Economic Analysis

Hydrogen cyanide is prepared by the Andrussow method

Group 06

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Content

1. Capital Investment

Total capital investment consists of two parts, fixed capital investment (FCI) and working capital investment. Fixed capital investment is certain percentage amount of the purchased equipment while the working capital is 15% of the total capital investment.

1.1 Purchased Equipment Cost

Chemical Engineering Plant Cost Index (CEPCI) for all the corresponding year is shown as follows:

CEPCI (1989) = 357.6
CEPCI (1998) = 389.5
CEPCI (2004) = 444.2
CEPCI (2010) = 550.8
CEPCI (2019) = 607.5
CEPCI (2021) = 720.4

All the result is shown in the tables below.

Table 1. Purchased equipment cost of heat exchanger.

	Shell and tube heat exchanger HE-001	**Shell and tube heat exchanger HE-002**	**Shell and tube heat exchanger HE-003A**	**Shell and tube heat exchanger HE-003B**	**Shell and tube heat exchanger HE-004**
S （m^3）	4.2	12.02	618.82	9.37	95.93
a	3200	3200	3200	3200	3200
b	70	70	70	70	70
n	1.2	1.2	1.2	1.2	1.2
Ce in 2010 $	32392	33384	188666	33026	48728
Ce in 2021 $	42366	43663	246759	43195	63732
In UK £	33633	34662	195894	34291	50595

Table 2. Purchased equipment cost of heat exchanger.

	Shell and tube heat exchanger HE-005A	**Shell and tube heat exchanger HE-005B**	**Shell and tube heat exchanger HE-006A**	**Shell and tube heat exchanger HE-006B**	**Shell and tube heat exchanger HE-007A**
S （m^3）	6.59	40.2	77.76	2.98	25.89
a	3200	3200	3200	3200	3200
b	70	70	70	70	70
n	1.2	1.2	1.2	1.2	1.2
Ce in 2010 $	32673	37891	45002	32260	35474
Ce in 2021 $	42733	49558	58859	42193	46397
In UK £	33924	39342	46726	33495	36833

Table 3. Purchased equipment cost of heat exchanger.

	Shell and tube heat exchanger HE-007B	**Shell and tube heat exchanger HE-008**	**Shell and tube heat exchanger HE-009**	**Condenser C-001**	**Boiler BL-001**
S （m^3）	254	76.62	6.94	190.78	155.21
a	3200	3200	3200	3200	3200
b	70	70	70	70	70
n	1.2	1.2	1.2	1.2	1.2
Ce in 2010 $	85814	44774	32716	70171	61799
Ce in 2021 $	112238	58560	42789	91778	80828
In UK £	89102	46489	33969	72860	64167

Table 4. Purchased equipment cost of heat exchanger.

	Boiler BL-001	**Air-cooled Heat exchanger AC-001**
S （m^3）	52.34	301.64
a	3200	3200
b	70	70
n	1.2	1.2
Ce in 2010 $	40085	98143
Ce in 2021 $	52428	128363
In UK £	41621	101903

Table 5. Purchased equipment cost of distillation column DC-001.

	Distillation column vessel	**Distillation column trays**
S	2965.82 kg	1.1 m
a	17400	210
b	79	400
n	0.85	1.9
Ce in 2010 $	88024	689
Ce in 2021 $	115128	902
In UK £	91396	716
Quantity	1	25
Total cost £	109291	

Table 6. Purchased equipment cost of Absorption tower A-001.

	A-001 vessel	**A-001 packing**
S m^2	5384.47 kg	44.97
a	17400	0
b	79	5500
n	0.85	1
Ce in 2010 $	134646	247335
Ce in 2021 $	176106	323493
In UK £	139804	256810
Total cost £	396615	

Table 7. Purchased equipment cost of Absorption tower A-002.

	A-002 vessel	**A-002 packin**
S m^2	3394.04	38.274
a	17400	0
b	79	5500
n	0.85	1
Ce in 2010 $	96602	210507
Ce in 2021 $	126347	275325
In UK £	100303	218571
Total cost £	318874	

Table 8. Purchased equipment cost of furnace, waste heat boiler and external deaeration.

	Furnace F-001	**Waste heat boiler WH-001**	**External deaeration ED-001**
S	22 MW	51480 kg/h	11500 kg/h
a	43000	124000	124000
b	111000	10	10
n	0.8	1	1
Ce in 2010 $	1359016	638800	239000
Ce in 2021 $	1777478	835497	312592
Total cost £	1411080	663272	248156

Table 9. Purchased equipment cost of evaporator, centrifuge, dryer.

	Evaporator EV-001	**Centrifuge CN-001**	**Dry D-001**
S	76.62 m^2	15 kW	15 m^2
a	330	65000	15000
b	36000	750	10500
n	0.55	1.5	0.9
Ce in 2010 $	391793	108571	135136
Ce in 2021 $	512432	142002	176746
Total cost £	406802	112730	140313

Table 10. Purchased equipment cost of mixing tank 001.

	MT-001 tank	**Mt-001 Agitator**
S	60 m^3	15 kW
a	5800	17000
b	1600	1130
n	0.7	1.05
Ce in 2010 $	33908	36408
Ce in 2021 $	44348	47618
In UK £	35207	37802
Total cost £	73009	

Table 11. Purchased equipment cost of mixing tank 002.

	MT-002 tank	**Mt-002 Agitator**
S	5 m^3	8 kW
a	5800	17000
b	1600	1130
n	0.7	1.05
Ce in 2010 $	10736	27031
Ce in 2021 $	14042	35354
In UK £	11148	28066
Total cost £	39214	

Table 12. Purchased equipment cost of mixing tank 003.

	MT-003 tank	**Mt-003 Agitator**
S	12 m^3	9 kW
a	5800	17000
b	1600	1130
n	0.7	1.05
Ce in 2010 $	14911	28351
Ce in 2021 $	19502	37081
In UK £	15482	29437
Total cost £	44919	

Table 13. Purchased equipment cost of blender 001.

	BE-001 tank	**BE-001 Agitator**
S	3.8 m^3	30 kW
a	113000	17000
b	3250	1130
n	0.65	1.05
Ce in 2010 $	120740	57184
Ce in 2021 $	157918	74792
In UK £	125366	59375
Total cost £	184741	

Table 14. Purchased equipment cost of tank-001, vessel-002 and flash column-001.

	Tank T-001	**Vessel V-002**	**Flash column FC-001**
S	970 m^3	126.88 kg	751 kg
a	5800	12800	17400
b	1600	73	79
n	0.7	0.85	0.85
Ce in 2010 $	202979	17279	39375
Ce in 2021 $	265479	22600	51499
In UK £	210755	17941	40883

Table 15. Purchased equipment cost of compressor and water treatment

	Compressor CM-001	**Water treatment WT-001**
S	167 kW	85 m^3/h
a	260000	14000
b	2700	6200
n	0.75	0.75
Ce in 2010 $	385430	187562
Ce in 2021 $	504110	245316
In UK £	400196	194748

Table 16. Purchased equipment cost of reactor R-001.

	Reactor R-001
S kg	21524
a	10200
b	31
n	0.85
Ce in 2010 $	159599
Ce in 2021 $	208742
In UK £	165713

Table 17. Purchased equipment cost of blower.

	Blower B-001&B-002	**Blower B-003**	**Blower B-004&B-005**	**Blower B-006&B-007**
S m^3/h	80067	44186.8	48277.9	15561.3
a	4450	4450	4450	4450
b	57	57	57	57
n	0.8	0.8	0.8	0.8
Ce in 2010 $	481580	301008	322777	133130
Ce in 2021 $	629866	393692	422165	174123
In UK £	500030	312539	335143	138230

Table 18. Purchased equipment cost of diaphragm pumps.

	Diaphragm pump DP-001&DP-002	**Diaphragm pump DP-003&DP-004**	**Diaphragm pump DP-005A&DP-006A**	**Diaphragm pump DP-005B&DP-006B**
S W	233.84	838.45	2536.16	4668.53
S HP	2	2	4	6.5
a	-	-	-	-
b	-	-	-	-
n	-	-	-	-
Ce in 1989 $	1000	1000	1400	1700
Ce in 2021 $	2015	2015	2820	3425
In UK £	1599	1599	2239	2719

Table 19. Purchased equipment cost of diaphragm pumps.

	Diaphragm pump DP-007&DP-008	**Diaphragm pump DP-009&DP-010**	**Diaphragm pump DP-011&DP-012**	**Diaphragm pump DP-013&DP-014**	**Diaphragm pump DP-015&DP-016**
S W	477.77	80.04	736.97	8965.88	153.57
S HP	2	2	2	12.5	2
a	-	-	-	-	
b	-	-	-	-	
n	-	-	-	-	
Ce in 1989 $	1000	1000	1000	2200	1000
Ce in 2021 $	2015	2015	2015	4432	2015
In UK £	1599	1599	1599	3518	1599

Table 20. Purchased equipment cost of screw pumps.

	Screw pump SP-001	**Diaphragm pump DP-009&DP-010**
S W	232.45	58.888
S HP	1	1
a	-	-
b	-	-
n	-	-
Ce in 1989 $	2600	2600
Ce in 2021 $	5238	5238
In UK £	4158	4158

Since some pumps have less than the minimum power rating (on the pump power diagram), consider their power as the minimum power rating.

Table 21. Purchased equipment cost of centrifugal pumps.

	Centrifugal pump P-001&P-002	**Centrifugal pump P-003&P-004**	**Centrifugal pump P-005&P-006**	**Centrifugal pump P-007&P-008**	**Centrifugal pump P-009&P-010**
S L/s	64.38	64.38	23.35	23.35	0.16
a	6900	6900	6900	6900	6900
b	206	206	206	206	206
n	0.9	0.9	0.9	0.9	0.9
Ce in 2010 $	15644	15644	10410	10410	6939
Ce in 2021 $	20461	20461	13615	13615	9076
In UK £	16243	16243	10809	10809	7205

Table 22. Purchased equipment cost of centrifugal pumps.

	Centrifugal pump P-011&P-012	Centrifugal pump P-013&P-014	Centrifugal pump P-015&P-016	Centrifugal pump P-017&P-018	Centrifugal pump P-019&P-020
S L/s	23.73	99.01	2.38	2.37	5.27
a	6900	6900	6900	6900	6900
b	206	206	206	206	206
n	0.9	0.9	0.9	0.9	0.9
Ce in 2010 $	10461.1	19782	7349	7348	7820
Ce in 2021 $	13682.2	25873	9612	9611	10228
In UK £	10861.8	20540	7631	7630	8120

Table 23. Purchased equipment cost of centrifugal pumps.

	Centrifugal pump P-021&P-022	**Centrifugal pump P-023&P-024**	**Centrifugal pump P-025&P-026**	**Centrifugal pump P-027&P-028**	**Centrifugal pump P-029&P-030**
S L/s	22.69	27.23	8.29	3.83	2.65
a	6900	6900	6900	6900	6900
b	206	206	206	206	206
n	0.9	0.9	0.9	0.9	0.9
Ce in 2010 $	10321	10931	8283	7590	7395
Ce in 2021 $	13499	14297	10833	9927	9672
In UK £	10716	11350	8600	7881	7678

Table 24. Purchased equipment cost of centrifugal pumps.

	Centrifugal pump P-031&P-032	**Centrifugal pump P-033&P-034**	**Centrifugal pump P-035&P-036**	**Centrifugal pump P-037&P-038**	**Centrifugal pump P-039&P-040**
S L/s	0.04	6.59	3.59	2.29	51.53
a	6900	6900	6900	6900	6900
b	206	206	206	206	206
n	0.9	0.9	0.9	0.9	0.9
Ce in 2010 $	6911	8024	7551	7334	14057
Ce in 2021 $	9039	10494	9876	9593	18386
In UK £	7176	8331	7840	7615	14596

Table 25. Purchased equipment cost of fan FN-001.

	Fan FN-001
S 1000cfm	125
a	-
b	-
n	-
Ce in 1989 $	150000
Ce in 2021 $	302181
In UK £	239891

Table 26. Purchased equipment cost of fan FN-002

	Fan FN-002
X	10 lbs air/hr/(suction Torr)
Ce in 2009 $	171443
Ce in 2021 $	224233
In UK £	178011

Vacuum pumps: $C = 16.0X^{1,03}$ K$,
$0.3 < X < 15$ (lbs air/hr)/(suction Torr).

The cost of vacuum fan can be calculated by using the above formula.

Table 27. Purchased equipment cost of turbine TB-001.

	Turbine TB-001
S kW	200
a	-12000
b	1630
n	0.75
Ce in 2010 $	74688
Ce in 2021 $	97686
In UK £	77550

Table 28. Purchased equipment cost of conveyor

	Conveyor Belt 0.5 m wide CY-001	**Conveyor Belt 0.5 m wide CY-002**
S m	19.3	50
a	36000	36000
b	640	640
n	1	1
Ce in 2010 $	48352	68000
Ce in 2021 $	63240	88938
In UK £	50204	70605

Table 29. Purchased equipment cost of chimney

	Chimney CN-001
S ft	120
a	-
b	-
n	-
Ce in 1989 £	27000
Ce in 2021 £	54393
In UK £	43180

1.2 Fixed Capital & Working Capital

Therefore, the value for fixed capital and working capital can be calculated according to the tables above.

Table 30. Total Capital Investment

	Component	Percent	Costs (£)
Direct cost	Purchased equipment delivered	100%	8,574,350
	Purchased equipment installation	47%	4,029,945
	Instrumentation and control (installed)	36%	3,086,766
	Piping (installed)	68%	5,830,558
	Electrical systems (installed)	11%	943,179
	Buildings (including services)	18%	1,543,383
	Service facilities (installed)	70%	6,002,045
	Total direct cost	350%	30,010,226
Indirect cost	Engineering and supervision	33%	2,829,536
	Construction expenses	41%	3,515,484
	Legal expenses	4%	342,974
	Contractor's fee	22%	1,886,357
	Contingency	44%	3,772,714
	Total indirect cost	144%	12,347,065
Fixed capital investment		85%	42,357,291
Working capital		15%	7,474,816
Total capital investment		100%	49,832,107

2. Annual revenue

It is assumed that the average maintenance period and break period per year are 5 days. The plant is operating 24 hours per day. The annual revenue is shown below.

Table 31. Annual revenue

Components	Value
Annual production period (day)	360
Annual production period (h)	8,640
Product price-HCN (£/t)	850
Product price-Steam (£/t)	10
Product price-AMS (£/t)	280
Total production of HCN (t/year)	57,370
Total production of Steam (t/year)	587,036
Total production of AMS (t/year)	21,047
Total revenue of HCN (£)	48,764,160
Total revenue of Steam (£)	5,870,362
Total revenue of AMS (£)	5,893,171
Total revenue (£)	60,527,693

3. Operating cost

Table 32. Annual operating cost

	Components	Price	Consumption (6640 kg/h HCN) t/year	Cost £/year
Raw material	Ammonia	400 £/t	43,494	17,397,504
	Natural gas	0.01 £/kWh	564,852,288 kWh/year	5,648,523
	Air	-	-	-
Consumables	H2SO4	180 £/t	18,541	3,337,459
	LM-4 Coolant	3357 £/t	350	1,176,393
	H2O2	385 £/t	950	365,904
	NaOH	500 £/t	432	216,000
	HCl	40 £/t	5,184	207,360
Utility	Electricity	0.1 £/kWh	18,635,422 kWh/year	1,863,542
	Air	-	-	-
	Platinum catalyst	24.67 £/g	20,267 g/year	500,000
	Process water	1.5 £/t	726,175	1,089,262
	Cooling water	0.1 £/t	3,080,318	308,032
Maintenance cost (10% Fixed capital investment) £		-	-	4,235,729
Operator and other staff cost £		-	-	4,816,497
Tax		-	-	423,573
Total operating cost £		-	-	41,585,778

Note: Change the coolant every 100 days, Platinum catalysts are replaced every three years.

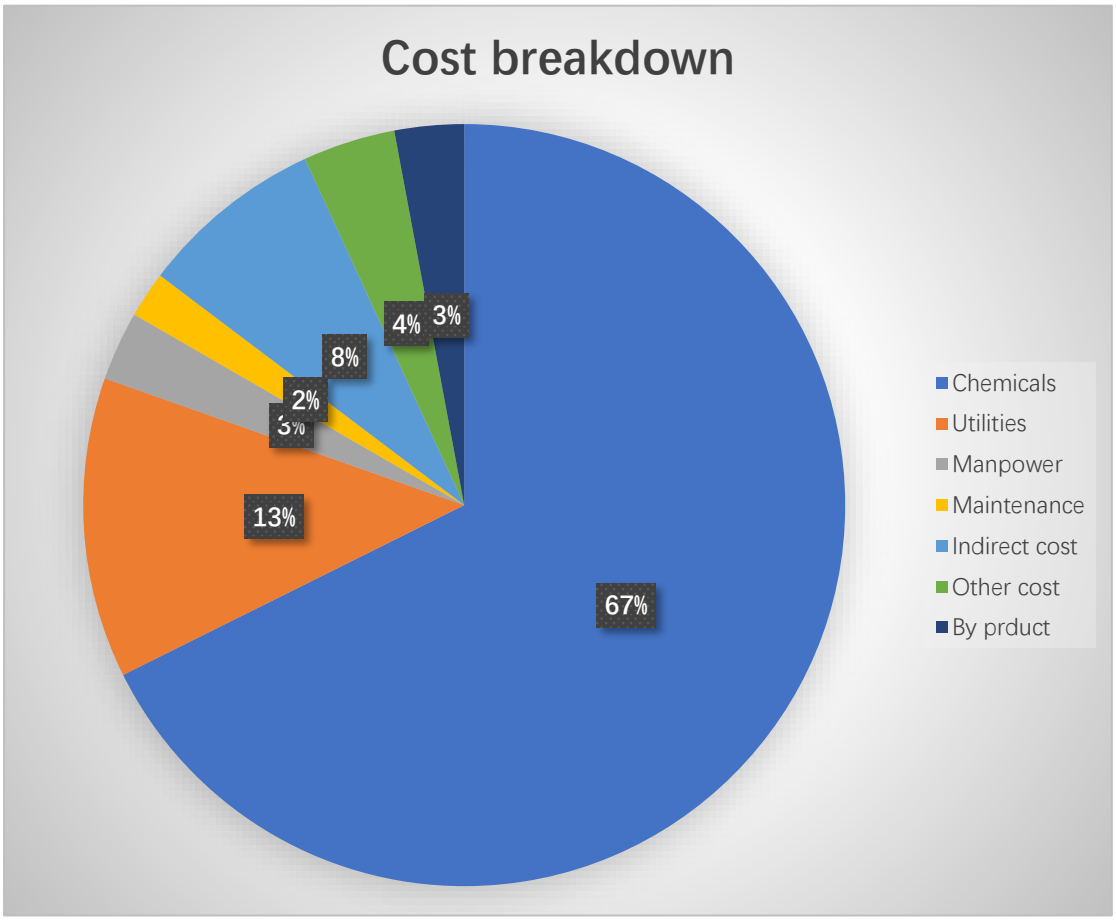


Figure 1. The cost breakdown for the project

4. Probability Analysis

Year	Costs	Revenues	Explanation
1st year	30% of fixed capital	0	Engineering + long lead-time items
2nd year	40–60% of fixed capital	0	Procurement and construction
3rd year	10–30% of fixed capital + working capital + FCOP + 30% VCOP	30% of design basis revenue	Remaining construction Initial production
4th year	FCOP + 50–90% VCOP	50–90% of design basis revenue	Shake-down of plant
5th year +	FCOP + VCOP	100% of design basis revenue	Full production at design rates

Figure 2. Annual cost and revenues

FCOP=Sum of all the variable costs of production minus by-product revenues=9,475,799 £

VCOP=Sum of all the fixed costs of production=32,109,979 £

4.1 Cost and revenues over 24 years

Table 33. Cost, revenues and explanation in the plant

Year	Cost £	Revenues £	Explanation
0	-12,707,187	0	Engineer + long lead-time items
1	-25,414,375	0	Procurement and construction
2	-30,819,338	18,158,308	Remaining construction & Initial production
3	-35,163,782	48,422,154	Shake-down of plant
4	-41,585,778	60,527,693	Full production
5	-41,585,778	60,527,693	Full production
6	-41,585,778	60,527,693	Full production
7	-41,585,778	60,527,693	Full production
8	-41,585,778	60,527,693	Full production
9	-41,585,778	60,527,693	Full production
10	-41,585,778	60,527,693	Full production
11	-41,585,778	60,527,693	Full production
12	-41,585,778	60,527,693	Full production
13	-41,585,778	60,527,693	Full production
14	-41,585,778	60,527,693	Full production
15	-41,585,778	60,527,693	Full production
16	-41,585,778	60,527,693	Full production
17	-41,585,778	60,527,693	Full production
18	-41,585,778	60,527,693	Full production
19	-41,585,778	60,527,693	Full production
20	-41,585,778	60,527,693	Full production
21	-41,585,778	60,527,693	Full production
22	-41,585,778	60,527,693	Full production
23	-33,558,283	45,395,770	75%VCOP+FCOP
24	-30,347,285	39,343,000	65%VCOP+FCOP

4.2 NPV and DCFIRR analysis and calculation

MIRR (Minimum Acceptable Rate of Return) =5 %

Table 34. Cash flow, present worth value, PV for DCFIRR and cumulative in the plant

Year	Cash flow (£)	Present worth value (£)	PV for DCFIRR (£)	Cumulative (£)
0	-12,707,187	-12,707,187	-12,707,187	-12,707,187
1	-25,414,375	-24,204,166	-20,022,499	-36,911,353
2	-12,661,030	-11,483,927	-7,858,628	-48,395,281
3	13,258,372	11,453,080	6,483,459	-36,942,200
4	18,941,915	15,583,560	7,297,588	-21,358,640
5	18,941,915	14,841,486	5,749,343	-6,517,154
6	18,941,915	14,134,749	4,529,571	7,617,595
7	18,941,915	13,461,665	3,568,584	21,079,260
8	18,941,915	12,820,634	2,811,478	33,899,894
9	18,941,915	12,210,127	2,214,999	46,110,022
10	18,941,915	11,628,693	1,745,069	57,738,714
11	18,941,915	11,074,945	1,374,837	68,813,660
12	18,941,915	10,547,567	1,083,154	79,361,227
13	18,941,915	10,045,302	853,354	89,406,529
14	18,941,915	9,566,954	672,307	98,973,483
15	18,941,915	9,111,385	529,672	108,084,868
16	18,941,915	8,677,510	417,297	116,762,378
17	18,941,915	8,264,295	328,764	125,026,672
18	18,941,915	7,870,757	259,014	132,897,429
19	18,941,915	7,495,959	204,062	140,393,388
20	18,941,915	7,139,009	160,769	147,532,397
21	18,941,915	6,799,056	126,660	154,331,453
22	18,941,915	6,475,291	99,788	160,806,744
23	11,837,487	3,853,946	49,131	164,660,690
24	8,995,715	2,789,283	29,415	167,449,973

According to table 34, the NPV, DCF and IRR values can be calculated.

Table 35. NPV and DCFIRR

NPV calc.	167,449,973	£
DCFIRR from "Goal Seek"	0.2693	
	26.93%	
NPV for DCFIRR	0	£
DCFIRR from "IRR"	26.93%	

The IRR (Internal Rate of Return) is larger than 26.93%, which means this is a good project.

4.3 Pay Back Period (PBP)

Note: Change the coolant every 100 days, Platinum catalysts are replaced every three years.

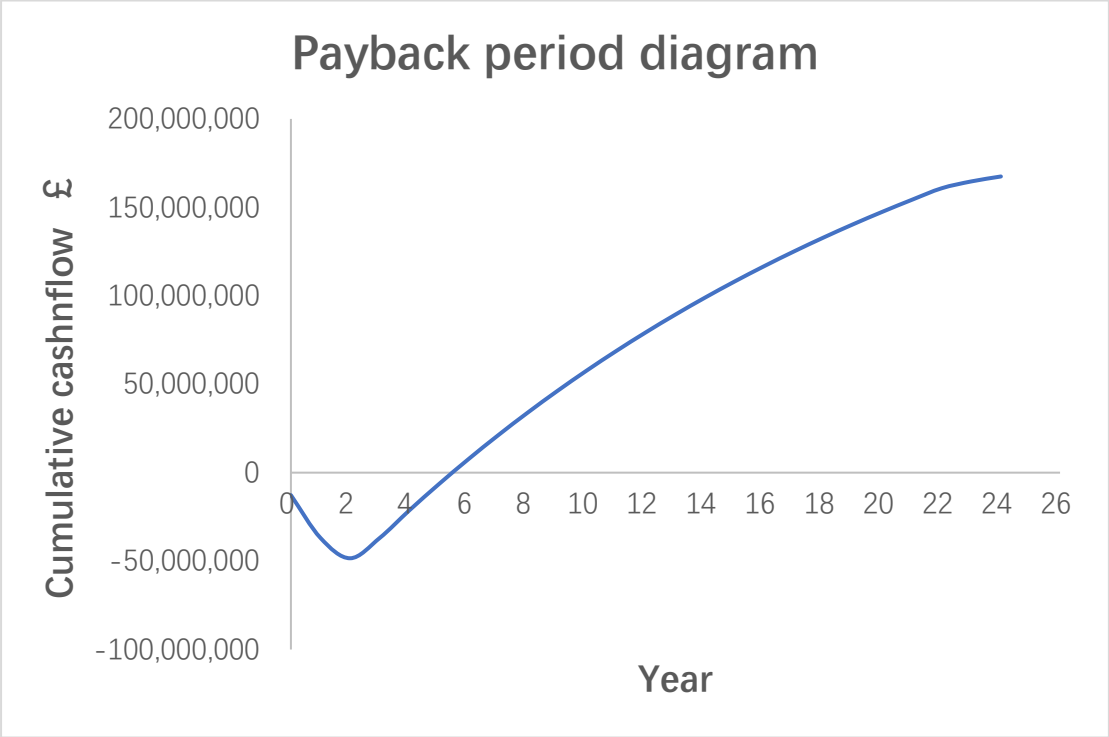


Figure 3. Payback period

According to figure 2, this plant is going to pay back in year 5.7. And by year six, cumulative cash flow is positive.

5. Sensitivity analysis

5.1 Sensitivity analysis for product

When economic fluctuations and the process flow of the factory has a downward trend caused the price of hydrogen cyanide to drop to 630 pounds per ton. In this case,

Table 36. Cost and revenues in the plant when HCN is 630 £ /T

Year	Cost £	Revenues £
0	-12,707,187	0
1	-25,414,375	0
2	-30,819,338	14,371,914
3	-35,163,782	38,325,105
4	-41,585,778	47,906,381
5	-41,585,778	47,906,381
6	-41,585,778	47,906,381
7	-41,585,778	47,906,381
8	-41,585,778	47,906,381
9	-41,585,778	47,906,381
10	-41,585,778	47,906,381
11	-41,585,778	47,906,381
12	-41,585,778	47,906,381
13	-41,585,778	47,906,381
14	-41,585,778	47,906,381
15	-41,585,778	47,906,381
16	-41,585,778	47,906,381
17	-41,585,778	47,906,381
18	-41,585,778	47,906,381
19	-41,585,778	47,906,381
20	-41,585,778	47,906,381
21	-41,585,778	47,906,381
22	-41,585,778	47,906,381
23	-33,558,283	35,929,786
24	-30,347,285	31,139,148

Therefore, the NPV and DCFIRR analysis is shown below

Table 37. NPV and DCFIRR analysis for this plant when HCN is 630 £ /T

Year	Cash flow (£)	Present worth value (£)	PV for DCFIRR (£)	Cumulative (£)
0	-12,707,187	-12,707,187	-12,707,187	-12,707,187
1	-25,414,375	-24,204,166	-20,203,581	-36,911,353
2	-16,447,423	-14,918,298	-10,394,311	-51,829,651
3	3,161,323	2,730,869	1,588,238	-49,098,782
4	6,320,603	5,199,976	2,524,377	-43,898,806
5	6,320,603	4,952,358	2,006,795	-38,946,448
6	6,320,603	4,716,531	1,595,336	-34,229,917
7	6,320,603	4,491,935	1,268,239	-29,737,982
8	6,320,603	4,278,033	1,008,207	-25,459,949
9	6,320,603	4,074,317	801,491	-21,385,632
10	6,320,603	3,880,302	637,159	-17,505,330
11	6,320,603	3,695,526	506,520	-13,809,804
12	6,320,603	3,519,548	402,667	-10,290,256
13	6,320,603	3,351,951	320,106	-6,938,305
14	6,320,603	3,192,334	254,474	-3,745,971
15	6,320,603	3,040,318	202,298	-705,653
16	6,320,603	2,895,541	160,820	2,189,888
17	6,320,603	2,757,658	127,847	4,947,546
18	6,320,603	2,626,341	101,634	7,573,887
19	6,320,603	2,501,277	80,796	10,075,165
20	6,320,603	2,382,169	64,230	12,457,333
21	6,320,603	2,268,732	51,061	14,726,066
22	6,320,603	2,160,697	40,591	16,886,763
23	2,371,503	772,093	12,107	17,658,856
24	791,862	245,531	3,214	17,904,387

Table 38. NPV and DCFIRR

NPV calc.	17,904,387	£
DCFIRR from "Goal Seek"	0.0978	
	9.78%	
NPV for DCFIRR	0	£
DCFIRR from "IRR"	8.20%	

Therefore, when the price of HCN is 630 pounds, it is the lowest price acceptable for this project.

According to the table 37, the payback period diagram can be obtained.

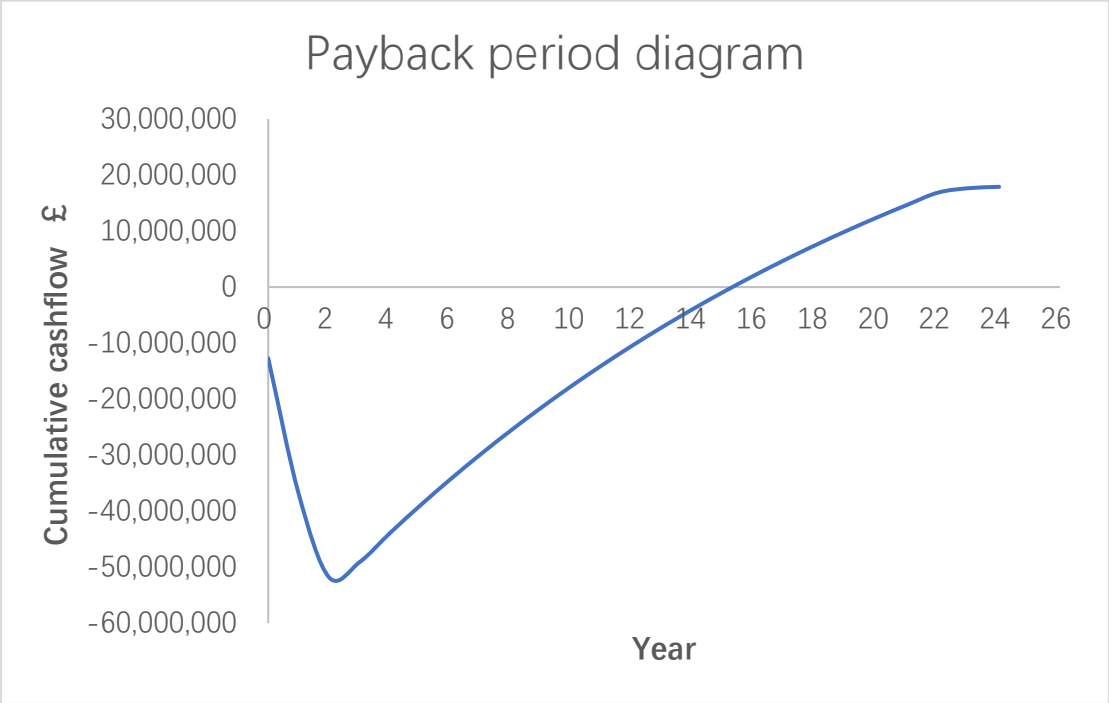


Figure 4. Payback period

Therefore, with economic fluctuations affecting product prices, the cumulative cash flow of the factory in year 16 is positive.

However, economic fluctuations are continuous, so raw material and utility cost may change every year, which leads to different cash flows every year.

5.2 Sensitivity analysis for raw material and utility

Table 39. Cost and revenues with economic fluctuation.

Year	Cost £	Revenues £	Explanation
0	-12,707,187	0	Engineer + long lead-time items
1	-25,414,375	0	Procurement and construction
2	-30,819,338	18,158,308	Remaining construction & Initial production
3	-35,163,782	42,369,385	Shake-down of plant
4	-41,585,778	60,527,693	Full production
5	-39,506,489	46,606,323	Economic fluctuation (80%)
6	-41,585,778	60,527,693	Full production
7	-37,427,200	48,422,154	Economic fluctuation (90%)
8	-39,980,279	42,369,385	Economic fluctuation (80%)
9	-41,585,778	60,527,693	Full production
10	-41,585,778	60,527,693	Full production
11	-41,585,778	60,527,693	Full production
12	-38,374,780	48,422,154	Economic fluctuation (90%)
13	-41,585,778	48,422,154	Economic fluctuation (90%)
14	-37,427,200	60,527,693	Economic fluctuation (90%)
15	-37,427,200	60,527,693	Economic fluctuation (90%)
16	-41,585,778	60,527,693	Full production
17	-41,585,778	60,527,693	Full production
18	-39,980,279	54,474,924	Economic fluctuation (95%)
19	-41,585,778	60,527,693	Full production
20	-41,585,778	60,527,693	Full production
21	-38,374,780	60,527,693	Full production
22	-37,427,200	47,211,600	Economic fluctuation (85%)
23	-33,558,283	45,395,770	75%VCOP+FCOP
24	-30,347,285	39,343,000	65%VCOP+FCOP

MIRR (Minimum Acceptable Rate of Return) =5 %

Table 40. Cash flow, present worth value, PV for DCFIRR and cumulative with economic fluctuation.

Year	Cash flow (£)	Present worth value (£)	PV for DCFIRR (£)	Cumulative (£)
0	-12,707,187	-12,707,187	-12,707,187	-12,707,187
1	-25,414,375	-24,204,166	-20,203,581	-36,911,353
2	-12,661,030	-11,483,927	-8,001,416	-48,395,281
3	7,205,603	6,224,471	3,620,071	-42,170,810
4	18,941,915	15,583,560	7,565,185	-26,587,249
5	7,099,835	5,562,906	2,254,202	-21,024,343
6	18,941,915	14,134,749	4,780,985	-6,889,595
7	10,994,954	7,813,909	2,206,154	924,314
8	2,389,106	1,617,041	381,089	2,541,355
9	18,941,915	12,210,127	2,401,951	14,751,483
10	18,941,915	11,628,693	1,909,471	26,380,175
11	18,941,915	11,074,945	1,517,966	37,455,121
12	10,047,374	5,594,754	640,088	43,049,875
13	6,836,377	3,625,476	346,228	46,675,351
14	23,100,493	11,667,319	930,050	58,342,670
15	23,100,493	11,111,732	739,358	69,454,402
16	18,941,915	8,677,510	481,955	78,131,912
17	18,941,915	8,264,295	383,138	86,396,206
18	14,494,645	6,022,824	233,071	92,419,031
19	18,941,915	7,495,959	242,133	99,914,990
20	18,941,915	7,139,009	192,487	107,053,998
21	22,152,913	7,951,619	178,961	115,005,617
22	9,784,400	3,344,796	62,836	118,350,413
23	11,837,487	3,853,946	60,434	122,204,359
24	8,995,715	2,789,283	36,510	124,993,642

Table 41. NPV and DCFIRR

NPV calc.	124,993,642	£
DCFIRR from "Goal Seek"	0.2139	
	21.39%	
NPV for DCFIRR	0	£
DCFIRR from "IRR"	20.85%	

The IRR value proves that the project may make some money.

Therefore, the payback period with economic fluctuation diagram is shown below,

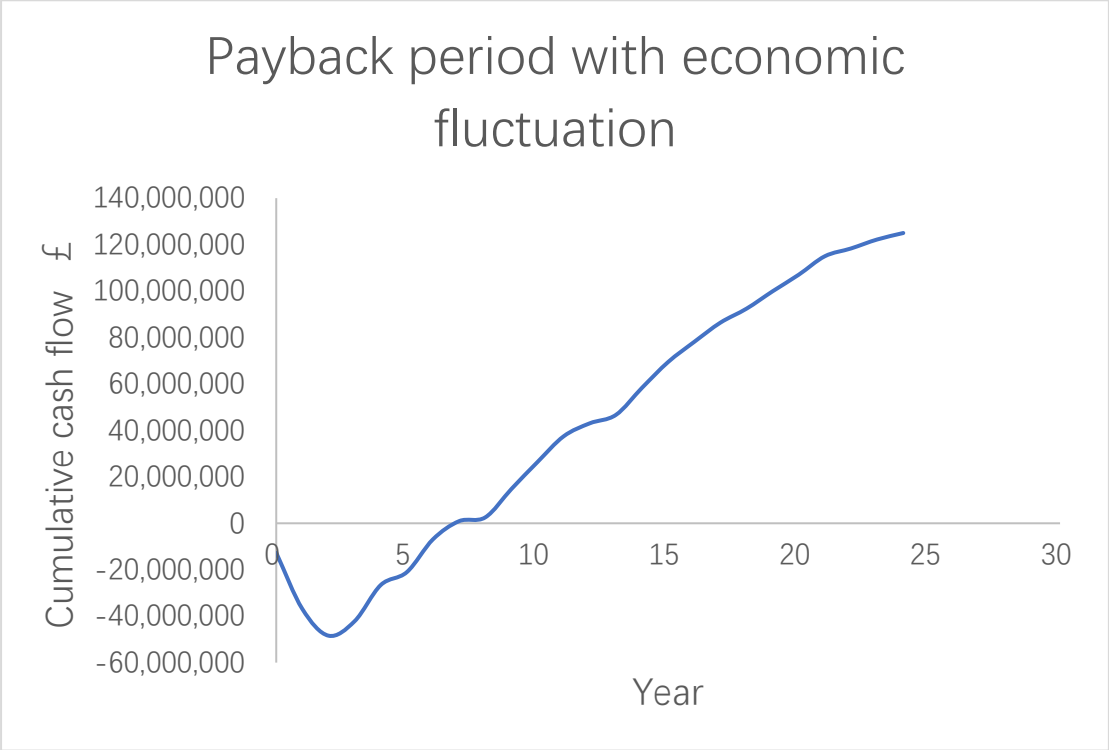


Figure 5. Payback period

According to the figure 5, in the case of economic fluctuations, the prices of raw material and utility will change so that the cumulative cash flow of the factory is positive in year 7.

6. Equations

6.1 Location

$$C_{UK} = C_{US} \times L_F \times E_R \quad (1)$$

Where,

C_{UK}=cost in UK

C_{US}=cost in US

L_F=location factor=1.02

E_R=currency exchange rate=0.7783

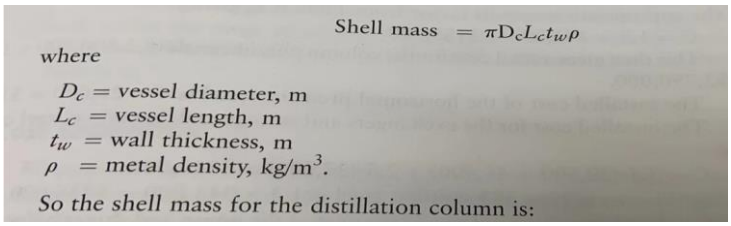
6.2 Preliminary estimates of equipment cost

For those design engineers who lack access to reliable cost data, the following correlation can be used for preliminary estimates:

$$C_e = a + b \times S^n \quad (2)$$

Where,

C_e= purchased equipment cost on a Jan. 2010 (CEPCI = 532.9)
a,b= cost constants in the following tables
S= size parameter
n= exponent for that type of equipment



$$\text{Shell mass} = \pi D_c L_c t_w \rho$$

where

D_c = vessel diameter, m
L_c = vessel length, m
t_w = wall thickness, m
ρ = metal density, kg/m^3.

So the shell mass for the distillation column is:

Figure 6. Shell mass calculation

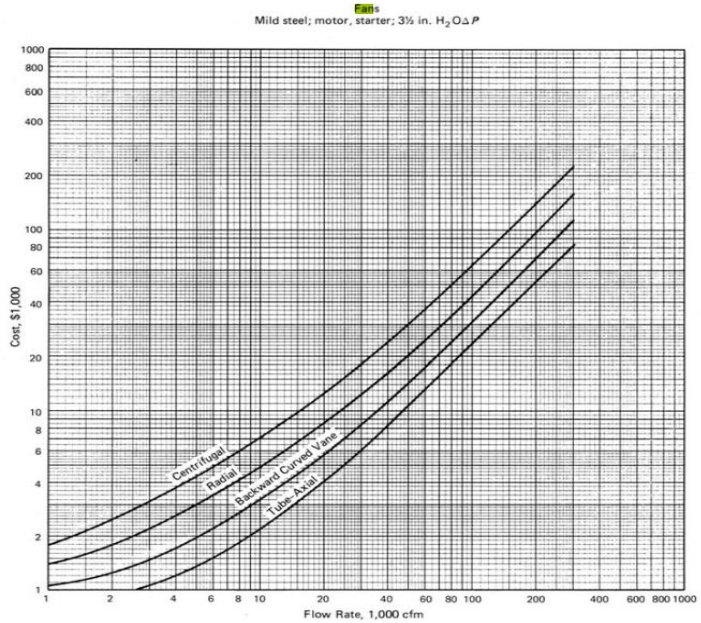


Figure 7. Purchased equipment cost for fan

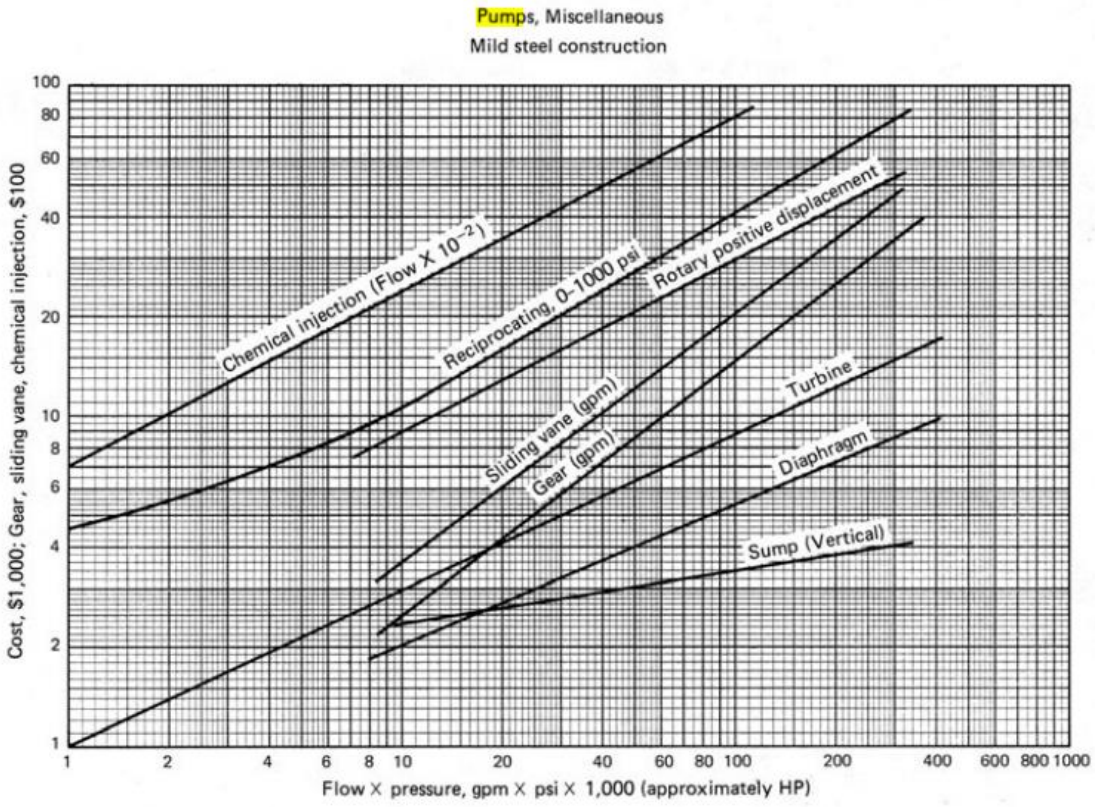


Figure 8. Purchased equipment cost for diaphragm pump

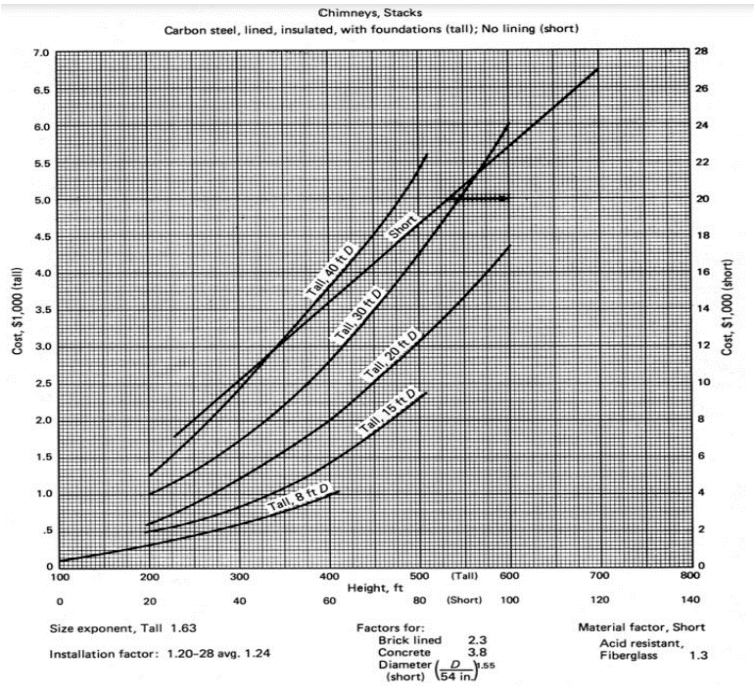


Figure 9. Purchased equipment cost for chimney

Table 42. Purchased equipment cost for common plant equipment

Equipment	Units for Size, S	S_{lower}	S_{upper}	a	b	n	Note
Agitators & mixers							
Propeller	driver power, kW	5.0	75	17,000	1,130	1.05	
Spiral ribbon mixer	driver power, kW	5.0	35	30,800	125	2.0	
Static mixer	liters/s	1.0	50	570	1,170	0.4	
Boilers							
Packaged, 15 to 40 bar	kg/h steam	5,000	200,000	124,000	10.0	1.0	
Field erected, 10 to 70 bar	kg/h steam	20,000	800,000	130,000	53	0.9	
Centrifuges							
High speed disk	diameter, m	0.26	0.49	57,000	480,000	0.7	
Atmospheric suspended basket	power, kW	2.0	20	65,000	750	1.5	
Compressors							
Blower	m^3/h	200	5,000	4,450	57	0.8	
Centrifugal	driver power, kW	75	30,000	580,000	20,000	0.6	
Reciprocating	driver power, kW	93	16,800	260,000	2,700	0.75	
Conveyors							
Belt, 0.5 m wide	length, m	10	500	41,000	730	1.0	
Belt, 1.0 m wide	length, m	10	500	46,000	1,320	1.0	
Bucket elevator, 0.5m bucket	height, m	10	30	17,000	2,600	1.0	
Crushers							
Reversible hammer mill	t/h	30	400	68,400	730	1.0	
Pulverizers	kg/h	200	4,000	16,000	670	0.5	
Jaw crusher	t/h	100	600	−8,000	62,000	0.5	
Gyratory crusher	t/h	200	3,000	5,000	5,100	0.7	
Ball mill	t/h	0.7	60	−23,000	242,000	0.4	
Crystallizers							
Scraped surface crystallizer	length, m	7	280	10,000	13,200	0.8	
Distillation columns							
See pressure vessels, packing and trays							

Table 43. Purchased equipment cost for common plant equipment

Equipment	Units for Size, S	S_{lower}	S_{upper}	a	b	n	Note
Dryers							
Direct contact Rotary	m^2	11	180	15,000	10,500	0.9	1
Atmospheric tray batch	area, m^2	3.0	20	10,000	7,900	0.5	
Spray dryer	evap rate kg/h	400	4,000	410,000	2,200	0.7	
Evaporators							
Vertical tube	area, m^2	11	640	330	36,000	0.55	
Agitated falling film	area, m^2	0.5	12	88,000	65,500	0.75	2
Exchangers							
U-tube shell and tube	area, m^2	10	1,000	28,000	54	1.2	
Floating head shell and tube	area, m^2	10	1,000	32,000	70	1.2	
Double pipe	area, m^2	1.0	80	1,900	2,500	1.0	
Thermosiphon reboiler	area, m^2	10	500	30,400	122	1.1	
U-tube Kettle reboiler	area, m^2	10	500	29,000	400	0.9	
Plate and frame	area, m^2	1.0	500	1,600	210	0.95	2
Filters							
Plate and frame	capacity, m^3	0.4	1.4	128,000	89,000	0.5	
Vacuum drum	area, m^2	10	180	−73,000	93,000	0.3	
Furnaces							
Cylindrical	duty, MW	0.2	60	80,000	109,000	0.8	
Box	duty, MW	30	120	43,000	111,000	0.8	
Packings							
304 ss Raschig rings	m^3			0	8,000	1.0	
Ceramic intalox saddles	m^3			0	2,000	1.0	
304 ss Pall rings	m^3			0	8,500	1.0	
PVC structured packing	m^3			0	5,500	1.0	
304 ss structured packing	m^3			0	7,600	1.0	3
Pressure vessels							
Vertical, cs	shell mass, kg	160	250,000	11,600	34	0.85	4
Horizontal, cs	shell mass, kg	160	50,000	10,200	31	0.85	4

Table 44. Purchased equipment cost for common plant equipment

Equipment	Units for Size, S	S_{lower}	S_{upper}	a	b	n	Note
Vertical, 304 ss	shell mass, kg	120	250,000	17,400	79	0.85	4
Horizontal, 304 ss	shell mass, kg	120	50,000	12,800	73	0.85	4
Pumps and drivers							
Single stage centrifugal	flow, liters/s	0.2	126	8,000	240	0.9	
Explosion proof motor	power, kW	1.0	2,500	−1,100	2,100	0.6	
Condensing steam turbine	power, kW	100	20,000	−14,000	1,900	0.75	
Reactors							
Jacketed, agitated	volume, m^3	0.5	100	61,500	32,500	0.8	2
Jacketed, agitated, glass lined	volume, m^3	0.5	25	12,800	88,200	0.4	
Tanks							
floating roof	capacity, m^3	100	10,000	113,000	3,250	0.65	
cone roof	capacity, m^3	10	4,000	5,800	1,600	0.7	
Trays							
Sieve trays	diameter, m	0.5	5.0	130	440	1.8	5
Valve trays	diameter, m	0.5	5.0	210	400	1.9	
Bubble cap trays	diameter, m	0.5	5.0	340	640	1.9	
Utilities							
Cooling tower & pumps	flow, liters/s	100	10,000	170,000	1,500	0.9	6
Packaged mechanical refrigerator							
evaporator	duty, kW	50	1,500	24,000	3,500	0.9	
Water ion exchange plant	flow m^3/h	1	50	14,000	6,200	0.75	

Notes:
1. Direct heated.
2. Type 304 stainless steel.
3. With surface area 350 m^2/m^3.
4. Not including heads, ports, brackets, internals, etc. (see Chapter 14 for how to calculate wall thickness).
5. Cost per tray, based on a stack of 30 trays.
6. Field assembly.
7. All costs are U.S. Gulf Coast basis, Jan. 2010 (CEPCI index = 532.9, NF refinery inflation index = 2281.6).

6.3 Net present value (NPV)

The equation for discrete discounting of a single future value (FV) to obtain its present value (PV) at interest rate (r) after n years is:

$$PV = \frac{FV}{(1+r)^n} \tag{3}$$

The NPV is the total present worth value of all cash flow minus total present worth value of all capital investments.

$$NPV = -C_0 + \frac{C_1}{1+r} + \frac{C_2}{(1+r)^2} + \cdots + \frac{C_T}{(1+r)^T} \tag{4}$$

Where,
-C_0=Initial investment
C=Cash flow
R=Discount rate
T=Time (year)

6.4 Discounted Cash Flow Rate of Return (DCFIRR)

DCFIRR is the return rate when NPV = 0, it can reflect whether the project is worth the investment. The DCFIRR can be determined by equation NPV to zero and solve for interest rate r in the equation

$$-C_0 + \frac{C_1}{1+r} + \frac{C_2}{(1+r)^2} + \cdots + \frac{C_T}{(1+r)^T} = 0 \tag{5}$$

7. Reference

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