Combinations

		Reactor		
		A	**B**	**C**
Column	**A**	$ 482,000	**$ 378,000**	$ 606,000
	B	$ 540,000	$ 493,000	$ 664,000
	C	$ 588,000	$ 511,000	$ 712,000

As seen in *Tables 2 and 3*, Reactor B paired with Column A has both the lowest yearly utility costs and the lowest yearly rental costs. Reactor B paired with Column A is the lowest cost option overall with a total annual cost of approximately $688,000. Reactor B and Column A was then used as the basis for further economic analysis versus the alternative solutions.

Optimized Solution

As discussed above, Reactor B with Column A is the most economically viable set of the nine sets created by the Engineering team. The stream table, equipment summary, and utility summary for this optimized solution are displayed below in *Tables 4, 5, and 6* respectively.

Table 4: Stream Table for Optimized Solution

	S1	S2	S3	S4	S5
Temperature (˚C)	30.00	30.14	123.53	254.00	380.38
Pressure (bar)	1.01	7.36	7.26	6.96	6.79
Mass Flow (kg/hr)	2662.04	3161.91	3161.91	3161.91	3161.91
Molar Flow (kmol/hr)	83.15	98.76	98.76	98.76	98.76
Component Flows					
H_2O (kmol/hr)	0.15	0.18	0.18	0.18	41.53
Methanol (kmol/hr)	83.00	98.58	98.58	98.58	15.88
DME (kmol/hr)	0.00	0.00	0.00	0.00	41.35

	T101_Feed	S6	S7	S8	S9
Temperature (˚C)	84.16	18.55	129.22	65.38	30.12
Pressure (bar)	6.69	4.88	5.06	5.06	1.01
Mass Flow (kg/hr)	3161.91	1914.54	1247.37	747.50	499.87
Molar Flow (kmol/hr)	98.76	41.66	57.10	41.49	15.61
Component Flows					
H_2O (kmol/hr)	41.53	0.01	41.52	41.49	0.03
Methanol (kmol/hr)	15.88	0.29	15.58	0.00	15.58
DME (kmol/hr)	41.35	41.35	0.00	0.00	0.00

Table 5: Equipment Summary for Optimized Solution

Equipment on PFD	Toller's Equipment	Yearly Rental Cost	Yearly Utility Cost
R-101	Reactor B	$76,000	-
T-101	Column A	$70,000	-
E-101	Exchanger D	$41,000	$146,000
E-102	Exchanger E	$80,000	$73,000
E-103	Exchanger C	$44,000	$13,000
E-104	Exchanger B	$54,000	$62,000
E-105	Exchanger G	$13,000	$16,000
	Yearly Costs:	$378,000	$310,000
	Overall Yearly Cost:	$688,000	

Table 6: Utility Summary for Optimized Solution

Equipment on PFD	Utility Used	Quantity of Utility (kW)	Yearly Utility Cost
P-101	Electricity	1.02	$1000
P-102	Electricity	5.65×10^{-5}	$0
E-101	Low Pressure Steam	1032.77	$146,000
E-102	High Pressure Steam	413.07	$73,000
E-103	Cooling Water	1066.67	$12,000
E-104	Refrigerated Water	418.45	$62,000
E-105	Low Pressure Steam	111.65	$16,000

From the equipment sizes given in *Table 1* in Optimization Challenges, it is clear why Reactor B and Column A is the most economically viable set, in that both Reactor B and Column A are the smallest out of their respective three options from the Toller, which also translates to having the lowest monthly rental cost out of the options. Furthermore, the Engineering team was able to utilize the four smallest heat exchangers, as seen in *Table 5,* which leads to further reduction in the monthly rental cost of this set. The fifth smallest heat exchanger could not be used, since using it in the place of E-102 would violate the maximum pressure constraint of said exchanger, the details of which are discussed in the Optimization Strategy.

In terms of utilities, the Engineering team was able to substitute LPS for MPS in E-105, leading to a reduction in the overall utility cost. Additionally, as seen in *Table 6*, the Engineering team was able to optimize the process in such a way that the utility requirements of P-102 were essentially negligible, leading to further reductions in the hourly utility costs of the process. The combination of all the above substitutions and choices of equipment contributed to the Engineering team’s determination that Reactor B and Column A is the most economically viable set and should be used moving forward.

Process Safety

The Engineering team recognizes that process safety management should remain at the core of all company operations. The undertaking of the methanol to dimethyl ether process presents multiple safety considerations and challenges that are addressed in this section of the executive summary. Notable among these considerations are the risk of rental equipment, process hazards that arise from pressurized equipment, and chemical hazards of raw materials and products.

All major equipment for the dimethyl ether production process would be rented from a Toller. While the communicated optimized solution is certainly preferred, safety issues with possible rental equipment may disqualify specific units from use in the process. The Engineering team recommends equipment reinspection of the Toller's available units to confirm certifications before signing any agreement to avoid unnecessary costs or delays in project implementation.

One important note for equipment inspection is that inadequate conditions of different units will have various consequences for the viability and economic success of the project. For example, each of the nine reactor-column combinations is economically viable with their optimal heat exchanger topography as discussed in the previous section. However, inadequate condition for some heat exchangers may sacrifice the viability of all combinations. For example, Heat Exchanger C is the only one that can withstand the high reactor effluent temperatures. If this exchanger cannot be used, then all combinations are no longer viable. Two options exist from here if DME production process is desired. First, a different Toller may provide the needed equipment, but this option would then involve a new economic analysis. Second, a heat exchanger could be purchased for this application, but this will require more upfront capital investment. One of these two steps would be necessary in order to move forward in this process while still maintaining the high safety requirements.

As a further safety consideration, both the reactor and column used for dimethyl ether production will operate under high pressure. While the operation pressure for the optimized set is well below the rated maximum allowable working pressure for both the reactor and column, risks associated with non-ambient pressure operation still exist. The Engineering team acknowledges the need for pressure relief systems on both units; however, the specific design of these systems is beyond the scope of this project.

Finally, process and chemical hazards arise from the physical properties of both methanol and dimethyl ether. Notable among such hazards is high flammability. According to CAMEO Chemicals, methanol and dimethyl ether have flammability values of 3 and 4, respectively, on the NFPA Fire Diamond. Dimethyl ether also has a health risk value of 2 due to loss of consciousness and other senses through inhalation. Both chemicals are heavily regulated by the EPA (methanol in particular), with the storage and transportation of said chemicals receiving particular attention from current federal guidelines. The rental of new equipment, startup of a new process, and handling of new chemicals will require extensive management of change documentation to ensure safe operation.

Economic Analysis

A cash flow analysis of each of the nine optimized sets was performed to determine the order in which the sets should be selected. The income statement for this cash flow analysis on the optimized set containing Reactor B and Column A is shown in

Figure 2. The cash flow analysis assumed a minimum acceptable rate of return (MARR) of 12% and a project lifespan of two years. As seen in *Figure 2*, there is no investment activity because the company already owns the land and buildings where the process will be. There is no capital investment required for equipment purchase because the equipment is being rented from the Toller. The working capital cost included 6 months of labor costs and 3 months of raw material costs. Additionally, the project will begin in 2022, to give ample time to install and set-up the process. The years preceding 2022 in Figure 2 are there to stay consistent with the format of a traditional economic model and analysis, despite the fact that there are no investment activities in these years.

		2019	2020	2021	2022	2023
End of Year		-2	-1	0	1	2
Income Statement						
Revenue					$13,729,549	$13,729,549
Expenses	Inflation					
Materials (C_{RM})	0%				(6,900,008)	(6,900,008)
Catalyst (C_{Cat})	0%			-		
Equipment Rental (C_{rent})	0%				(378,120)	(378,120)
Labor (C_{OL})	3%				(1,167,000)	(1,202,010)
Utilities (C_{UT})	0%				(309,608)	(309,608)
Waste Treatment (C_{WT})	0%				-	-
Other (C_{OT})					(3,677,122)	(3,737,689)
Depreciation						
Land Depreciation					-	-
Land (BV)				$0	-	-
Building Depreciation					-	-
Bldg BV				$0	-	-
		MACRS Bldg			2.4573%	2.5641%
Equipment Depreciation					-	-
Equipment BV				$0	-	-
		MACRS Equp			14.29%	24.49%
Taxable Income / (Loss)			-	-	1,297,691	1,202,114
Income Taxes	28%			0	(363,354)	(336,592)
Net Income / (Loss)				-	**934,337**	**865,522**
Cash Flow Statement						
Operating Activities						
Net Income / (Loss)		$0	$0	-	$934,337	$865,522
Depreciation					-	-
Investment Activities						
Land						
Purchase		-				
Sale						
Book Value						
Taxable Gain/(Loss)						
Taxes						
Net Gain/(Loss)						
Net Cash Flow		-				
Buildings						
Purchase			-	-		
Sale						
Book Value						
Taxable Gain/(Loss)						
Taxes						
Net Gain/(Loss)						
Net Cash Flow			-	-		
Equipment						
Purchase			-	-		
Sale						
Book Value						
Taxable Gain/(Loss)						
Taxes						
Net Gain/(Loss)						
Net Cash Flow			-	-		
Financing Activities						
Working Capital				(2,308,502)	-	2,308,502
Net Cash Flow		-	-	**(2,308,502)**	**934,337**	**3,174,024**
Cumulative Cash Flow		-	-	(2,308,502)	(1,374,165)	1,799,859
Payback Calc Conv						1.433
PV @ S/U (12.0%MARR)		-	-	(2,308,502)	834,230	2,530,312
Cumul Discounted CF		-	-	(2,308,502)	(1,474,272)	1,056,040
Payback Calc Disc						1.583

Figure 2: Income and Cash Flow Statement for Optimized Case

Table 7 shows the net present value (NPV) of each set using the Excel cash flow template shown in *Figure 2*. As previously discussed, Reactor B with Column A yielded the greatest NPV at 2 years, and all further economic analysis was performed using this set of equipment.

Table 7: NPV of Viable Sets at 12% MARR over a 2 Year Project Lifespan

Rank	Reactor	Column	NPV @ 12%
1	B	A	$1,056,000
2	A	A	$842,000
3	B	B	$831,000
4	A	B	$725,000
5	C	A	$688,000
6	B	C	$602,000
7	C	B	$577,000
8	A	C	$415,000
9	C	C	$283,000

As shown in *Figure 3*, the NPV of the DME process utilizing Reactor B and Column A is preferential to selling methanol at the spot price at all project lifespans. Even if the sale price of DME decreased by 20% (also shown on *Figure 3*), it would still be preferential to convert methanol to DME instead of selling methanol at the spot price. Additionally, it should be noted that as seen in *Table 7* and *Figure 3*, any of the nine sets will be preferential to selling methanol over a project lifespan of 2 years.

If, upon inspection of the Toller equipment, the Engineering team finds that Reactor B or Column A fail to meet safety requirements, other sets will have to be considered. If Reactor B fails inspections, the next best set would be Reactor A and

Column A, which is the 2nd best option as seen in *Table 7*. On the other hand, if Column A fails safety inspections, the next best set to utilize would be Reactor B and Column B, or the 3rd best set on *Table 7*. Finally, if both Reactor B and Column A fail safety checks, then it will be necessary to move forward with Reactor A and Column B, the 4th best set. Of course, if either piece of equipment is unsatisfactory in Reactor B or Column A, the new pieces of equipment in the remaining sets will have to be inspected with equal rigor.

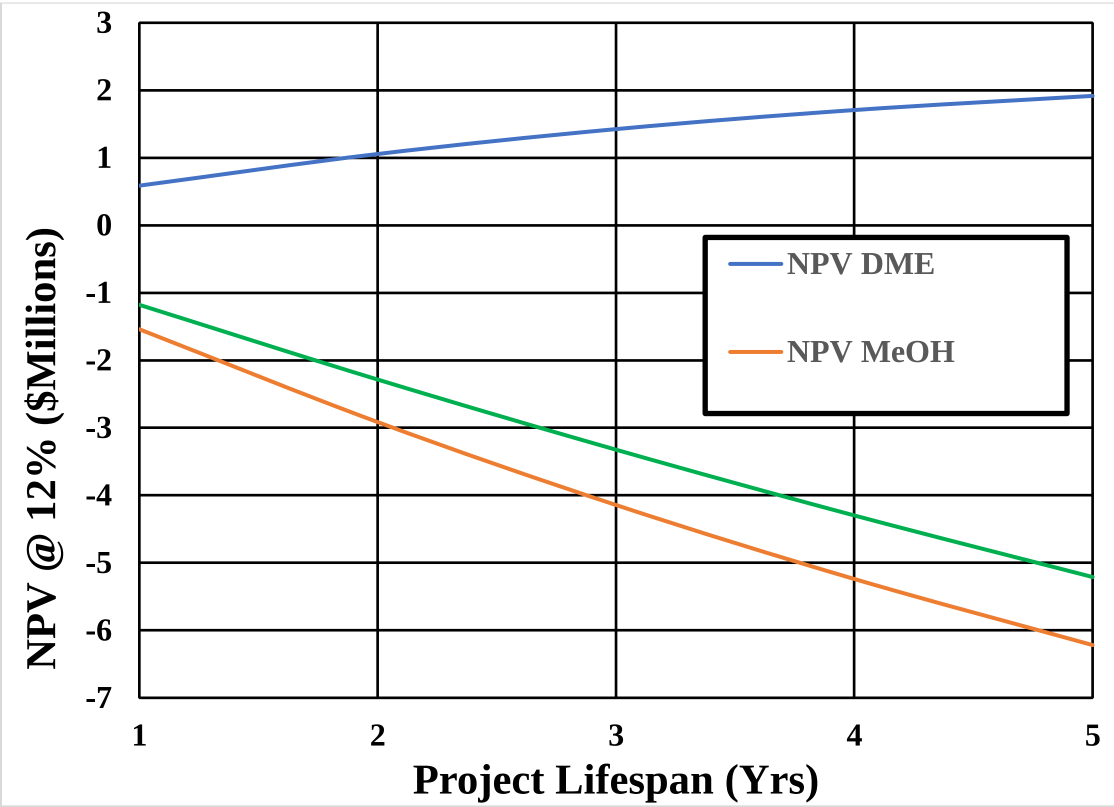

Figure 3: NPV Comparison of Project Options

Final Recommendations

The Engineering team has completed a robust economic analysis for the nine reactor and column configurations from the available Toller equipment. From this analysis, it is apparent that viable equipment sets for all nine configurations will likely provide an economic advantage to selling the excess methanol in the local market at the volatile spot price.

The Engineering team recommends that the company move forward with equipment inspections in preparation for implementing the optimized solution for DME production. The team also recommends that Management prepare the necessary funds for working capital and initial equipment rental so that payments are quickly made after approved equipment inspection.

Time is of the essence, since the longer it takes for the company to implement the methanol to DME production process, the more money the company will lose from having to sell the methanol at the spot price. However, while moving quickly, it is still important to ensure that all the proper steps are taken to ensure that the process is implemented safely and effectively. Should Management take our recommendations and move forward, the Engineering team will continue to work closely with Management, the Toller, and plant operators to ensure the methanol to DME project is implemented correctly, efficiently, and safely.

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