Appendix A

A. Capital Cost Part

Capital Cost Model

$$TCI = \sum_{i=1}^{n} TCI_i \qquad A.1$$

TCI = Total capital Cost, $
TCI_i = Total capital Cost of equipment i, $
n = number of equipment

$$TCI_i = FCI_i + WC_i \qquad A.2$$

FCI_i = Fixed capital cost of equipment i, $
WC_i = Working capital for equipment i, $

$$FCI_i = DC_i + IC_i \qquad A.3$$

DCi = Direct cost of equipment i, $
ICi = Indirect cost of equipment i, $

$$WC_i = E_i^{'} \times X \times W \qquad A.4$$

Ei = working capital of equipment i, $
W = working capital fraction
X = Delivery fraction

Delivery faction is equal to 1.1. W is 0.7 for solid processing, 0.75 for solid-fluid processing and 0.89 for fluid processing or the users can define value of X and W by themselves.

$$DC_i = E_i^{'} \times X \times (Y + 1) \qquad A.5$$

$E_i^{'}$ = Purchase cost of equipment i at year k, $
Y = total direct cost fraction

Total direct cost fraction is equal to 2.69 for solid processing, 3.02 for solid – fluid processing, and 3.6 for fluid processing or the users can define value of Y by themselves.

$$IC_i = E_i' \times X \times Z \qquad A.6$$

IC_i = Indirect cost of euipment i
Z = indirect cost fraction

Z is 1.28 for solid processing, 1.26 for solid-fluid processing and 1.44 for fluid processing. The users can define value of X and Z by themselves.

Purchase Cost Model

$$E_i' = UF \times E_i \qquad A.7$$

E_i = Purchase cost of equipment i, $
UF = Update factor

$$UF = \frac{\text{CPI Inedex at year k}}{\text{CPI Index=390.4}} \qquad A.8$$

CPI index is shown in table A-1

Table A-1 CPI cost index

year	CPI Index
1999	390,6
2000	394,1
2001	394,3
2002	395,6
2003	402
2004	444,2
2005	468,2
2006	499,6
2007	529,4
2008	575,4
2009*	600,24
2010*	632,6
2011*	664,96

* Linear estimate of CPI cost index in2009-2011 based on data from 2004-2008

$$E_i = cost_i \times AF \qquad A.9$$

$Cost_i$ = Base cost of equipment i, $
AF = adjustment factor (See at table A − 2 andA − 3)

Base Cost Model

$$\mathrm{cost_i} = \alpha \times \mathrm{S}^{\beta} \qquad \text{A.10}$$

α and β are equipment parameter that shown in table$\mathrm{A}-2$. Mixing, heater, furnace, air cooled heat exchanger, double pipe heat exchanger, compressor, multiple pipe heat exchanger, and centrifugal pump (flow rate: 9.0E-3 to 1 m^3/s) cost can be calculated by Eq.A.10

$$\mathrm{cost_i} = \mathrm{aS^6 + bS^5 + cS^4 + dS^3 + eS^2 + fS + C} \qquad \text{A.11}$$

a, b, c, d, e, f, and C are equipment parameter that shown in table A-3. Tray, vertical column, electronic motor, shell and tube heat exchanger, reactor (PFR calculate same method with shell & tube heat exchanger or reactor vessel calculate same method with column) and centrifugal pump (flow rate: 1.5E-4 to 9.0E-3 m^3/s) cost can be calculated.

Table A-2 Equipment parameter for Eq. 1.10 and adjustment factor

Equipment	Range	S	α	β	P Adjustment	M Adjustment
mixing (CS)	0,378 to 26,5	capacity, m^3	6583,3	0,5253	-	-
mixing (SS)	0,378 to 26,5	capacity, m^3	9457,3	0,5482	-	-
centrifugal pump	9,0e-3 to 1e+0	flowrate, m^3/s	18441	0,3849	-	-
compressor						Material adjustment factor carbon steel 1.0 Stainless steel 2.5 Nickel alloy 5.1
centrifugal - motor	75 to 6000	power required, kW	877,3	0,9435	-	
centrifugal - turbine	75 to 6000	power required, kW	1217,9	0,9195	-	
centrifugal - rotary	75 to 6000	power required, kW	3159,3	0,6738	-	
reciprocating-gas turbine	75 to 6000	power required, kW	1564,5	0,9467	-	
reciprocating-motor	75 to 6000	power required, kW	1435,4	0,9138	-	
reciprocating-steam	75 to 6000	power required, kW	892,22	0,9567	-	
direct-fired heater						
CS tube 690 kPa	200 to 10000	heat duty, kW	176,04	0,7628	-	-
CS tube 3450 kPa	100 to 8790	heat duty, kW	913,92	0,6784	-	-
Chrome/Moly tubes 6895 kPa	100 to 8790	heat duty, kW	1398,2	0,671	-	-
SS tubes 10340 kPa	100 to 8790	heat duty, kW	1433,8	0,6836	-	-
Furnace						
CS tubes 3450 kPa (process fired heater	2000 to 100000	heat duty, kW	199,85	0,8659	-	-
Chrome/Moly tubes 6895 kPa (pyrolysis furnace)	2000 to 100000	heat duty, kW	288,61	0,8578	-	-
SS tubes 13790 kPa (reformer furnace)	2000 to 100000	heat duty, kW	515,4	0,8251	-	-
Air cooled heat exchanger	3,3 to 11000	heat transfer area, m^2	3788	0,4216	-	material adjustment factors Carbon steel 1.0 Copper 1.2 Stainless steel 2.3 Nickel alloy 2.8 Titanium 7.2
HX double pipe					Pressure adjustment factors upto 4,135 kPa (600psia) 1.0 6,205 kPa (900psia) 1.1 10,340 kPa (1500psia) 1.3 20,680 kPa (3000psia) 2.0 30,000 kPa (4350psia) 3.0	
CS tube and shell	0,232 to 29,3	surface area, m^2	1039,3	0,0635		
Admiralty tube and CS shell	0,232 to 19,3	surface area, m^2	1300,2	0,0746		
SS tube and CS shell	0,232 14,3	surface area, m^2	1959,9	0,0699		
Multiple pipe					Pressure adjustment factors upto 4,135 kPa (600psia) 1.0 6,205 kPa (900psia) 1.1 10,340 kPa (1500psia) 1.3 20,680 kPa (3000psia) 2.0 30,000 kPa (4350psia) 3.0	
CS tube and shell	10 to 200	surface area, m^2	129,79	0,9711		
Admiralty tube and CS shell	10 to 200	surface area, m^2	154,47	0,9759		
SS tube and CS shell	10 to 200	surface area, m^2	230,05	0,9666		

Table A-3 Equipment parameter for Eq. 1.11 and adjustment factor

Equipment	Range	S	a	b	c	d	e	f	C	P adjustment	Adjustment
Tray											**Quantity factor apply for all types** 1 3.00 10 1.50 19 1.05 2 2.80 11 1.45 20-29 1.00 3 2.65 12 1.40 30-39 0.98 4 2.50 13 1.35 40+ 0.97 5 2.30 14 1.30 6 2.15 15 1.25 7 2.00 16 1.20 8 1.80 17 1.15 9 1.65 18 1.10
sieve trays (CS)	0,5 to 3,81	diameter, m	-	-	-	-32,7	234,91	-66,321	293,53		
Valve trays (CS)	0,61 to 3,81	diameter, m	-	-	-	38,289	-26,568	332,36	152,51		
Sieve trays (SS) or bubble cap trays (CS)	0,61 to 3,81	diameter, m	-	-	-	-84,874	638,2	-454,1	774,21		
Stamped turbogrid trays (SS)	0,61 to 3,81	diameter, m	-	-	-	9,5515	85,623	290,8	262,45		
Valve trays (SS)	0,61 to 3,81	diameter, m	-	-	-	87,816	-44,382	631,32	362,42		
Bubble cap trays (SS)	0,61 to 3,81	diameter, m	-	-	-	77,593	270,1	264,98	542,95		
vertical columns										**Pressure factors** 1035 kPa (150psia) 1.6 5000 kPa (725 psia) 3.2 10000kPa (1450psia) 4.6 20000 kPa (2900psia) 8.7 30000 kPa (4350psia) 12.2 40000 kPa (5800psia) 15.8	**Material adjustment factor** carbon steel 1.0 316 stainless steel 3.0 Nickel alloy 7.4
D = 0,5 m	1,5 to 20 m	height	-	-	-	-	15,401	1588,5	1495,5		
D = 1 m	2,5 to 30 m	height	-	-	-	-	13,929	2028,4	1850,6		
D = 2 m	4 to 45 m	height	-	-	-	-	3,011	3139,4	7166,9		
D = 3 m	6 to 50 m	height	-	-	-	-	-23,555	5119,4	10945		
D = 4 m	7 to 50 m	height	-	-	-	-	-49723	5021,1	24285		
electric-motors										**Pressure adjustment factors** P, kPa Tube Tube and shell 1,035 1.00 1.00 5,000 1.07 1.16 10,000 1.10 1.24 15,000 1.12 1.31	
explosion-proof	4 to 4480	delivered power, kW	-3,00E-16	5,00E-12	-3,00E-08	9,00E-05	-0,1566	163,04	324,57		
enclosed, fan-cooled	1 to 4480	delivered power, kW	-1,00E-16	2,00E-12	-2,00E-08	5,00E-05	-0,0961	113,86			
open, drip proof	1 to 4480	delivered power, kW	-9,00E-17	1,00E-12	-9,00E-09	3,00E-05	-0,0535	73,041	239,95		
squirrel-cage induction (open drip proof)	4,48 to 97	delivered power, kW	-	-	-	-	0,1286	43,371	252,17		
Heat exchanger Fixed tube shell & tube										**Pressure adjustment factors** P, kPa Tube Tube and shell 1,035 1.00 1.00 5,000 1.07 1.16 10,000 1.10 1.24 15,000 1.12 1.31	**Diameter** x = diameter (in) y = relate cost dollar /m^2 y = 0.6132e^(0.5196x) y_2/y_1 = e^(0.5196*(x_2-x_1) or y_2/y_1 = e^(20.456*(m_2-m_1) m = diameter (m) **Length** x = length (in) y = relate cost dollar /m^2 y = 1.4754e^(-2.99x) or y = 1.4754e^(-0.076m) m = length(m)
CS	3,52 to 635	surface area, m^2	-	-	-	-	-	59,628	4071,2		
304 SS	3,52 to 635	surface area, m^2	-	-	-	-	-	123,52	3380,2		
316 SS	3,52 to 635	surface area, m^2	-	-	-	-	-	165,06	3154		
U tube											
CS	2,79 to 440	surface area, m^2	-2,00E-11	`3e-8	-2,00E-05	0,0052	-0,7456	139,58	1975		
SS	2,79 to 352	surface area, m^2	-2,00E-10	2,00E-07	-9,00E-05	0,0192	-2,0939	302,37	2420,1		
floating tube											**Material adjustment factors** shell tube factor CS CS 1.0 CS CU 1.25 CS SS 1.7 CS NI ALLOY 2.8 SS SS 3.0 CS TI 7.2 CS - Carbon steel CU - Copper SS - Stainless steel Ni alloy - Nickel alloy Ti - Titanium **Diameter** x = diameter (in) y = relate cost dollar /m^2 y = 0.6132e^(0.5196x) y_2/y_1 = e^(0.5196*(x_2-x_1) or y_2/y_1 = e^(20.456*(m_2-m_1) m = diameter (m) **Length** x = length (in) y = relate cost dollar /m^2 y = 1.4754e^(-2.99x) or y = 1.4754e^(-0.076m) m = length(m)
690 kPa	9,3 to 1000	surface area, m^2	-	-	-	4,00E-05	-0,0759	99,873	3070,4		
1035 kPa	9,3 to 1000	surface area, m^2	-	-	-	3,00E-05	-0,051	104,15	4208,3		
2070 kPa	9,3 to 1000	surface area, m^2	-	-	-	5,00E-05	-0,0758	125,31	4608,7		
3105 kPa	9,3 to 1000	surface area, m^2	-	-	-	6,00E-05	-0,0867	141,35	4803,5		
6895 kPa	9,3 to 1000	surface area, m^2	-	-	-	7,00E-05	-0,102	178,16	5786,4		
centrifugal pump with eltric motor	6 to 70	volumetric * pressure discharge (m^3/s*kPa)	-	-	-	-	-0,7712	795,92	8081,1	-	-
centrifugal pump	1,5e-4 to 9,0e-3	flowrate, m^3/s	-	-	-	-	-1,00E+07	318781	1017,3	-	-

B. Operating Cost Part

Total Product Cost Model

$$\mathrm{TPC} = \mathrm{MC} + \mathrm{GE} \tag{B.1}$$

TPC = Total product cost, $
MC = Manufacturing cost, $
GE = General expense, $

Manufacturing Cost Model

$$\mathrm{MC} = \mathrm{VAR} + \mathrm{FIX} + \mathrm{PO} \tag{B.2}$$

VAR = Variable cost, $
FIX = Fixed charge, $
PO = Plant over head, $

Variable Cost Model

$$\mathrm{VAR} = \mathrm{RAW} + \mathrm{UC} + \mathrm{LC} + \mathrm{OS} + \mathrm{MR} + \mathrm{OSP} + \mathrm{LAB} + \mathrm{ROY} + \mathrm{CAT} \tag{B.3}$$

RAW = Raw material cost, $
UC = Utilities cost, $
LC = Labor cost, $
OS = Operating supervision cost, $
MR = Maintenance and repair cost, $
OSP = Operating supplies, $
LAB = Laboratory charge, $
ROY = Royalties, $
CAT = Catalyst or solvent cost, $

Raw Material Cost Model

$$\mathrm{RAW} = \sum_{\hbar=1}^{\mathrm{m}} \mathrm{RAW}_{\hbar} \tag{B.4}$$

$RAW_{\hbar}$ = cost of Raw material $\hbar$, $
m = number of raw material

$$\mathrm{RAW}_{\hbar} = \mathrm{RQ}_{\hbar} + \mathrm{RP}_{\hbar} \qquad \text{B.5}$$

$RQ_{\hbar}$ = Quantity of raw material $\hbar$, \$
$RP_{\hbar}$ = Price of raw material $\hbar$, \$

Utilities Cost Model

$$\mathrm{UC} = \sum_{e=1}^{g} \mathrm{UC}_e \qquad \text{B.6}$$

UC_e = Cost of utility e, \$

$$\mathrm{UC}_e = \mathrm{UQ}_e \times \mathrm{UP}_e \qquad \text{B.7}$$

UQ_e = Quantities of utilities e
UP_e = Price of utilities e, \$

Labor Cost Model

$$\mathrm{LC} = \mathrm{LR} \times \mathrm{time} \times \mathrm{SLC} \times \mathrm{step} \qquad \text{B.8}$$

LR = Operating labor requirement, employee-hours/ (day)(process step)
time = hour per year
SLC = skilled labor cost, \$/hr (for year 2001 = 33.67\$/hour or defined by user)
step = No. of process step such as fluid flow process, heat transfer process, mass transfer process, thermodynamic process and mechanical process.

$$LR = ux^{v} \qquad \text{B.9}$$

u and v are labor requirement parameter that be shown in table4

TableB-4 parameter for Eq.B.9

Process	***u***	***v***
Batch Process	4,1145	0,2617
Continueous	3,3226	0,2353
Avg. Condition	2,2718	0,2369

General Variable Cost

$$\mathrm{OS} = \mathcal{A} \times \mathrm{LC} \qquad \text{B.10}$$

$\mathcal{A}$ is operating supervision factor equal to 0.15 or the users can define value of $\mathcal{A}$ by themselves.

$$\mathrm{MR} = \mathcal{B} \times \mathrm{FCI} \qquad \text{B.11}$$

$\mathcal{B}$ is Maintenance and repair factor equal to 0.06 or the users can define value of $\mathcal{B}$ by themselves

$$OSP = \mathcal{C} \times MR \qquad \text{B.12}$$

$\mathcal{C}$ is Operating suplies factor equal to 0.15 or the users can define value of $\mathcal{C}$ by themselves

$$LAB = \mathcal{D} \times LC \qquad \text{B.13}$$

$\mathcal{D}$ is Laboratory factor equal to 0.15 or the users can define value of $\mathcal{D}$ by themselves

$$ROY = \mathcal{F} \times TPC \qquad \text{B.14}$$

$\mathcal{F}$ *is Royalties factor equal to* 0.01 or the users can define value of $\mathcal{F}$ by themselves

Catalysis Cost Model

$$CAT = \sum_{\wp=1}^{q} CAT_{\wp} \qquad \text{B.15}$$

$CAT_{\wp}$ = Cost of catalyst or solvent, $\wp$

$$CAT_{\wp} = CQ_{\wp} \times CP_{\wp} \qquad \text{B.16}$$

$CQ_{\wp}$= Quantity of catalyst or solvent, $\wp$
$CP_{\wp}$ = Price of catalyst or solvent, $\wp$

Fix Charge Cost Model

$$\mathrm{FIX} = \mathrm{TAX} + \mathrm{INS} \qquad \text{B.17}$$

TAX = Taxes (property), $
INS = Insurance, $

$$TAX = \mathcal{G} \times FCI \quad \text{B.18}$$

$\mathcal{G}$ is taxes factor equal to 0.02 or the users can define value of $\mathcal{G}$ by themselves

$$INS = \mathcal{H} \times FCI \quad \text{B.19}$$

$\mathcal{H}$ is Insurance factor equal to 0.01 or the users can define value of $\mathcal{H}$ by themselves

Plant Over Head Cost Model

$$\mathrm{PO} = \mathcal{S} \times (\mathrm{LC} + \mathrm{SC}) \quad \text{B.20}$$

$\mathcal{S}$ is Plant over head factor equal to 0.6 or the users can define value of $\mathcal{S}$ by themselves

General Expense Model

$$GE = AD + DI + RE \quad \text{B.21}$$

AD = Administration, $

DI = Distribution & selling, $

RE = Research & development, $

$$AD = \mathcal{I} \times (\mathrm{LC} + \mathrm{SC}) \quad \text{B.22}$$

$\mathcal{I}$ is Administrative factor equal to 0.2 or the users can define value of $\mathcal{I}$ by themselves

$$DI = \mathcal{J} \times \mathrm{TPC} \quad \text{B.23}$$

$\mathcal{J}\ is$ Distribution & $selling$ factor equal to 0.05 or the users can define value of $\mathcal{J}$ by themselves

$$RE = \mathcal{K} \times \mathrm{TPC} \quad \text{B.24}$$

$\mathcal{K}\ is$ Research & $development$ factor equal to 0.04 or the users can define value of $\mathcal{K}$ by themselves

C. Economic Evaluation Model

Net Present Worth (NPW)

$$NPW = \sum_{j=1}^{N} PWF_{cf,j}\left[\left(s_j + c_{oj} + d_j\right)(1-\phi) + rec_j + d_j\right] - \sum_{j=-b}^{N} PWF_{v,j}\, T_j \qquad C.1$$

$PWF_{cf,j}$ = the selected present worth factor for cash flow in year j
s_j = the value of sales in year j, $
c_{oj} = the total product cost not including depreciation in year j, $
d_j = depreciation at year j, $
$\phi = income\ taxes$ (Defined by user)
$rec_j = recovery\ of\ working\ capital\ and\ physical\ at\ year\ j,$ $
$PWF_{v,j}$ = the appropriate present worth factor for investments occurring in year j
T = the total investment in year j, $

for annual end of year cash flow

$$PWF_{cf,j} = (1+m_{ar})^{-j} \qquad C.2$$

for continuous cash flow

$$r_{ma} = \ln(1+m_{ar}) \qquad C.3$$

$$PWF_{cf,j} = (1+r_{ma})^{-j} \qquad C.4$$

m_{ar} = minimum acceptable rate of return
r_{ma} = minimum acceptable nominal rate for continuous compounding

Discounted Cash Flow Rate of Return (DCFR)

$$0 = \sum_{j=1}^{N} PWF_{cf,j}\left[\left(s_j + c_{oj} + d_j\right)(1-\phi) + rec_j + d_j\right] - \sum_{j=-b}^{N} PWF_{v,j}\, T_j \qquad C.5$$

The DCFR is concern the project rate favorably compared to the value of m_{ar} that used in calculating the net present worth. DCFR is m_{ar} or r_{ma} when NPW that is calculated equal to zero. If DCFR greater than m_{ar} or r_{ma} so the m_{ar} or r_{ma} value used is a good starting point.

Return on Investment (ROI)

$$\text{ROI} = \frac{\left(\frac{1}{N}\right)\sum_{j=1}^{N}(N_{p,j})}{\sum_{j=-b}^{N}(T_j)} \qquad \text{C.6}$$

$N =$ evaluation period
$N_{p,j} =$ the net profit in year j, \$
$-b =$ the year in which the first investment is made
$T_j =$ the total capital investment in year j, \$

3.4 Pay Back Period (PBP)

$$\text{PBP} = \frac{V + A_x}{\left(\frac{1}{N}\right)\sum_{j=1}^{N} A_j} \qquad \text{C.7}$$

$V =$ Manufacturing fixed − capital cost, \$
A_x= Non manufacturing fixed – capital cost, \$
A_j =Annual cash flow, \$
N = evaluation period

3.5 Net Return (R_n)

$$R_n = \left(\frac{1}{N}\right)\sum_{j=1}^{N}(N_{p,j}) - M_{ar}T \qquad \text{C.8}$$

(Peters *et al*., 2004) The product sale revenue minus the total product cost gives the gross profit, also called gross earning. Gross profit is expressed both with and without depreciation included as follows:

$$g_j = s_j - c_{oj} \qquad \text{C.9}$$

where g_j is gross profit, depreciation not included, in year j, and

$$G_j = s_j - c_{oj} - d_j \qquad \text{C.10}$$

where G_j is gross profit, depreciation included, in year j.

Net profit, also *net earnings,* is the amount retained of the profit after income taxes have been paid.

$$N_{pj} = G_j(1 - \Phi) \qquad \text{C.11}$$

Where N_{pj} is the net profit in year j.

The cash flow resulting from process operations is given by

$$A_j = N_{pj} + d_j \qquad \text{C.12}$$