CML403: PLANT DESIGN AND ECONOMICS

PROJECT REPORT ON :

PRODUCTION OF Maleic Anhydride

GROUP 9

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ABSTRACT

The plant design and economics for production of Maleic Anhydride was studied. This report gives us the information regarding all the expenditure involved in the production of Maleic Anhydride. All the information required for the preliminary design was provided by the course coordinator. Capital cost required for various equipment, utility costs, working labour costs, funds required to purchase land and raw materials were estimated by taking appropriate assumptions in calculations. The non-discounted and discounted cash flow diagrams were generated. A preliminary Risk evaluation in the cost estimations was done using Sensitivity Analysis and Profit Margin Analysis.

INTRODUCTION:

The plant design and economics for production of Maleic anhydride was studied. Based on the preliminary information available and taking proper assumptions, capital costs, utility and labor costs, and manufacturing costs for the entire production process were calculated. Non-discounted and discounted cash flow diagrams were generated. Profitability analysis was done via various methods. Further, scenario and sensitivity analysis were also performed.

Assumptions:

-The plant is situated in Sambhajinagar,Maharashtra,India.
-The cost of electricity is ₹ 6/kWh
-CEPCI was taken as 854.6 for year 2023 and 397 for year 2001.
-The taxation rate is 30%.
- The depreciation method used is the MACRS 5-year schedule.
-The plant life is 10 years.
-The Salvage value of the plant is ₹10 Cr.
-The discount rate is 10%.
-Grass root of plant is being designed from the scratch on a new piece of land.
Accordingly, the values of various parameters were chosen in the costing of utilities

RESULTS:

Process Flow Diagram:

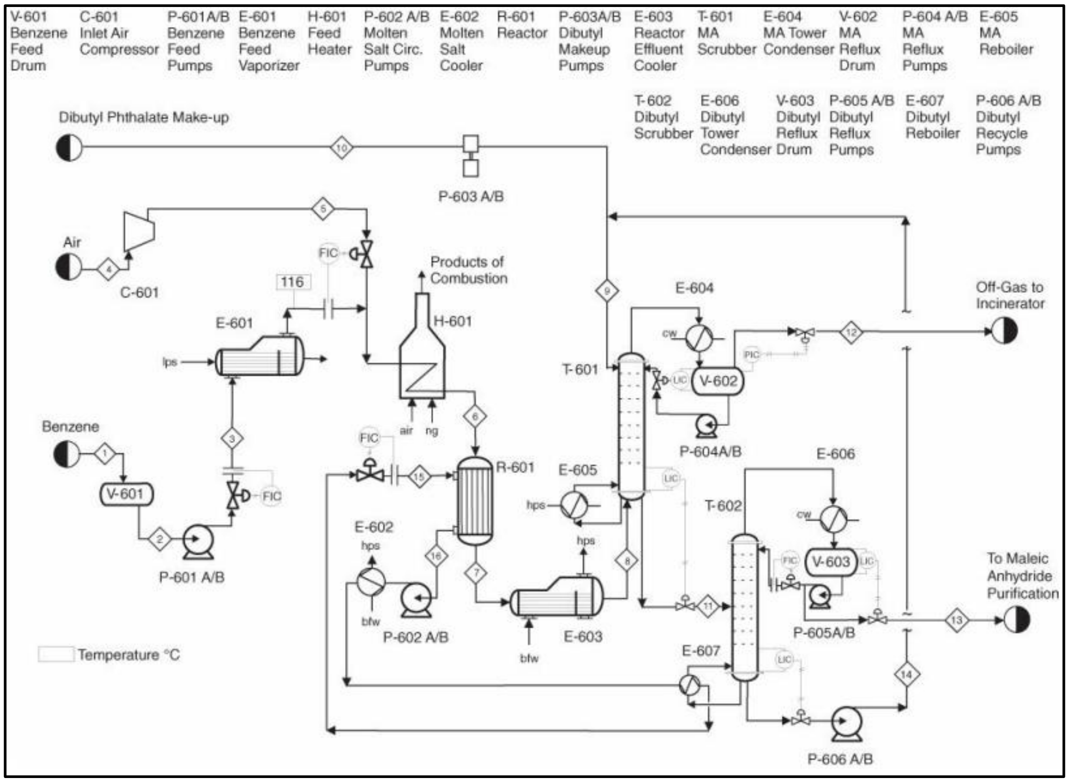


Fig. 1. Process Flow Diagram for the Production of Maleic Anhydride

Stream Flow Tables

Table 1. Property Data of all Process Streams

Stream Number	1	2	3	4	5	6	7	8
Temperature (°C)	30	30	30	30	170	460	608	270
Pressure (kPa)	101	101	280	101	250	235	220	215
Total kg/h	3304	3304	3304	80,490	80,490	83,794	83,794	83,794
Total kmol/h	42.3	42.3	42.3	2790.0	2790.0	2832.3	2825.2	2825.2
Component Flowrates (kmol/h)								
Maleic anhydride	0.0	0.0	0.0	0.0	0.0	0.0	26.3	26.3
Dibutyl phthalate	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitrogen	0.0	0.0	0.0	2205.0	2205.0	2205.0	2205.0	2205.0
Water	0.0	0.0	0.0	0.0	0.0	0.0	91.5	91.5
Oxygen	0.0	0.0	0.0	585.0	585.0	585.0	370.2	370.2
Benzene	42.3	42.3	42.3	0.0	0.0	42.3	2.6	2.6
Quinone	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.7
Carbon dioxide	0.0	0.0	0.0	0.0	0.0	0.0	129.0	129.0
Maleic acid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sodium nitrite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sodium nitrate	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Stream Number	9	10	11	12	13	14	15	16
Temperature (°C)	330	320	194	84	195	330	419	562
Pressure (kPa)	82	100	82	75	80	82	200	200
Total kg/h	139,191.6	30.6	141,866	81,225	2597	139,269	391,925	391,925
Total kmol/h	500.1	0.1	526.2	2797.9	26.2	500.0	5000.0	5000.0
Component Flowrates (kmol/h)								
Maleic anhydride	0.0	0.0	4.8	0.5	24.8	0.0	0.0	0.0
Dibutyl phthalate	500.1	0.1	500.0	0.0	0.0	500.0	0.0	0.0
Nitrogen	0.0	0.0	0.0	2205.0	0.0	0.0	0.0	0.0
Water	0.0	0.0	0.0	91.5	0.0	0.0	0.0	0.0
Oxygen	0.0	0.0	0.0	370.2	0.0	0.0	0.0	0.0
Benzene	0.0	0.0	0.0	2.6	0.0	0.0	0.0	0.0
Quinone	0.0	0.0	0.4	0.4	0.4	0.0	0.0	0.0
Carbon dioxide	0.0	0.0	0.0	129.0	0.0	0.0	0.0	0.0
Maleic acid	0.0	0.0	1.0	0.0	1.0	0.005	0.0	0.0
Sodium nitrite	0.0	0.0	0.0	0.0	0.0	0.0	2065.6	2065.6
Sodium nitrate	0.0	0.0	0.0	0.0	0.0	0.0	2934.4	2934.4

Table 2: Utility Summary

E-601	E-602	E-603	E-604	E-605	E-606
lps	bfw → hps	bfw → hps	cw	hps	cw
1750 MJ/h	16,700 MJ/h	31,400 MJ/h	86,900 MJ/h	19,150 MJ/h	3050 MJ/h
841 kg/h	7295 kg/h	13,717 kg/h	2.08×10^6 kg/h	11,280 kg/h	73,000 kg/h

Table 3: Major Equipment Summary

Compressor and Drives

C-601
Centrifugal/electric drive
Carbon steel
Discharge pressure = 250 kPa
Efficiency = 65%
Power (shaft) = 3108 kW
MOC carbon steel

D-601A/B (not shown on PFD)
Electric/explosion proof
W = 3200 kW
98% efficient

Fired Heater

H-601
Total (process) heat duty required = 26,800 MJ/h
Design capacity = 32,000 kW
Carbon steel tubes
85% thermal efficiency
Design pressure = 300 kPa

Heat Exchangers

E-601
A = 14.6 m^2
1-2 exchanger, floating head, stainless steel
Process stream in tubes
Q = 1750 MJ/h
Design pressure = 600 kPa

E-602
A = 61.6 m^2
1-2 exchanger, floating head, stainless steel
Process stream in shell
Q =16,700 MJ/h
Design pressure = 4100 kPa

E-603
A = 1760 m^2
1-2 exchanger, floating head, stainless steel
Process stream in shell
Q = 31,400 MJ/h
Design pressure = 4100 kPa

E-604
A = 1088 m^2
1-2 exchanger, fixed head, stainless steel
Process stream in tubes
Q = 86,900 MJ/h
Design pressure = 300 kPa

E-605
A = 131 m^2
1-2 exchanger, floating head, stainless steel
Process stream in shell
Q = 19,150 MJ/h
Design pressure = 4100 kPa

E-606
A = 11.7 m^2
1-2 exchanger, floating head, stainless steel
Process stream in shell
Q = 3050 MJ/h
Design pressure = 300 kPa

E-607
A = 192 m^2
1-2 exchanger, floating head, stainless steel
Molten salt in tubes
Q = 55,600 MJ/h
Design pressure = 4100 kPa

Pumps

P-601 A/B
Centrifugal/electric drive
Carbon steel
Power = 0.3 kW (actual)
65% efficient
Design pressure = 300 kPa

P-602 A/B
Centrifugal/electric drive
Stainless steel
Power = 3.8 kW (actual)
65% efficient
Design pressure = 300 kPa

P-603 A/B
Reciprocating/electric drive
Stainless steel
Power = 0.1 kW (actual)
65% efficient
Design pressure = 200 kPa

P-604 A/B
Centrifugal/electric drive
Stainless steel
Power = 6.75 kW (actual)
65% efficient
Design pressure = 200 kPa

P-605 A/B
Centrifugal/electric drive
Stainless steel
Power = 0.7 kW (actual)
65% efficient
Design pressure = 400 kPa

P-606 A/B
Centrifugal/electric drive
Stainless steel
Power = 2.4 kW (actual)
65% efficient
Design pressure = 150 kPa

Reactor

R-601
Shell-and-tube vertical design
Stainless steel
L = 7.0 m
D = 3.8 m
12,100 1-in diameter, 6.4 m length catalyst-filled tubes
Design pressure = 300 kPa

Towers

T-601
Stainless steel
14 sieve trays plus reboiler and condenser
50% efficient trays
Partial condenser
Feeds on trays 1 and 14
Reflux ratio = 0.189
24-in tray spacing, 2.2-in weirs
Column height = 10 m
Diameter = 4.2 m
Design pressure = 110 kPa

T-602
Stainless steel
42 sieve trays plus reboiler and condenser
65% efficient trays
Total condenser
Feed on tray 27
Reflux ratio = 1.24
15-in tray spacing, 1.5-in weirs
Column height = 18 m
Diameter = 1.05 m
Design pressure = 110 kPa

Vessels

V-601
Horizontal
Carbon steel
L = 3.50 m
D = 1.17 m
Design pressure = 110 kPa

V-602
Horizontal
Stainless steel
L = 13.2 m
D = 4.4 m
Design pressure = 110 kPa

V-603
Horizontal
Stainless steel
L = 3.90 m
D = 1.30 m
Design pressure = 110 kPa

Capital Costs (Equipment):

Table 4. Equipment Cost Summary

Heat exchangers	**Purchase Cost ₹**	**Bare Module Cost (C_{bm}) ₹**
E-601	3303872.201	20741709.68
E-602	3763726.073	26605658.32
E-603	47106040.35	332991081.1
E-604	14402422.2	90418406.58
E-605	5067551.097	35822355.39
E-606	3407437.891	21391895.08
E-607	6257113.247	44231331.89

Pumps	**Purchase Cost (C_{p0}) ₹**	**Bare Module Cost (C_{bm}) ₹**
P-601 A/B	317962.8635	1287749.597
P-602 A/B	402752.9604	1957379.388
P-603 A/B	706584.1411	3624776.644
P-604 A/B	566371.3506	2752564.764
P-605 A/B	370956.6741	1802849.436
P-606 A/B	466345.5331	2266439.291

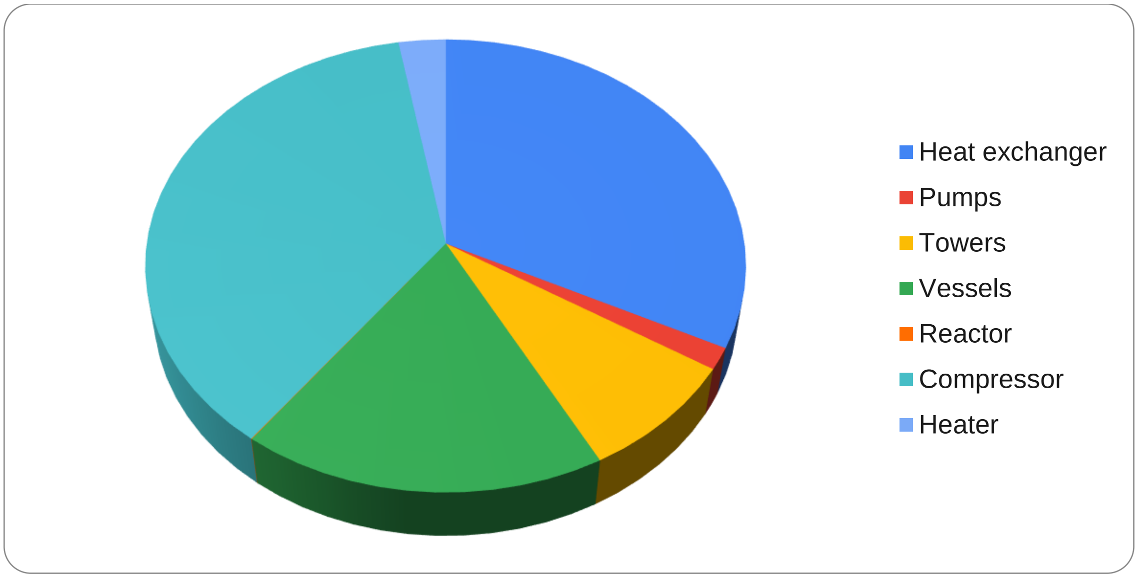
Reactor	**Purchase Cost (C_{p0}) ₹**	**Bare Module Cost (C_{bm}) ₹**
R-601	140164.7428	560658.9711

Fired Heater	**Purchase Cost ₹ (C_{p0})**	**Bare Module Cost (C_{bm}) ₹**
H-601	7831382783	49313721.65

Towers	**Purchase Cost (C_{p0}) ₹**	**Bare Module Cost (C_{bm}) ₹**
T-601	5870611.941	41094283.59
T-602	8805917.911	61641425.38

Vessels	**Purchase Cost (C_{p0}) ₹**	**Bare Module Cost (C_{bm}) ₹**
V-601	2551200.218	6206553.254
V-602	3290238.376	14409022.07
V-603	51028796.69	297616762.9

Compressor	**Purchase Cost (C_{p0}) ₹**	**Bare Module Cost (C_{bm}) ₹**
C-601	93332699.19	541329655.3
D-601 A/B	90442770.06	113053462.6



- Total Bare Module Cost: ₹ 176,87,59,971
- Total Module Cost: ₹ 2087136766
- Total Capital Cost of the plant: ₹ 632,16,20,190
- Total Grass roots: ₹639,66,20,190
- Total Land Cost: ₹ 7,50,00,000

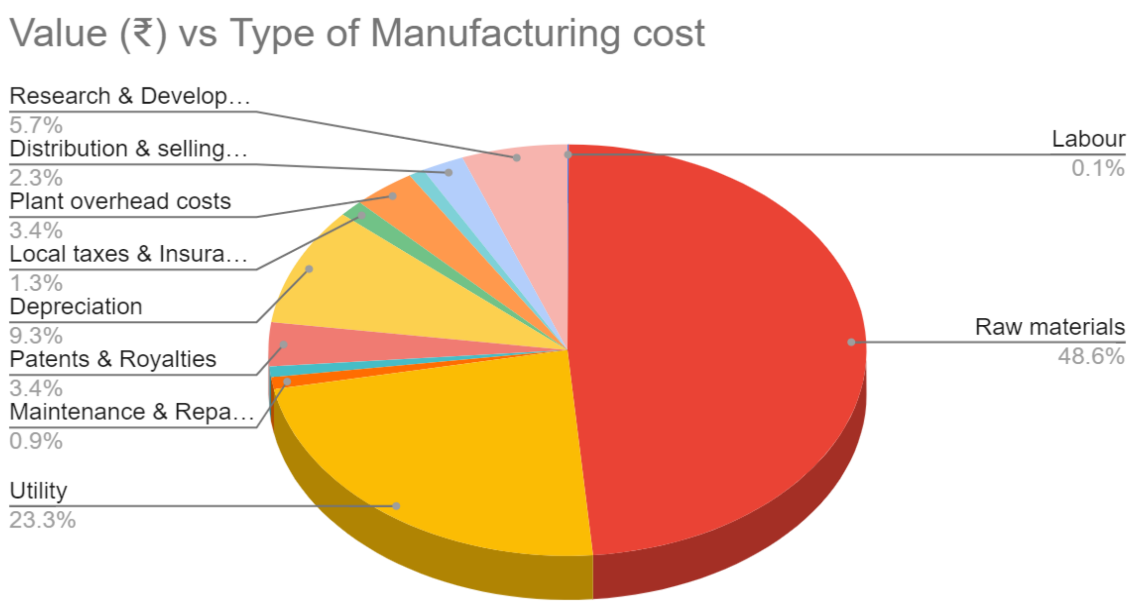
Investment Summary

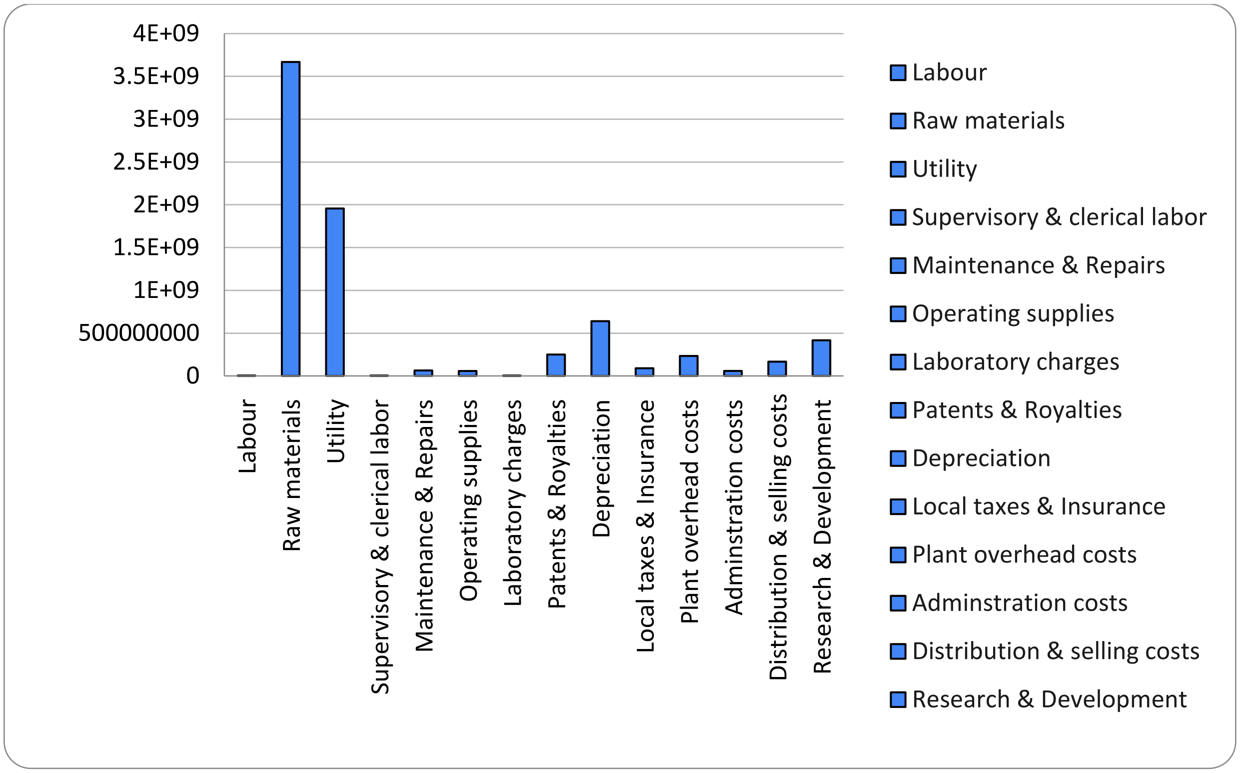
Land Area	5 acres(₹)
Cost of Land	Rs.7,50,00,000(₹)
FCI	6396620190(₹)
FCI L	6321620190(₹)
Salvation Value	100000000(₹)

Manufacturing Costs

Type of Manufacturing cost	Value (₹)
Labour(C_{ol})	4200000
Raw materials(C_{rm})	3347357622
Utility(C_{ut})	1606444183
Supervisory & clerical labor	420000
Maintenance & Repairs	63966201.9
Operating supplies	57569581.71

Laboratory charges	630000
Patents & Royalties	236713822.4
Depreciation	639662019
Local taxes & Insurance	89552682.66
Plant overhead costs	233251926.8
Administration costs	58312981.71
Distribution & selling costs	157809215
Research & Development	394523037.4
Total Cost of Manufacturing (COM_d)	7256040669
COM	7895702688
Total Direct Manufacturing Cost (DMC)	5637473961
Total Fixed Manufacturing Cost (FMC)	1077605792
General Manufacturing Expenses (GME)	1320786701
Total Costs	8035866455





Discussion:

- The plant is set up in Sambhajinagar, Maharashtra, India.
- Reason-This location was chosen because of pre-existence of Maleic Anhydride manufactures and dealers in the neighboring locations. Thus, indicating that there is an already established market for the product.
- This location was chosen based on the optimization of certain parameters like the availability of raw materials, the cost of land and utilities.
- The area of land for setting up the plant is 5 acres.
- The land cost-The cost of land was considered by considering the current land price in Maharashtra.
- The land is bought at the rate of ₹ 1,50,00,000/acre which costs ₹7,50,00,000.
- The fixed capital investment needed is ₹ 639,66,20,190.
- The total manufacturing costs (COM_d) amount to ₹ 8138509365.

- The Net Present Value (NPV) is ₹ 1149,12,86,790
- Discounted Payback Period (DPBP) is 1.83 years, with a PVR of 3.03 indicating that there are reasonable chances of the project being profitable.
- From the sensitivity analysis we infer that NPV is highly sensitive to changes in COMd and revenue, and least sensitive to changes in FCIL.
- The Break-even price of Maleic Anhydride is ₹ 108.17kg.

Conclusion:

The bare module for non-base conditions method was used for the calculation of the capital costs, and grassroots costs were calculated.

The direct manufacturing costs of raw materials, utilities, wastewater treatment and operating labor were calculated from scratch using appropriate formulae.

Other aspects of the direct manufacturing costs and fixed and general manufacturing costs were calculated using empirical relations, and it was observed that the direct manufacturing costs account for a significant chunk of the total manufacturing costs.

Non-discounted and discounted cash flow diagrams were generated.

Using the discounted cash flow diagrams, the profitability analysis and break even Analysis were carried out.

Further, Scenario analysis and Sensitivity analysis were done to assess the impact of changes in the dynamic market on the net present value of the project.

We conclude that from our estimates, the project has promising chances of economic success.

References:

1. Richard Turton, Analysis, Synthesis, and Design of Chemical Processes, Punjab, 4th Edition
2. https://www.indiamart.com
3. https://www.mahadiscom.in/consumer/en/home

APPENDICES:

APPENDIX A.1 Introduction and Process Integration

APPENDIX A.2 Material and Energy Balances

APPENDIX A.3 Capital Cost Estimation for Equipment and Utility Cost Estimations

APPENDIX A.4 Economic Analysis

APPENDIX A.1 Introduction

Currently, the preferred method to produce maleic anhydride in the United States is through isobutene in fluidized bed reactors. However, an alternative process via benzene may be carried out using a shell-and-tube reactor, with a catalyst in the tubes and a cooling medium is being circulated through the shell. The process produces 62.122 metric tons per year of 99.9% by mole AA product. The number of operating hours is taken to be 7665/yr.

PROCESS DESCRIPTION

A process flow diagram for the reactor section of the maleic anhydride process is shown in the figure below. Benzene is vaporized in E-601, mixed with compressed air, and then heated in a fired heater, H-601, prior to being sent to a packed-bed catalytic reactor, R-601, where the following reactions take place.

$$\underset{\text{benzene}}{C_6H_6} + 4.5O_2 \xrightarrow{k_1} \underset{\text{maleic anhydride}}{C_4H_2O_3} + 2CO_2 + 2H_2O$$

$$\underset{\text{benzene}}{C_6H_6} + 7.5O_2 \xrightarrow{k_2} 6CO_2 + 3H_2O$$

$$\underset{\text{maleic anhydride}}{C_4H_2O_3} + 3O_2 \xrightarrow{k_3} 4CO_2 + H_2O$$

$$\underset{\text{benzene}}{C_6H_6} + 1.5O_2 \xrightarrow{k_4} \underset{\text{quinone}}{C_6H_4O_2} + 2H_2O$$

All of the reactions are substantially exothermic. For this reason, a very high air-to-benzene ratio is maintained when it enters the reactor. It uses a standard air benzene inlet concentration (Stream 6) of about 1.5 vol%. A mixture of sodium nitrite and sodium nitrate molten salt is circulated simultaneously through the reactor's shell and through the tubes holding the catalyst and reactant gases to cool the system. Before entering the reactor, this molten salt is cooled in two external exchangers, E-602 and E-607.

The reactor effluent, Stream 7, which contains trace amounts of unreacted benzene, maleic anhydride, quinone, and combustion by-products, is cooled in E-603 before being sent to a column of the absorber, T-601, which includes a reboiler and condenser. In T-601, the recycled heavy organic solvent (dibutyl phthalate), Stream 9, comes into touch with the vapour feed. Maleic anhydride, quinone, and trace amounts of water are all absorbed by this solvent. Maleic anhydride combines with any water in the solvent leaving the bottom of the absorber T-601 to create maleic acid, which needs to be separated and purified from the maleic anhydride. The dibutyl phthalate is recovered as the bottom product, Stream 14, and recycled back to the absorber once the bottom product from the absorber is delivered to a separation tower, T-602. To make up for losses, a little quantity of new solvent, Stream 10, is introduced. The bottom product, 95 mol%

maleic acid, is separated from the overhead product from T-602, Stream 13, which is then transported to the maleic acid column, T-603.

APPENDIX A.2 Material and Energy Balances:

Stream Number	1	2	3	4	5	6	7	8
Temperature (°C)	30	30	30	30	170	460	608	270
Pressure (kPa)	101	101	280	101	250	235	220	215
Total kg/h	3304	3304	3304	80,490	80,490	83,794	83,794	83,794
Total kmol/h	42.3	42.3	42.3	2790.0	2790.0	2832.3	2825.2	2825.2
Component Flowrates (kmol/h)								
Maleic anhydride	0.0	0.0	0.0	0.0	0.0	0.0	26.3	26.3
Dibutyl phthalate	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitrogen	0.0	0.0	0.0	2205.0	2205.0	2205.0	2205.0	2205.0
Water	0.0	0.0	0.0	0.0	0.0	0.0	91.5	91.5
Oxygen	0.0	0.0	0.0	585.0	585.0	585.0	370.2	370.2
Benzene	42.3	42.3	42.3	0.0	0.0	42.3	2.6	2.6
Quinone	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.7
Carbon dioxide	0.0	0.0	0.0	0.0	0.0	0.0	129.0	129.0
Maleic acid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sodium nitrite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sodium nitrate	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

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Nitrogen	0.0	0.0	0.0	2205.0	0.0	0.0	0.0	0.0
Water	0.0	0.0	0.0	91.5	0.0	0.0	0.0	0.0
Oxygen	0.0	0.0	0.0	370.2	0.0	0.0	0.0	0.0
Benzene	0.0	0.0	0.0	2.6	0.0	0.0	0.0	0.0
Quinone	0.0	0.0	0.4	0.4	0.4	0.0	0.0	0.0
Carbon dioxide	0.0	0.0	0.0	129.0	0.0	0.0	0.0	0.0
Maleic acid	0.0	0.0	1.0	0.0	1.0	0.005	0.0	0.0
Sodium nitrite	0.0	0.0	0.0	0.0	0.0	0.0	2065.6	2065.6
Sodium nitrate	0.0	0.0	0.0	0.0	0.0	0.0	2934.4	2934.4

E-601	E-602	E-603	E-604	E-605	E-606
lps	bfw → hps	bfw → hps	cw	hps	cw
1750 MJ/h	16,700 MJ/h	31,400 MJ/h	86,900 MJ/h	19,150 MJ/h	3050 MJ/h
841 kg/h	7295 kg/h	13,717 kg/h	2.08×10^6 kg/h	11,280 kg/h	73,000 kg/h

APPENDIX A.3 Capital Cost Estimation for Equipment and Utility Cost Estimations

MANUFACTURING COSTS:

Direct Manufacturing Costs

Table 2. Manufacturing Costs

Type of Cost	Parameter Values	Cost (₹/year)= C_{OL}

Operating Labor	P=0, N_{NP}=11, N_{OL}=2.969, 14 operators are required, Average Salary=300000Rs. /year	**₹ 4200000**

Type of Cost	**Flowrate of waste water (kmol/h)**	**Volumetric Flowrate (m^3/h)**	**Cost of primary treatment (₹/m^3)**	**Cost (₹/year)= C_{WT}**
Wastewater Treatment	91.5	1.647	3364.36	**₹46545247.73**

Type of Cost	**Material**	**Amount needed (kg/h)**	**Cost (₹/kg)**	**Cost (₹/year)= C_{RM}**
Raw Materials	Benzene	3299.4	52	1441177920
	Air(O2)	18720	14	2201472000
	Dibutyl pthalate	27.8	110	25687200
			Total Cost	**₹3668337210**

Utility	**Equipment**	**Duty (GJ/hr)**	**Cost of Steam (₹/GJ)**	**Cost (₹/year)**
Low Pressure Steam	E-601	1.75	1089.7568	16019424.96

High Pressure Steam	E-602	16.7	1452.462	2037551369.4
	E-603	31.4	1452.462	383101377.1
	E-605	19.15	1452.6422	233643037.3
Cooling Water	E-60	86.9	29.04924	21204783.23
	E-606	3.05	29.04924	744241.5288
	Total			858464233.5

Utility	Equipment	Power(MJ/hr)	Groos calorific Value(MJ/kg)	Cost (₹/kg)	Annual Cost
Coal	E-601	1750	50	10	2940000
	E-602	16700	50	10	28056000
	E-603	31400	50	10	52752000
	E-604	86900	50	10	145992000
	E-605	19150	50	10	32172000
	E-606	3050	50	10	5124000
	E-607	55600	50	10	93408000
	Total				360444000

Utility	Equipment	Shaft Power Ws (kW)	Efficiency of Drive	Total power(kW)	Cost (₹/year)
	P-601 A/B	0.3	0.65	0.462	23261.53
	P-602 A/B	3.8	0.65	5.846	294646.15
Electricity	P-603 A/B	0.1	0.65	0.153	7753.84
	P-604 A/B	6.75	0.65	10.384	523384.61
	P-605 A/B	0.7	0.65	1.076	54276.92
	P-606 A/B	2.4	0.65	3.692	186092.30
	C-601	3108	1	3108	156643200
	D-601 A/B	3200	1	3200	161280000
	Total			6329.6153	319012615.4

Natural Gas	Energy Consumed (joules)	Thermal Efficiency	Actual Energy Consumed()	Gross Calorific Value	Cost per kg	Annual Cost(₹/year)
Fired Heater H-601	26800000000	0.85	31529411765	50000000	79	418458352.9

Formulae used:

$$\log_{10} C_p^o = K_1 + K_2 \log_{10}(A) + K_3[\log_{10}(A)]^2$$

Purchase cost of equipment

$$\log_{10} F_P = C_1 + C_2 \log_{10} P + C_3 (\log_{10} P)^2$$

in general

$$F_{P,vessel} = \frac{\dfrac{(P+1)D}{2[850 - 0.6(P+1)]} + 0.00315}{0.0063}$$

for Vessel

$$\log_{10} F_q = 0.4771 + 0.08516 \log_{10} N - 0.3473 (\log_{10} N)^2 \text{ for } N<20$$

$$F_q = 1 \text{ for } N \geq 20$$

For Sieve trays

$$C_{BM} = C_p^o F_{BM} = C_p^o (B_1 + B_2 F_M F_P)$$

Bare module cost

Fixed Capital Investment:

C_{tm}=1.18*total(C_{bm})

C_{tm}(2023)=1.18*{(heat exchangers=572202438)+(pump=27383518.24)+(Towers+Trays=102735709+43948469.01=146684178)+(vessels=318232338.2)+Reactor(560658.9711)+compressor(654383117.9)+Heater(49313721.65)

FCI=Gross-Root cost C_{gr}=(0.5*total(C_{bm}) + C_{tm})*CEPCI(854.6/397)
=6396620190₹

Working Capital:

FCI_L = 6321620190₹

Working Capital (Rs) = $0.15*FCI_L$

=948243028.5₹

- **Total Manufacturing Costs (COM)**= $0.28FCI+2.73C_{OL}+1.23(C_{UT}+C_{WT}+C_{RM})$= ₹8778171384
- **Total Manufacturing Costs (COM_d)**= $0.18FCI+2.73C_{OL}+1.23(C_{UT}+C_{WT}+C_{RM})$=₹8138509365
- **Total Direct Manufacturing Costs =** $0.069FCI+1.33C_{OL}+C_{UT}+C_{WT}+C_{RM}+0.03COM$ = ₹6368072025
- **Fixed Manufacturing Costs=**$0.708C_{OL}+0.168FCI$ = 0.708(4470942) +0.168(126849974.8) = ₹1077605792
- **General Manufacturing Costs =** $0.177C_{OL}+0.009FCI+0.16COM$ = ₹1390887180

CAPITAL COSTS

Table 3. Capital Costs

Equipment	Parameter	Description	Purchased Cost (₹)	Bare Module Cost (₹)
Heat Exchangers				
E-601	14.6 m^2	Floating head, carbon steel, shell-and-tube design Process stream in tubes.	3303872.201	20741709.68
E-602	61.6 m^2	Floating head, carbon steel, shell-and-tube design Process stream in tubes.	3763726.073	26605658.32

E-603	1760 m^2	Floating head, carbon steel, shell-and-tube design Process stream in tubes.	47106040.35	332991081.1
E-604	1088 m^2	Floating head, carbon steel, shell-and-tube design Process stream in tubes.	14402422.2	90418406.58
E-605	131 m^2	Fixed head, carbon steel, shell-and-tube design Process stream in tubes.	5067551.097	35822355.39
E-606	11.7 m^2	Floating head, carbon steel, shell-and-tube design Process stream in tubes.	3407437.891	21391895.08
E-607	192 m^2	Floating head, carbon steel, shell-and-tube design Process stream in tubes.	6257113.247	44231331.89
Pumps				
P-601 A/B (no. = 2)	0.3 kW	Centrifugal/ electric drive, Carbon Steel	317962.8635	1287749.597
P-602 A/B (no. = 2)	3.8 kW	Centrifugal/ electric drive, Stainless Steel	402752.9604	1957379.388
P-603 A/B (no. = 2)	0.1 kW	Reciprocating/electric drive, Stainless Steel	706584.1411	3624776.644
P-604 A/B (no. = 2)	6.75 kW	Centrifugal/ electric drive, Stainless Steel	566371.3506	2752564.764

P-605 A/B (no. = 2)	0.7 kW	Centrifugal/electric drive, Stainless Steel	370956.6741	1802849.436
P-606 A/B (no. = 2)	2.4 kW	Centrifugal/electric drive, Stainless Steel	466345.5331	2266439.291

Reactors				
R-601	79.3478 m^3	Shell and Tube(Vertical design), Stainless Steel	140164.7428	560658.9711
Towers				
T-601	138.474 m^3	Carbon steel 22 SS sieve trays plus reboiler and condenser 24-in tray spacing	5870611.941	41094283.59
T-602	62.3133 m^3	Carbon steel 26 SS sieve trays plus reboiler and condenser 18-in tray spacing	8805917.911	61641425.38

Vessels				
V-601	18.0530532 m^3	Horizontal Carbon steel	2551200.218	6206553.254
V-602	24.834888 m^3	Horizontal Carbon steel	3290238.376	14409022.07
V-603	962.919936 m^3	Horizontal Carbon steel	51028796.69	297616762.9

Appendix A.4: Economic Analysis-

4.1 Cash Flow Table

Table 4.1: Non-Discounted Cash Flow

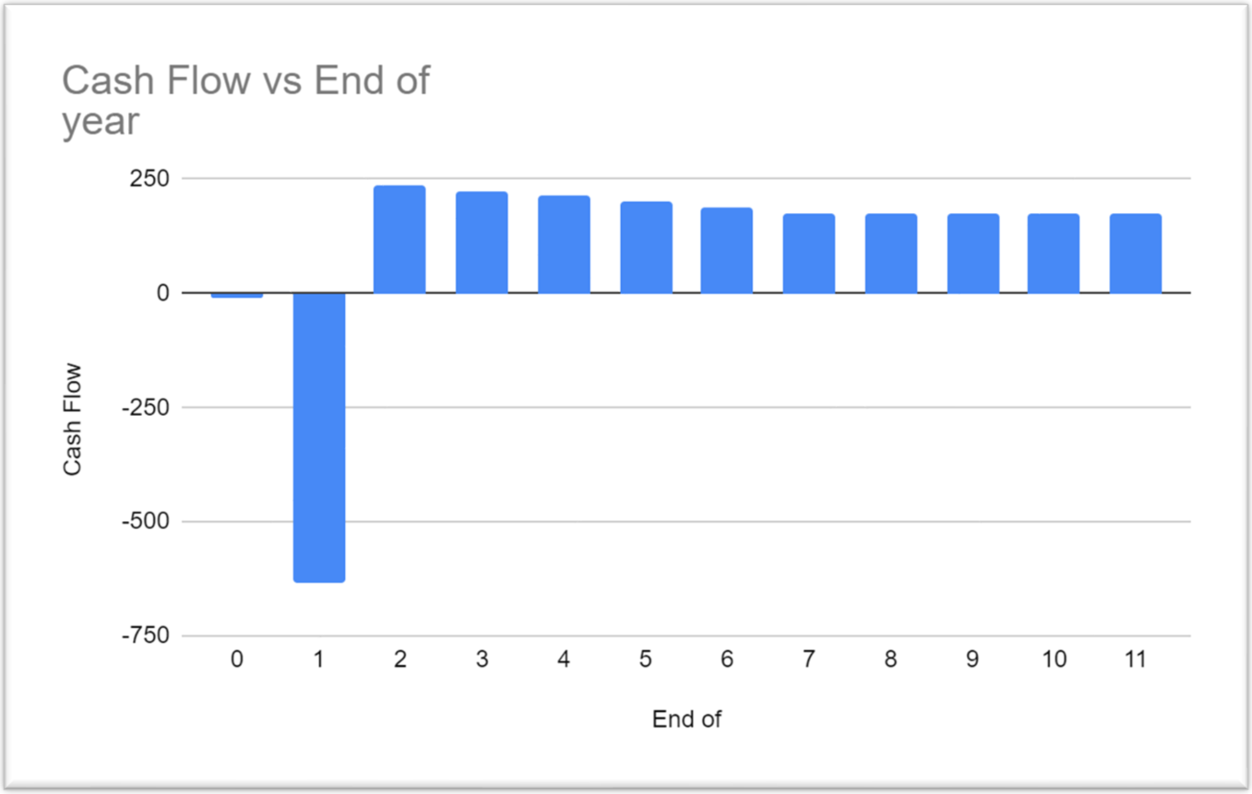
End of year	Investment	dk	R	COM_d	(R-COM-dk)*(1-t)+dk	Cash Flow	Cumulative Cash Flow
0	-7.5	0	0	0	0	-7.5	-7.5
1	-632.162019	0	0	0	0	-632.162019	-639.662019
2	0	207.3873397	1063.985664	813.8509365	237.3105112	237.3105112	-402.3515078
3	0	165.9098717	1063.985664	813.8509365	224.8672708	224.8672708	-177.484237
4	0	124.4324038	1063.985664	813.8509365	212.4240304	212.4240304	34.93979336
5	0	82.95493587	1063.985664	813.8509365	199.98079	199.98079	234.9205834
6	0	41.47746793	1063.985664	813.8509365	187.5375496	187.5375496	422.458133
7	0	0	1063.985664	813.8509365	175.0943093	175.0943093	597.5524423
8	0	0	1063.985664	813.8509365	175.0943093	175.0943093	772.6467516
9	0	0	1063.985664	813.8509365	175.0943093	175.0943093	947.7410608
10	0	0	1063.985664	813.8509365	175.0943093	175.0943093	1122.83537
11	0	0	1063.985664	813.8509365	175.0943093	175.0943093	1297.929679

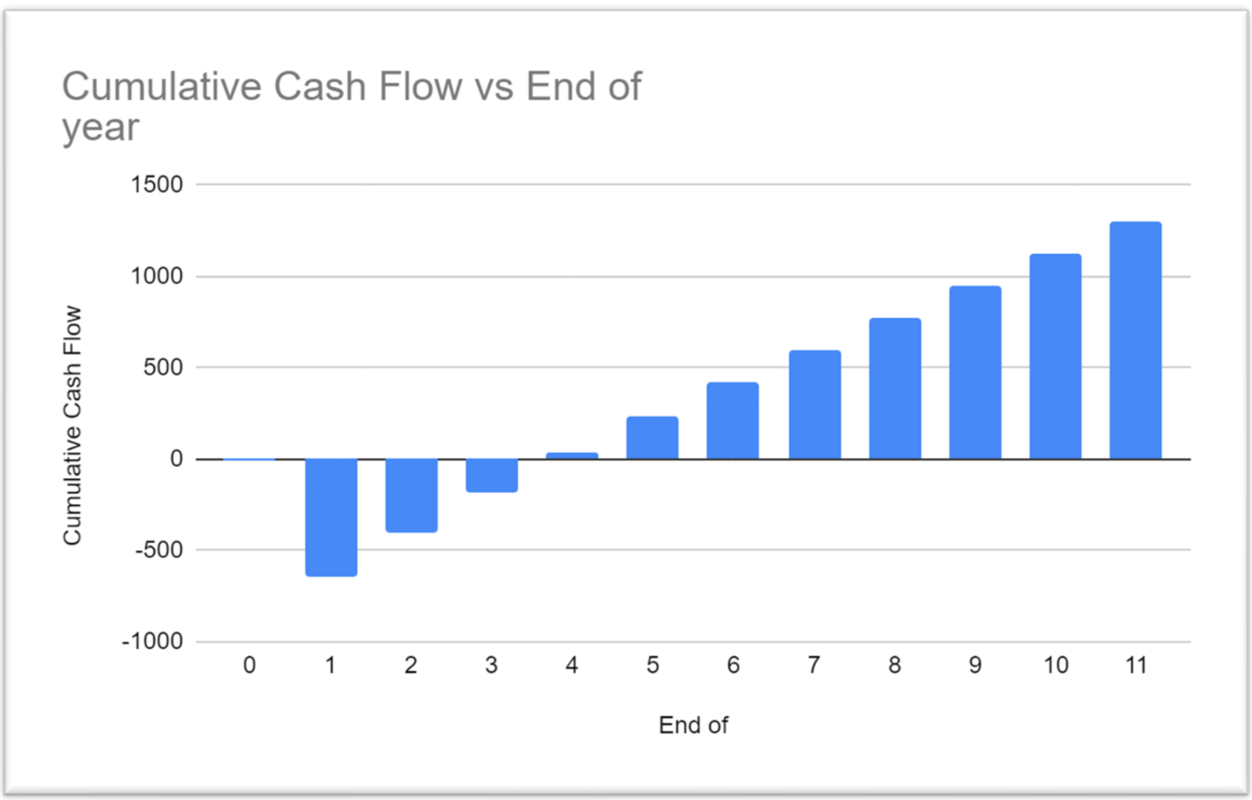
Table 4.2: MACRS Depreciation

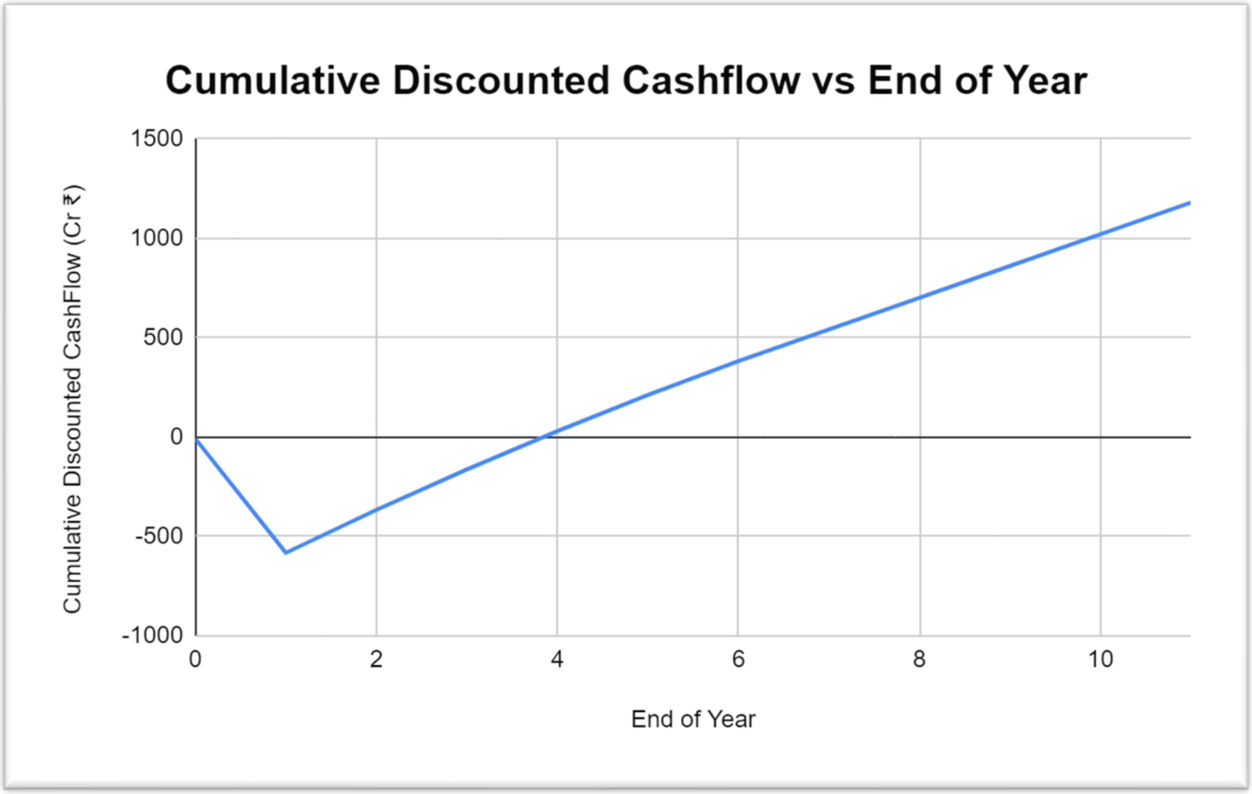
End of year	point	dk	sum dk	FCiL - dk
0	0	0	0	632.162019
1	0	0	0	632.162019
2	0.2	126.4324038	126.4324038	505.7296152
3	0.32	202.2918461	328.7242499	303.4377691
4	0.192	121.3751076	450.0993575	182.0626615
5	0.1152	72.82506459	522.9244221	109.2375969
6	0.1152	72.82506459	595.7494867	36.41253229
7	0.0576	36.41253229	632.162019	0

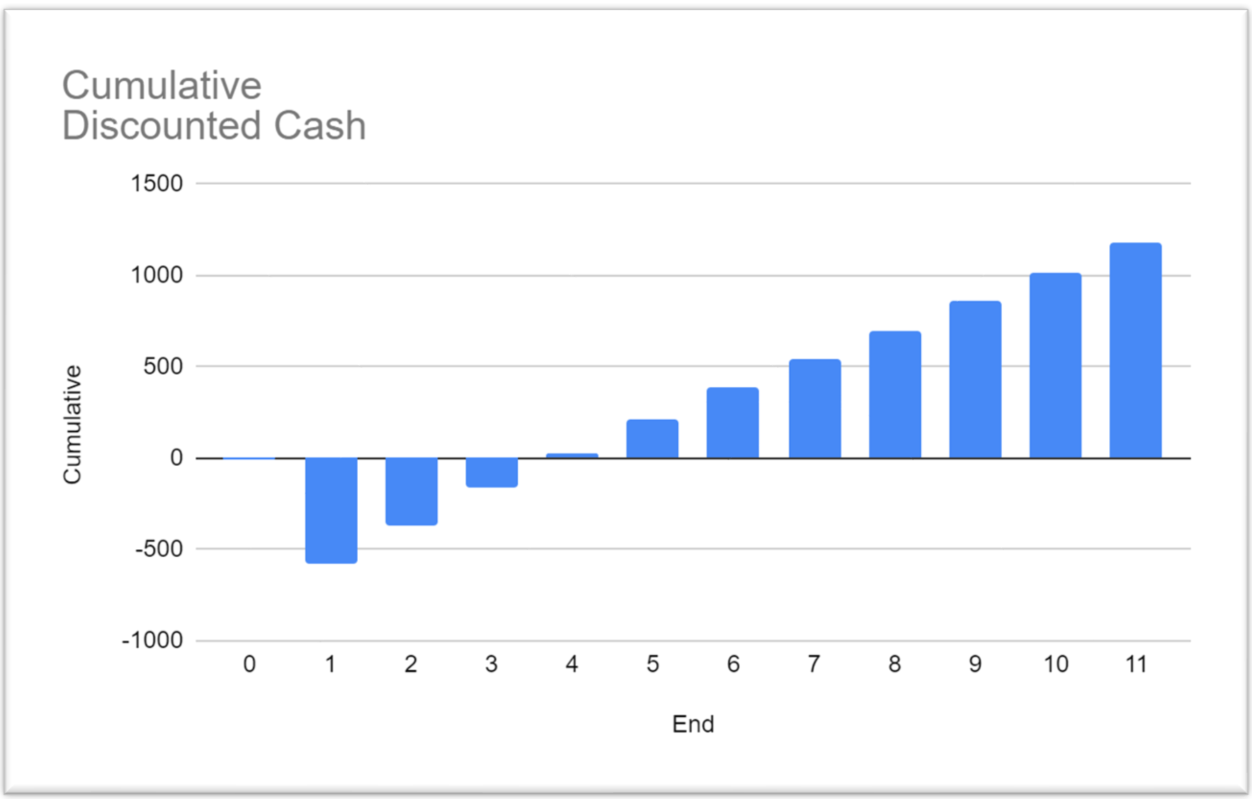
Table 4.3 Discounted Cash Flow

End of Year	Non discounted cash flow	Discounted Cash Flow	Cumulative Discounted Cash Flow (Cr Rs)
0	-7.5	-6.818181818	-6.75
1	-632.162019	-574.6927445	-581.4427445
2	237.3105112	215.7368283	-365.7059162
3	224.8672708	204.4247916	-161.2811246
4	212.4240304	193.1127549	31.83163032
5	199.98079	181.8007182	213.6323485
6	187.5375496	170.4886815	384.12103
7	175.0943093	159.1766448	543.2976748
8	175.0943093	159.1766448	702.4743196
9	175.0943093	159.1766448	861.6509644
10	175.0943093	159.1766448	1020.827609
11	175.0943093	159.1766448	1180.004254


Cash Flow vs End of year
250
0
-250
-500
-750
Cash Flow
0
1
2
3
4
5
6
7
8
9
10
11
End of


Cumulative Cash Flow vs End of year
1500
1000
500
0
-500
-1000
Cumulative Cash Flow
0
1
2
3
4
5
6
7
8
9
10
11
End of


Cumulative Discounted Cashflow vs End of Year
Cumulative Discounted CashFlow (Cr ₹)
1500
1000
500
0
-500
-1000
0
2
4
6
8
10
End of Year


Cumulative
Discounted Cash
Cumulative
1500
1000
500
0
-500
-1000
0
1
2
3
4
5
6
7
8
9
10
11
End

Profitability Analysis

1. Time Criterion

Discounted worth of land = ₹ -7.5 Cr
Discounted worth of Working Capital = ₹ -948243028.5
Sum of the discounted worth of land and WC = ₹ -1023242028.5 Cr
From interpolating in the cumulative cash flow diagram, we get
Discounted payback period (DPBP) = 1.88 years.

2. Cash Criterion

Net present Value (NPV) = ₹ 1180.004254 Cr
Sum of positive discounted cash flows = ₹ 1761.446999 Cr
Sum of negative discounted cash flows = ₹ 581.5109264 Cr
Present Value Ratio (PVR) = 3.03
NPV is ₹ 1180.004254 Cr, which is a great amount considering the initial investment in the plant.
PVR is 3.03, which is greater than 1, therefore our plant is profitable.

3.Interest Rate Criterion of Profitability

Table 4.4: Variation of NPV with Discount rate

Discounted rate(%)	NPV Cr(₹)
10	1180.004254
20	1081.608066
75	741.6741025
100	648.9648397
350	370.8370512
500	259.5859359

4.2 Break Even Analysis:

By varying the price of Maleic Anhydride, we tried to see how are NPV changes

They are tabulated as below

Table4.5: Variation of NPV with the selling price of Maleic Anhydride

Price of Maleic Anhydride (₹ /Kg)	NPV (Cr ₹)
100	-106.163426
150	543.4162103
199	1180.004254
250	1842.57583

Using Interpolation, the Breakeven price of Maleic Anhydride (at which NPV= 0) is ₹ 108.171/kg.

4.3 Scenario Analysis

Table 4.4: Worst case and best-case values for the parameters for scenario analysis

Parameter	Worst Case	Best Case
Revenue, R	-20%	+5%
Cost of Manufacture, COM_d	+10%	-10%
Capital Investment, FCI_L	+30%	-20%

Table 4.5: Net Present Values (NPVs) for the Scenario Analysis

Case	Net Present Value
Worst Case	-812.7499362
Base Case	1180.004254
Best Case	1955.993304

As can be seen, the worst-case scenario results in a negative NPV. However, we can't estimate the likelihood of this scenario, but it gives the idea of the best loss and best profit we get.

4.4 Sensitivity analysis

Parameters	**percentage**	**Value**	**NPV**	**percentage**	**value**	**NPV**	**Si (delta(npv)/delta(value))**
Revenue, R	+0.5%	106.93055923	1213.858343	-0.5%	105.8665736	1146.150165	63.63636306
Cost of Manufacture	+0.5%	81.79201912	1154.108997	-0.5%	80.97816818	1205.899511	-63.63636346
Capital Investment, FCIL	+0.5%	63.53228291	1177.992829	-0.5%	62.90012089	1182.015679	-6.36363761

Summary of Sensitivity Analysis

coefficient	Parameter value	sensitivity
s1	Revenue, R	63.63636306
s2	Cost of Manufacture	-63.63636346
s3	Capital Investment, FCIL	-6.36363761

The NPV is least sensitive to changes in FCIL and significantly sensitive to changes in Revenue and Cost of Manufacturing.