SLURRY HYDROCRACKER PROJECT

Appendix I – Economic Analysis

PREPARED FOR

Frank Nolte, PEng

Worley Limited

PREPARED BY

Team 15: TR Solutions

Jaryl Schmidt, Student

Jose Te Eng Fo, Student

Naira Correia, Student

Xingming Shan, Student

Yichun Zhang, Student

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I.1 SUMMARY

This appendix contains all the data, calculation and assumptions for the economic analysis. The capital costs sample calculation contains all the equipment cost calculations as well as class five estimations on capital cost. The operating costs sample calculation contains sample calculations for utility cost calculations, diluent cost calculations, operating labour cost calculations, waste disposal cost calculations. Finally, in the discounted cash flow sample calculation section, a cash flow for the first operating year (2025) is illustrated, a net present value (NPV) is and sensitivity analysis is obtained.

All prices related to the operating cost is taken from the 2019 average price as the price for January 2020. A currency rate of 1.34 CAD = 1 USD is used. To account for the location from the U.S coast in U&V (2004) to Edmonton, a location factor of 1.35 is applied. CE Plant Cost Index value 620 for 2020 is used. An operating factor of 0.9 is applied.

I.2 CAPITAL COSTS

Table 1 shows the capital cost estimation including the bare module costs for equipment cost and class five estimations. This table also includes estimations for construction DFL adjustments, indirect project expenses, auxiliary facilities etc. These estimations are done by estimating the cost to be a percentage of the total capital cost. The total grass-root capital cost is determined to be 6.9 billion dollars.

Table I1. (the capital cost table from capital cost spread sheet)

Equipment category	Equipment Number	Capacity or size specifications	Purchased Equipment Cost CP	Material factor FM	Pressure or other factors FP	Actual bare module factor FaBM	Actual bare module cost CaBM (2004)	Cost Index Adjustment CBM (2020)	Currency Adjustment CBM($CAD)	Location factor	Number of Trains	Number of equipment / train	Total
Reactors	R-A01 - R-B08	vertical D=4m L=30.8m	$160,000.00	2.5	7.2	33.4	$ 5,344,000.00	$ 8,283,200.00	$ 11,099,488.00	$ 14,984,308.80	2	4	$119,874,470.40
	R-05 & R-06	Vertical D=4m L=19.7m	$116,000.00	2.5	3.9	9.1	$ 1,049,878.00	$ 1,627,310.90	$ 2,180,596.61	$ 2,943,805.42	1	2	$5,887,610.84
Stripper Column	T-02	D=1.5m H=4.04m	$14,000.00	2.5	2.1	13	$ 182,000.00	$ 282,100.00	$ 378,014.00	$ 510,318.90	1	1	$510,318.90
Two-Phase Separators	D-01	vertical D = 4m L = 20m	$117,445.00	2.5	7.46	34.60	$ 4,064,148.99	$ 6,299,430.94	$ 8,441,237.46	$ 11,395,670.56	2	2	$45,582,682.26
	D-02	vertical D = 4m L = 20m	$117,445.00	2.5	7.43	34.46	$ 4,047,647.97	$ 6,273,854.35	$ 8,406,964.83	$ 11,349,402.52	2	2	$45,397,610.09
	D-04	vertical D = 1.5m L = 7.5m	$23,972.35	2.5	4.61	22.21	$ 532,473.84	$ 825,334.45	$ 1,105,948.16	$ 1,493,030.02	1	1	$1,493,030.02
	D-05	vertical D = 4m L = 20m	$117,445.00	2.5	2.18	11.91	$ 1,398,922.63	$ 2,168,330.07	$ 2,905,562.30	$ 3,922,509.10	1	4	$15,690,036.42
	D-06	vertical D = 4m L = 20m	$117,445.00	2.5	0.91	6.44	$ 756,087.42	$ 1,171,935.50	$ 1,570,393.57	$ 2,120,031.32	1	2	$4,240,062.65
Three-Phase Separators	D-03	horizontal D=3m L=7.08m	$26,000.00	2.5	7.39	28.81	$ 749,161.40	$ 1,161,200.17	$ 1,556,008.23	$ 2,100,611.11	1	1	$2,100,611.11
	D-07	horizontal D=1m L=1.1m	$3,500.00	2.5	4.64	18.69	$ 65,408.35	$ 101,382.94	$ 135,853.14	$ 183,401.74	1	1	$183,401.74
Compressors	CT-C01	centrifugal 26777 kW	$14,754,029.98	2.5			$ 36,885,074.95	$ 57,171,866.17	$ 76,610,300.67	$ 103,423,905.91	1	1	$103,423,905.91
	CT-C02	centrifugal 27957 kW	$15,351,488.28	2.5			$ 38,378,720.70	$ 59,487,017.09	$ 79,712,602.89	$ 107,612,013.91	1	1	$107,612,013.91
	CP-01	centrifugal 480 kW	$363,487.53	2.5			$ 908,718.83	$ 1,408,514.18	$ 1,887,409.00	$ 2,548,002.15	1	1	$2,548,002.15
	CP-02	centrifugal 9581 kW	$5,728,918.00	2.5			$ 14,322,295.00	$ 22,199,557.25	$ 29,747,406.72	$ 40,158,999.07	1	1	$40,158,999.07
Feed Pumps	P-01A	centrifugal capacity = 0.104 m3/s ws = 769 kW ps = 5 bar pd = 61 bar	$7,800.00	1.4	1	4	$ 31,200.00	$ 48,360.00	$ 64,802.40	$ 87,483.24	2	1	$174,966.48
	P-01B	centrifugal capacity = 0.104 m3/s ws = 769 kW ps = 61 bar pd = 116 bar	$7,800.00	1.4	2.3	6.6	$ 51,480.00	$ 79,794.00	$ 106,923.96	$ 144,347.35	2	1	$288,694.69

	P-01C	centrifugal capacity = 0.104 m3/s ws = 769 kW ps = 116 bar pd = 172 bar	$7,800.00	1.4	2.6	7.3	$ 56,940.00	$ 88,257.00	$ 118,264.38	$ 159,656.91	2	1	$319,313.83
	P-02	centrifugal capacity = 0.0016 m3/s ws = 0.847 kW ps = 0.9 bar pd = 4.9 bar	$3,500.00	1.4	1	4	$ 14,000.00	$ 21,700.00	$ 29,078.00	$ 39,255.30	1	1	$39,255.30
Coolers	C-01	A=653.4 m2	$61,184.37	1	1.2	3.3	$ 201,908.42	$ 312,958.05	$ 419,363.79	$ 566,141.12	2	1	$1,132,282.23
	CT-C01	A = 161.4 m2	$34,942.36	1	1.08	3.2	$ 111,815.55	$ 173,314.11	$ 232,240.90	$ 313,525.22	1	1	$313,525.22
Fire heaters	F-01	Q = 31627.5 kW	1.20E+06		1.35	2.1	$ 2,520,000.00	$ 3,906,000.00	$ 5,234,040.00	$ 7,065,954.00	2	1	$14,131,908.00
	F-02	Q = 56430.6 kW	2.00E+06		1.35	2.1	$ 4,200,000.00	$ 6,510,000.00	$ 8,723,400.00	$ 11,776,590.00	2	1	$23,553,180.00
Exchanger	E-01	A=1790, Floating Head	45000	1.7	1.3	4.8	$ 216,000.00	$ 334,800.00	$ 448,632.00	$ 605,653.20	2	1	$1,211,306.40
	E-02	A=59.0880257 U tube	6000	1.7	1.3	4.8	$ 28,800.00	$ 44,640.00	$ 59,817.60	$ 80,753.76	2	1	$161,507.52
Waste Heat Boiler	C-01	A=7396.1 m2	55000	1.7	1.15	4.5	$ 247,500.00	$ 383,625.00	$ 514,057.50	$ 693,977.63	2	4	$5,551,821.00
Airfin Coolers	C-02	A=3653.278 m2 1/train	90000	3	1.15	6.5	$ 585,000.00	$ 906,750.00	$ 1,215,045.00	$ 1,640,310.75	2	1	$3,280,621.50
	C-03	A=83.62918 m2	40000	3	1.15	6.5	$ 260,000.00	$ 403,000.00	$ 540,020.00	$ 729,027.00	1	1	$729,027.00
	C-04	A=1637.521 m2	80000	3	1.15	6.5	$ 520,000.00	$ 806,000.00	$ 1,080,040.00	$ 1,458,054.00	1	1	$1,458,054.00
	C-04	A=1794.176 m2	82000	1	1	4	$ 328,000.00	$ 508,400.00	$ 681,256.00	$ 919,695.60	1	1	$919,695.60
Gas Turbine	EX-01	Ws = 2640 kW	$328,901.76			3.5	$ 1,151,156.16	$ 1,784,292.05	$ 2,390,951.34	$ 3,227,784.31	1	1	$3,227,784.31
Amine Plant	-	Capacticy= 293.3 MMSCFD	-	-	-	-	-	-	-	-	-	-	$91,911,973.09
SMR	-	Capaticy= 1.73E+7 m3/d	-	-	-	-	-	-	-	-	-	-	$589,214,198.17
Sulfur Plant SRU	-	Capaticy= 1514 LT/d	-	-	-	-	-	-	-	-	-	-	$82,021,055.27
DRU	-	Capacity=130,000BPSD	-	-	-	-	-	-	-	-	-	-	$147,456,925.69
Zinc Oxide Bed	-	Capacity=8443.2 m3/h	-	-	-	-	-	-	-	-	-	-	$4,114,854.65
												Total Cp (with CI & currency adjustment):	**$1,465,914,705.40**

Table I2. Facility cost additions.

Total Cp (with CI & currency adjustment)		**$1,465,914,705.40**
Operating Facility	33%	$483,751,852.78
% DFL in Turnaround	58%	$842,900,955.61
% DFL in Winter	30%	$439,774,411.62
Total DFL		**$1,766,427,220.01**
Overhead for DFL additions	0.7*CL	$728,559,608.58
Misc - Total CAPEX in $M	10%	$176,642,722.00
CBM Facility Bare Module Capital		**$2,671,629,550.59**
Process Contingency	40%	$1,068,651,820
Contractual Fee	3%	$80,148,887
CTM Facility Total Module Capital		**$3,820,430,257**
Site development	5%	$191,021,513
Auxiliary Buildings	4%	$152,817,210
Off-Site facilities	21%	$802,290,354
Total Auxilliary Facilities	30%	$1,146,129,077
Sub Total Grass Roots Facility		**$4,966,559,335**
Project Contingency	20%	$993,311,867
Sub Total Grass Roots Facility and Contingency		**$5,959,871,201**
Engineering / Procurement	10%	$536,388,408
Owners' Cost	3%	$178,796,136
Commissioning & Startup	4%	$238,394,848
CGR Total Grass-roots Capital (Total Fixed Capital)		**$6,913,450,594**

A summary of costs regarding the equipment cost and class five capital cost estimation can be found in Table 2 and Table 3.

Table I3. Equipment cost summary.

Equipment Name	Number of Equipment	Total Cost
Reactors	8	$125,762,081
Separators	17	$114,687,434
Pumps	3	$822,230
Compressors	4	$253,742,921.03
Coolers	3	$1,445,807
Fire Heaters	4	$37,685,088
Heat Exchangers	4	$1,372,814
Waste Heat Boilers	8	$5,551,821
Expander	1	$3,227,784
Air Fin Coolers	5	$6,387,398
	Total:	**$551 M**

Table I4. Class five capital cost summary.

Equipment Name	Cost
Hydrocracker Unit	$551 M
Amine Treatment Unit	$92 M
Hydrogen Plant (SMR)	$589 M
Sulfur Plant	$82 M
Diluent Recovery Unit	$147 M
Zinc Oxide Bed	$4 M

I.3 OPERATING COSTS

Table 4 contains all the steps in reaching the total annual expenses of this project. This includes utility costs, raw materials cost, catalyst cost, operating costs etc. Indirect costs including overhead, tax and insurance etc are also estimated to be a percentage of total capital cost.

Table I5. Manufacturing cost summary.

Capital		
Fixed capital, CFC	$6,913,450,594	
Working capital (15% of fixed capital), CWC	$1,037,017,589	
Total capital investment. CTC	$7,950,468,183	
Annual Cost	$/yr	$/yr
Manufacturing expenses		
Direct		
Raw materials (Diluted Bitumen + Natural Gas + Process Steam)	$ 2,364,319,537	
Catalysts and solvents (Iron Catalyst @6655.16 kg/h)	$ 262,346,407	
Operating labour	$ 1,507,322	
Supervisory and clerical labour (10% of operating labour)	$ 150,732	
Utilities		
Electricity, 597330662.3 kWh @ $0.127/kWh	$ 80,507,322	
Natural Gas, 17862588688GJ @ $1.4/GJ	$ 22,499,449	
Demineralized Water 597330662.3 kWh @ $5.46/kWh	$ 8,400,098	
Process Steam 35478000 kg @ $0.022/m3	$ 26,176,751	
Cooling Water 2910884.844 m3 @$0.0507 /m3	$ 193,610	
Zinc Oxide Bed (Class V)	$31,611,306.00	
Maintenance and repairs (2% of fixed capital)	$ 138,269,012	
Operating supplies (10% of maint. & repairs)	$ 13,826,901	
Laboratory charges (10% of operating labour)	$ 57,821,148	
Total, ADME	**$ 3,323,494,670**	**$ 3,323,494,670**
Indirect Costs		
Overhead (payroll and plant), packaging, storage (50% op. labour, supervision and maintenance)	$ 289,181,107	
Local taxes (2% of fixed capital)	$ 138,269,012	
Insurance (1% of fixed capital)	$ 69,134,506	
Total, AIME	**$ 496,584,625**	**$ 496,584,625**
Total manufacturing expense, AME = ADME + AIME		**$ 3,820,079,295**
General expenses		
Administrative costs (25% of overhead)	$ 72,295,277	
Total general expense, AGE	**$ 72,295,277**	**$ 72,295,277**
Depreciation (approx. 10% of fixed capital), ABD		$ 691,345,059
Total expenses , ATE		$ 4,583,719,631
Revenue from sales (kg/yr @ $/kg), AS		$ 4,018,036,780
Net annual profit, ANP		$ (565,682,851)
Income taxes (net annual profit tax rate), AIT		$ (152,734,370)
Net annual profit after taxes (ANP-AIT), ANNP		**$ (412,948,481)**

Table I6. Utility cost summary.

Utility Type	Consumption	Unit	Unit Price (CAD)	Annual Cost (CAD)
Electricity	659829380	kwh	0.12201233	68,277,548
Natural Gas (Utility)	16061474.65	GJ	1.40083333	6,978,847
Demineralized Water	1,538,304	m3	5.46062341	8,400,098
Process Steam	1283520039	kg	0.02039450	26,176,750
Cooling Water	2910884.844	m3	0.06651250	193,610

Table I7. Summary of operating consumption.

Name	Price (CAD)
Bitumen	$1.64
Natural Gas	$0.02
Catalyst	$0.26
Other Direct Costs	$0.17
Utilities	$0.11
Indirect	$0.33
General Expenses	$0.03
Bitumen	$1.64
Naphtha	$0.7
Raw Materials	$0.03

I.4 FEED COSTS

The battery-limit feed cost to the process consists of three parts; bitumen, diluent and natural gas. Bitumen is the raw material that needs to be upgraded to crude oil. It is usually transported by pipe and mixed with diluent, with a ratio of 30 vol% of diluent and 70 vol% of bitumen. The natural gas is consumed in the SMR unit for hydrogen production.

The diluent is naphtha, but when it is used as diluent, the price is lower than naphtha as a chemical selling in the market. Refer to page I21, the price for diluent is calculated in order to prevent using the price for naphtha and to save some cost.

Table I8. Battery limit feed cost summary.

Feed	Prices (CAD)
Diluent	$ 699,100,792
Bitumen	$ 1,641,030,120
Natural Gas	$ 24,188,624.46

I.5 REVENUE

The revenue consists of three parts, the diluent recovered from the DRU is assumed to be pure naphtha available for sale. Sulphur recovered from the Claus plant is marketed as a product. The crude oil is priced as the WTI Cushing price. All prices are the average price in 2019.

Table I9. Summary of Annual Revenue

Name	Unit Price	Annual Revenue (CAD)
Crude Oil	475.83 CAD/m^3	$ 3,068,692,528.33
Naphtha	427.66 CAD/m^3	923804667.03
Sulphur	167.5 CAD/m^3	$ 25,539,584.59

I.6 CLASS V OPERATING COST ESTIMATES

The class five operating cost estimations is done through research, utilities for each of class five units is obtained and added to the total annual utility cost in the operating cost table.

The class five operating estimation for the zinc oxide bed is done by adding the cost for zinc oxide catalyst and the solid waste disposal together to get the annual expense. According to Hassan, Khammas, and Al-Mayah (2008), the price for zinc oxide is consist of 90 wt% of zinc oxide and 10 wt% of alumina, and the efficiency of the hydrogen sulphide removal reaction is assumed to be 90%. Due to lack of information, the price of zinc oxide and alumina is obtained from an online trading website called alibaba. The suppliers of zinc oxide and alumina from this market mostly ship their product f.o.b. with a range of prices listed, for example, for most of the suppliers, $2000 - 3000 USD per ton of zinc oxide powder is the normal price. The lower bound, $2000 USD/t is chosen since this project has a big consumption on zinc oxide catalyst, it is reasonable to assume that a discounted price can be given to the project with some negotiation.

I.7 CASH FLOW ANALYSIS

The evaluation of this project involves a 40 years of cash flow. The first five years will be the construction of the grass-root plant site. With a total fixed capital of $ 6,898,227,929 dollars to be installed each year. The working capital is estimated as 15% of total fixed capital invested at the beginning of the 5th year. A schedule of investment instalment is listed in the following table:

Table I10. Investment instalments in the construction period.

Year	Fixed Capital	Percent of Total Fixed Capital
0	$ (344,911,396.47)	5%
1	$ (1,034,734,189.42)	15%
2	$ (1,379,645,585.89)	20%
3	$ (1,379,645,585.89)	20%
4	$ (2,759,291,171.78)	40%

The reason why most of the instalments are installed to the last three years is (Appendix K) because for most of the projects, the first two years are mainly works on project scope, detail engineering etc. In the last three years of development the project is going to consume most of the investment including paying for bulk of equipment, mechanical constructing, building the steel wall equipment, building the piping systems and finishing the work etc.

The net present value by the end of the 35th operating year was determined to be $(-5,945,636,564) dollars.

The return on capital of this project is 0.11%, which is smaller than the hurdle rate of 15%. Which means this project will not be executed from an economic point of perspective.

I.7.1 Sensitivity Analysis

A sensitivity analysis is done on main factors that will significantly affect the cash flow and NPV of the project. These factors are bitumen price, crude oil price, total capital and discount factor. The values of these factors had been changed as an input to get the resultant NPV. The way these values had been adjusted is illustrated in the following table, and the sensitivity analysis of each factor is illustrated in the next figure.

Table I11. Factor adjustments for sensitivity analysis.

	Bitumen	WTI Cushing	Capital	Discount Rate
Increase	20%	20%	50%	at 20%
Decrease	-20%	-20%	-20%	at 10%

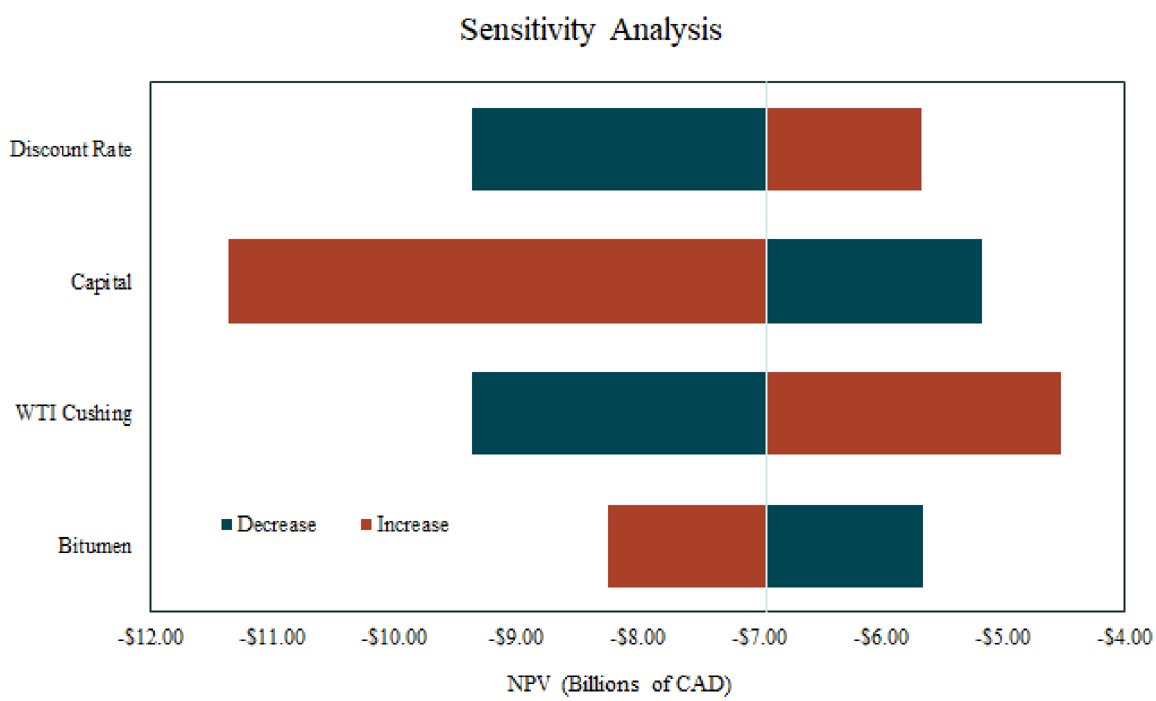


Figure I1. Sensitivity analysis.

I.8 SAMPLE CALCULATIONS

The following is sample calculations by hand for calculations related to capital cost, operating cost, and cash flow. The purpose for this section is to have a detailed demonstration on how the calculations in the economic excel sheet is done. The results from these hand calculations might be slightly different compared to the value in the excel sheet, due to calculation error, but the values should be consistent in general.

I.8.1 Capital Cost Sample Calculation

Slurry Reactor R-01 Cost using U&V

Basis:

- Vertical vessel
- Design $P = 250$ bar
- Design $T = 467\,°C$
- Diameter $: 4m$
- Length (tangent to tangent) $= 30.8\ m$
- Material of construction : Carbon Steel clad with stainless steel
- Location factor Edmonton 1.35
- $CEI = 620$ (2020)
- $CEI = 400$ (2004)
- Currency conversion 1.34

Using U&V Figure 5.44 pg. 387-388

$$C_P = \$160,000$$

$$F_M = 2.5$$

$$F_P = 7.2$$

$$F_P \times F_M = 2.5 \times 7.2 = 18$$

Bare module factor, Fig 5.46 $\quad F^a_{BM} = 33.4$

$$C_{BM} = C_P \times F^a_{BM} = \$160,000 \times 33.4$$

$C_{BM} = \$5.3M$ USD, USGC, 2004

$$C_{BM} = \$5.3M \times \frac{620}{400} \times 1.35 \times 1.34$$

$C_{BM,2020} = \$14.9M$ CAD

The rest of the 7 reactors are costed in the same manner.

Two - Phase Separator Costing

ex) Flash Drum D-01 (vertical)

According to Ulrich & Vasudevan (2004) Figures 5.44-5.45

For $L = 20m$, $D = 4m$, $C_p = \$1.17 \times 10^5$

Stainless clad was chosen to avoid corrosion

$F_M = 2.5$

$P = 168$ bar $\rightarrow$ $F_P = 7.5$

$F_P \times F_M = (2.5)(7.5) = 18.75 \rightarrow F^a_{BM} = 35$

$C^a_{BM} = (F^a_{BM})(C_p) = (35)(\$1.17 \times 10^5) = \$4.06 \times 10^6$

The rest of the two phase separators are costed in the same manner.

Pump Costing

ex) Pump P-02 (centrifugal)

According to Ulrich & Vasudevan (2004), Figures 5.49-5.51

At $\dot{W}_s = 0.8467$ kW, $C_p = \$3500$

At $P_s = 90$ kPa, $F_P = 1.0$

Cast steel was chosen to avoid corrosion $\rightarrow F_M = 1.4$

$F_P \times F_M = 1.4 \rightarrow F^a_{BM} = 4$

$C^a_{BM} = (F^a_{BM})(C_p) = (4)(\$3500) = \$14,000$

The rest of the pumps are costed in the same manner.

Compressor Costing

ex) Compressor CT-CP01 (centrifugal).

According to UMG Symmetry, the compressor duty required to achieve the pressure difference between inlet & outlet is $\dot{W}_s = 26777$ kW.

The equipment type was decided to be centrifugal.

Centrifugal compressors typically have an efficiency $\varepsilon_i = 50 \sim 85$ % (Ulrich & Vasdevan, 2004)

Assuming $\varepsilon_i = 0.75$,

$$\dot{W}_f = \varepsilon_i \dot{W}_s = (0.75)(26777 \text{ kW}) = 20083 \text{ kW}$$

According to Ulrich & Vasudevan, (2004), Figure 5.30,

$$C_p = \$1.48 \times 10^7$$

The risk of corrosion is low, so carbon steel material is selected.

$$F_{BM} = 2.5 \quad \text{(Ulrich \& Vasudevan, 2004)}$$

$$C^a_{BM} = (F_{BM})(C_p) \quad \text{(Ulrich \& Vasudevan, 2004)}$$

$$= (2.5)(\$1.48 \times 10^7)$$

$$= \$3.69 \times 10^7$$

The rest of the compressors are costed in the same manner.

Heater Costing

ex) Fired Heater F-01

According to VMG Symmetry, the duty required to achieve the desired temperature is $\dot{Q} = 31627.5 kW$

According to Ulrich & Vasudevan (2004), Figure 5.27

At $\dot{Q} = 31627.5$ kW, C_p of a non-reactive heater is $\$1.20 \times 10^6$.

At $P = 171$ bar, $F_P = 1.35$

Carbon steel was chosen because the risk of corrosion is low. $F_{BM} = 2.1$

$C^a_{BM} = (F_{BM})(C_p) = (2.1)(\$1.20 \times 10^6) = \$2.52 \times 10^6$

The rest of the heaters are costed in the same manner.

3 phase separator Costing

ax) Horizontal 3- phase separator D-03

According to Ulrich & Vasudevan (2004) Figure

For $D = 3m$, $L = 7.08m$

$C_p = 26{,}000$ USD

Carbon Steel was chosen $\rightarrow F_M = 2.5$

$P = 16700$ KPa $\rightarrow F_p = 7.8$

$F_{BM}^{a} = F_p \cdot F_M = 7.8 \times 1.67 = 13$

$C_{BM}^{a} = C_p \cdot F_{BM}^{a} = 26{,}000 \times 13 = 338{,}000$ USD

Inflation & currency

$$C_{BM}(2020) = C_{BM}^{a} \times \frac{620}{400} \times \frac{1.34 \text{ CDN}}{1 \text{ USD}} \times 1.35 \text{ (location factor)}$$

$$= 947{,}735 \text{ CDN in } 2020.$$

Another 3 phase separator is costed in the same manner.

Class 5 → Capital cost estimation M ≡ million

All the class 5 plants cost estimation used the Capacity ratio estimates (6/10th rule)

CEI (2020) = 620

Location - 1.35

Currency - 1.34

$$\frac{\text{Cost A}}{\text{Cost B}} = \left(\frac{\text{Capacity A}}{\text{Capacity B}}\right)^n$$

n ≡ depends on the type of process plant scale exeponent

Amine treater plant

Cost B = \$ 15 M, USD, 1991 (Maples)

Capacity B = 100 MMSCFD CEI (1991) = 360

Stream factor = 0.95

$n = 0.6$

Capacity A = 293.3 MMSCFD

$$\text{Cost A} = \$15M \times \left(\frac{293.3}{100 \times 0.95}\right)^{0.6} \times \frac{620}{360} \times 1.35 \times 1.34$$

Cost A = \$ 91.9 M (CAD, January 2020)

Sulfur Plant (SRU)

Cost B = \$ 5M, USD, 1991 (Mapples)

Capacity B = 100 LT/D stream factor = 0.95

Capacity A = 1513.92 LT/D n = 0.6

$$\text{Cost A} = \$5M \times \left(\frac{1513.92}{100 \times 0.95}\right)^{0.6} \times \frac{620}{360} \times 1.34 \times 1.35$$

Cost A = \$ 82 M (CAD, January 2020)

Diluent recovery unit (DRU)

Cost B = \$38M, USD, 1991 (Maples)

Capacity B = 100,000 BPSD stream factor = 0.95

Capacity A = 130,000 BPSD $n = 0.7$

$$\text{Cost A} = \$38M \times \left(\frac{130{,}000}{100{,}000 \times 0.95}\right)^{0.7} \times \frac{620}{360} \times 1.34 \times 1.35$$

Cost A = \$147 M (Cad, January 2020)

Steam Methane Reformer (SMR)

Cost B = \$50M, USD, 1995 (Murry Gray)

Capacity B = 1.7×10^6 m^3/day CEI (1995) = 382.9

Capacity A = 1.73×10^7 m^3/day $n = 0.6$

$$\text{Cost A} = \$50M \times \left(\frac{1.73 \times 10^7}{1.7 \times 10^6}\right)^{0.6} \times \frac{620}{382.9} \times 1.34 \times 1.35$$

Cost A = \$589 M (Cad, January 2020)

Zin Oxide Bed

The zinc oxide bed is estimated to be 2 vertical vessels in parrallel

The sizing calculation is shown in Appendix E excel sizing sheet "vessels"

Capacity = 8443.2 m^3/h

L = 17.9 m Material → Carbon steel

D = 4 m

P = 26 bar

Using U&V Fig 5.44, 5.45, 5.46

$C_p = \$108,000$

$F_M = 1$

$F_p \times F_M = 2.5$

$F_p = 2.5$

Bare module factor $F_{BM}^{a} = 6.9$

$C_{BM} = C_p \times F_{BM}^{a} = \$108,000 \times 6.9 = \$7452$

$C_{BM} = \$745200$ USD, USGC, 2004

$C_{BM\,2020} = \$745200 \times \frac{620}{400} \times 1.35 \times 1.34$

$C_{BM\,2020} = \$2M$ (Cad, 2020)

For the 2 vessels

$C_{BM} = \$2M \times 2 = \$4M$ (CAD, 2020)

Expander Costing

Equipment: Gas Turbine EX-01

According to sizing calculations (sample calculations shown in Appendix E)

$$\dot{W}_s = 2640 \text{ kW}$$

According to Ulrich & Vasudevan (2004, Figure 5.21)

At $\dot{W}_s = 2640$ kW, C_p of a gas turbine $= \$3.3 \times 10^5$

F_{BM} of a gas turbine $= 3.5$

$$C^a_{BM} = (3.5)(3.3 \times 10^5) = \$\ 1.15 \times 10^6$$

I.8.2 Utilities Unit Cost Sample Calculation

Utility unit cost sample calculation

According to Ulrich & Vasudevan (2004) P416-418

- price per unit of Utility

C_{unit} = a · CE plant Cost Index + b · Fuel Price

- where a, b are constants given in the book, some a, b depend on flow rates etc.
- CE plant cost index in 2020 = 620
- Natural Gas is selected as fuel and according to the government of Alberta the price in 2020 is 1.4/1.34 = 1.045 USD/GJ

- Electricity

$a = 0.00013 \quad b = 0.01$

$C_{unit} = 0.00013 \times 620 + 1.045 \times 0.01 = 0.091$ USD/kwh

$C_{unit} = 0.091 \times 1.34 = 0.122$ CDN/kwh

- Process steam

$\dot{m} = 1.25$ kg/s $\quad P = 1$ barg

$a = 0.000023 \times \dot{m}^{(-0.9)} = 0.000023 \times 1.25^{(-0.9)} = 0.0000188519$

$b = 0.0034 \times P^{0.05} = 0.0034 \times 1^{0.05} = 0.0034$

$C_{unit} = 0.0000188519 \times 620 + 1.045 \times 0.0034 = 0.015$ USD/kg

$C_{unit} = 0.015 \times 1.34 = 0.020$ CDN/kg

- Demineralized Water

$\dot{m} = 0.032389$ m^3/s

$a = 0.005 + 0.0002 \times \dot{m}^{(-0.6)} = 0.005 + 0.0002 \times 0.32389^{(0.6)}$
$= 0.006566$

$b = 0.0034$

$C_{unit} = 0.006566 \times 620 + 1.045 \times 0.0034 = 4.075$ USD/m^3

$C_{unit} = 4.075 \times 1.34 = 5.460$ CDN/m^3

- toxic or hazardous solids & liquids (Grass-root plant)

$a = 2\times10^{-3}$ $b = N/A$

Unit cost $= a \times$ CE plant cost Index $+ 0$ (USD/kg)

$= 2\times10^{-3} \times 620$ USD/kg

$= 1.24$ USD/kg

Unit cost $= 1.24$ USD/kg $\times 1.34$ CDN/USD $= 1.66$ CDN/kg

I.8.3 Utility Cost Sample Calculation

Utility Cost - Process Steam

- from class V estimation, the annual consumption of process steam from the sum of Amine Treat Plant, Hydrogen plant, & sulphur plant was 715,930,418 kg/yr

Annual Cost = 715,930,418 kg/yr × 0.020 CDN/kg = $\boxed{14,318,608 \text{ CDN/yr}}$

Utility cost - Demineralized Water

- Only cooler C-A01 / C-B01 consumes demineralized water and the consumption rate is 97,265.92 kg/h
- Annual consumption = 97,265.92 kg/h × 24 h/d × 365 d/yr × 0.9
= 766844493.4 kg/yr

Annual consumption = 766844493.4 kg/yr / 997 kg/m³
= 769151.9492 m³/yr

- Annual cost = 769151.9492 m³/yr × 5.46 CDN/m³ = $\boxed{4601043.6 \text{ CDN/yr}}$

Utility cost - Cooling water

- From class V estimation, only sulphur plant has a consumption of cooling water @ a annual flow of 2910884.844 m³/yr
- Annual Cost = 2910884.844 m³/yr × 0.0665125 CDN/m³ = $\boxed{193610 \text{ CDN/yr}}$

Utility cost - Waste Water Disposal

- S-52 is the waste water that need to be treated.
- Information from Simulation are:

  $\dot{m} = 7029\ kg/h$

- Since this water contains some ammonium salts, and the water PH is high, it is belongs to the Toxic or hazardous solids and liquid in U&V. The unit price for disposal have been determined to be 1.66 CDN/kg
- Annual Utility cost:

  $Cost = 7029\ kg/h \times 24\ h/d \times 365\ d/yr \times 0.9 \times 1.66\ CDN/kg$

  $= 91,991,615\ CDN/yr$

Utility Costs - Electricity

ex) Pump P-02

According to Ulrich & Vasudevan (2004) Figure 4.2

At $\dot{W}_s = 0.8467\ kW$, motor efficiency $e_d = 0.83$

$$\text{motor power} = \frac{\dot{W}_s}{e_d} = \frac{0.8467\ kW}{0.83} = 1.020\ kW$$

$$(1.020\ kW)(24\ h)(365\ days)(0.9) = 8042\ kWh$$

I.8.4 General Operating Expenses Sample Calculation

Diluent Cost Calculation

- A quotation to Natural Resources Canada (2020) is as following

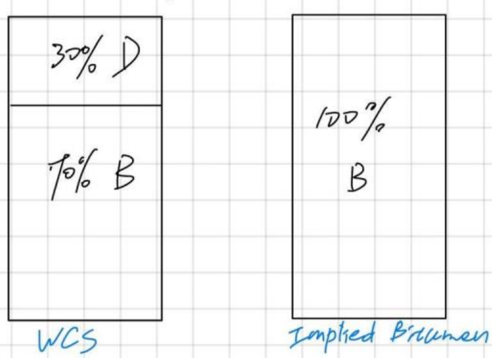
" Implied Bitumen Price: The implied bitumen price is derived from the price of Western Canadian Select (WCS), which is assumed to have a blend composition of 30% condensate and 70% bitumen. The value of the condensate is subtracted from the WCS price to arrive at the implied price of bitumen. The implied bitumen price represents the value of bitumen extracted from the oil sands before condensate is added to allow the oil to flow through pipelines. "

- According to Natural Resources Canada 2020), taking the average prices for WCS and Implied Bitumen the results are:

$P_{WCS} = 325\ CDN/m^3 \quad P_{Bitumen} = 325.58\ CDN/m^3$

- A illustration of how diluent (condensate) price is obtained is as follow:

D= Diluent price (CDN/m^3) B = Implied Bitumen price (CDN/m^3)



$$B \times 70\% + D \times 30\% = WCS$$

$$0.3D = WCS - 0.7B$$

$$D = \frac{WCS - 0.7B}{0.3}$$

$$= \frac{325 - 0.7 \times 325.58}{0.3} = 323.64\ CDN/m^3$$

To Double check:

$$323.64 \times 30\% + 325.58 \times 70\% = \boxed{\begin{array}{c} 30\%\ D \\ 70\%\ B \end{array}} = 325\ CDN/m^3$$

=WCS price

Operating Labor

- Operating factor = 0.9

- According to Statistics Canada. Table 14-10-0326-02 the average offered hourly wage, for North American Industry Classification System: Petroleum and coal product manufacturing positions [324], the statistics information are as follow:

Q1 2019	Q2 2019	Q3 2019	Q4 2019
No data	34.9	31.6	No data

- the average wage rate in 2019 is:

$$\frac{34.9 + 31.6}{2} = 33.25 \text{ CAD/hr}$$

- then the Annual wage is

$$33.25 \text{ CAD/hr} \times 24 \text{hr/d} \times 365 \text{ d/yr} \times 0.9 = 262,143 \frac{\text{CAD}}{\text{yr}}$$

- According to Ulrich & Vasudevan (2004) P414.
  Table 6.2 Operator Requirements for Various Types of Process Equipment.
  Detailed numbers are listed in the Excel sheets,

  The total # of op. labor = 5.75

  Annual Salary = 262,143 × 5.75 = 1,507,322.25 CAD/yr

Class V estimation - operating cost of Zinc Oxide Bed

- According to Hasson, Khamnas, and Al-Mayah (2008) the H_2S removal process usually use 90 wt% ZnO + 10 wt% Alumina.

  The efficiency is usually 90%

- The market price, according to a online trading site, Alibaba (2020), are

  \$2000 USD/t for ZnO powder form a supplier from Shanghai

  \$ 15 USD/kg for Alumina powder, in 2020.

- Assume 90wt% ZnO and 10wt% Alumina, catalyst price is:

$$P_{cata.} = 2000\ USD/t \times \frac{1t}{1000kg} \times 90\% + 15\ USD/kg \times 10\% = 3.3\ USD/kg$$

$$P_{cata.} = 3.3\ USD/kg \times 1.34\ CDN/USD = 4.42\ CDN/kg$$

- From stimulation, the feed to Zinc Oxide Bed is stream S-29.

  For S-29

  $F = 9310.5\ kmol/h$

  Sulfur molar fraction $= 0.0654$

  $F_{H_2S,tot} = 9310.5\ kmol/h \times 0.0654 = 608.9\ kmol/h$

- It's assumed that 99% of the H_2S will be processed by Amine Unit connected right next to stream S-29. The rest 1% of H_2S is being removed by Zinc Oxide Bed.

  $\Rightarrow F_{H_2S} = F_{H_2S,tot} \times 1\% = 6.089\ kmol/h$

- The reaction is:

$$ZnO + H_2S \rightarrow ZnS + H_2O$$

$$\Rightarrow F_{ZnS} = F_{H_2S} = 6.089 \text{ kmol/h}$$

- Annual consumption of ZnS is (Molar weight of ZnS is 97.474 kg/kmol)

$$m_{ZnS} = 6.089 \text{ kmol/h} \times 97.474 \text{ kg/kmol} \times 24 \times 365 \times 0.9$$
$$= 4679305.26 \text{ kg/yr}$$

- For a 90 wt% ZnO 10 wt% Alumina (Molar mass 101.96 kg/kmol)

$$m_{Al_2O_3} = \frac{m_{ZnO}}{90\%} \times 10\% = \frac{4679305.26 \text{ kg/yr}}{0.9} \times 0.1 = 519922.81 \text{ kg/yr}$$

$$\Rightarrow m_{cata} = m_{ZnO} + m_{Al_2O_3} = 5199228.06 \text{ kg/yr}$$

$\Rightarrow$ Annual Cost

$$C_{cata.} = m_{cata} \cdot P_{cata}$$
$$= 5199228.06 \text{ kg/yr} \times 4.42 \text{ CDN/yr}$$
$$= 22980588 \text{ CDN/yr}$$

- For annual solid waste disposal, it had been determined to be 1.66 CDN/kg

$\Rightarrow$ Cost for solid waste disposal is

$$C_{solid\ waste} = 5199228.06 \text{ kg/yr} \times 1.66 \text{ CDN/yr}$$
$$= 8630718.59 \text{ CDN/yr}$$

$\Rightarrow$ The total operating cost for Zinc Oxide Bed is

$$C_{cata} + C_{solid\ waste} = 22980588 + 8630718.59$$
$$= \boxed{31,611,306 \text{ CDN/yr}}$$

Specific Gravity Sample Calculation

- According to Gray, M.R. (2015) P.15, Equation 1.1.

$$°API = \frac{1.415 \times 10^5}{\rho} - 131.5$$

- The product density is 736.3 kg/m³

$$\Rightarrow °API = \frac{1.415 \times 10^5}{736.3} - 131.5 = 60.7$$

payout time

- According to CHE 464 Note, the payout time is defined as

$$POT = \frac{\text{Total Capital Cost}}{\text{Gross Material Income}}$$

where Gross Marited Income = Revenue − operating expense

- $$POT = \frac{6913450594}{4018036780 - 4011102003} = \boxed{997 \text{ years}}$$

→ If the product price rise 20% (WTI Cushing price)

Then Revenue becomes \$4631775286

$$POT = \frac{6913450594}{4631775286 - 4011102003} = \boxed{11.1 \text{ years}}$$

I.8.5 Discounted Cash Flow Sample Calculation

Sample Cash Flow for the First Operating Year (2025)

- Calculated results for the year 2020

Total Fixed Capital = $C_{FC,20}$ = 6913450594 CDN

Working Capital = $C_{WC,20}$ = 1037017589 CDN

Manufacturing Expense = $C_{ME,20}$ = 4011102003 CDN

Total Revenue = R_{20} = 4018036780 CDN

Tax Rate = $r_t = 27\%$

Discount Rate = $r_D = 15\%$

Inflation Rate = $r_I = 3\%$

- Manufacturing Expenses in 2025 (Inflation for 5 years)

$$C_{ME,25} = C_{ME,20} \times (1+r_I)^5 =$$
$$(-4011102003)(1+0.03)^5 = (-4649966561) \text{ CDN}$$

- Revenue in 2025 (inflation for 5 years)

$$R_{25} = R_{20}(1+r_I)^5 = 4018036780 \times (1+0.03)^5$$
$$= 4658005869 \text{ CDN}$$

- Total Capital Investment & Working capital in 2025

Since all the investments are done in the first five years

$C_{FC,25} = 0 \qquad C_{WC,25} = 0$

- Cash Flow Before tax in 2025

$$= (-C_{FC,25}) + (-C_{WC,25}) + R_{25} + (-C_{ME,25})$$
$$= 0 + 0 + 4658005869 + (-4649966561)$$
$$= 8039308 \text{ CDN}$$

- Capital Cost Allowance and Taxes in 2025.

CCA for the first operating year, 2025, is 15%

The un-depreciated capital from last year, 2024 is 6913450594 CDN

CCA_{25} (15%) = 6913450394 × 15% = 1037017589 CDN

The depreciated capital is then

6913450394 − 1037017589 = 5876433005 CDN

- Taxable income for 2025 = Cash flow 2025 − CCA_{25}
= 8039307 − 1037017589
= (−1028978281)

Taxes = (−1028978281) × 27% = (−277824136)

- Since the cash flow is negative, the taxes here becomes a credit.

- Cash flow after tax = Cash flow before tax in 2025 − tax
= 8039308 − (−277824136)
= 285863444

- Discount factor in 2025 = $(1+r_D)^{-5} = (1+0.15)^{-5}$
= 0.497177

- Discounted cash flow = Cash flow after tax × Discount factor
= 285863444 × 0.497177
= 142124654

- Cumulative Discounted Cash Flow
= Discounted cash flow in 2024 + Discounted cash flow in 2025
= (−537113827) + 142124653
= (−523398174) CDN

- Note the amount of cumulative cash flow from 2024 of (−537113827) is also obtained in a same manner.

- the same calculation applies to rest of the years

I.9 REFERENCES

CH E 464 and CH E 465 class notes and tutorials.

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