458.401 Process & Product Design

06

Estimation of Capital Costs

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Project Cost Estimation

- Bill of Material (B/M)
  - 견적서
- Total Investment Cost (TIC)
  - Fixed Investment Capital (FIC) + Working Capital (WC)
- Fixed Capital Investment (고정투자비)
  - All the costs associated with building the plant
  - Most of FIC depreciated except land
- Working Capital (시운전동안 안정적으로 운전하기 위한 비용)
  - The amount of capital required to start up the plant and finance the first few months of operation before revenues from the process start
  - 15 ~ 25% of the fixed capital investment

Types of Capital Cost Estimates

1. Order-of-Magnitude Estimate (Feasibility) - AACE Class 5
   - +40%, -20%
   - BFD, process modification (이전의 공장을 가지고 capa비교 산정)
2. Study Estimate / Major Equipment - AACE Class 4
   - +30%, -20%
   - PFD, cost chart, roughly sized major equipment
3. Preliminary Design (Scope) Estimate - AACE Class 3
   - +25%, -15%
   - PFD, vessel sketches, equip. diagrams, plot plan / Major equip. + piping + instr. + elec. + util
4. Definitive (Project Control) Estimate - AACE Class 2
   - +15%, -7%
   - PFD, P&ID, all vessel sketches, equip. diagrams, preliminary isometrics

Types of Capital Cost Estimates

5. Detailed (Firm or Contractors) Estimate - AACE Class 1
   - +6%, -4%
   - Everything included - ready to go to construction phase
   - Complete engineering, vendor quote

- Estimate low so actual cost will be high (+)
- Estimate high so actual cost will be low (-)
- Why is + # > -# ?

Table 7.2 Classification of Cost Estimates

Class of Estimate	Level of Project Definition (as % of Complete Definition)	Typical Purpose of Estimate	Methodology (Estimating Method)	Expected Accuracy Range (+/ − Range Relative to Best Index of 1)	Preparation Effort (Relative to Lowest Cost Index of 1)
Class 5	0% to 2%	Screening or Feasibility	Stochastic or Judgment	4 to 20	1
Class 4	1% to 15%	Concept Study	Primarily	3 to 12	2 to 4
		or Feasibility	Stochastic		
Class 3	10% to 40%	Budget, Authorization, or Control	Mixed but Primarily Stochastic	2 to 6	3 to 10
Class 2	30% to 70%	Control or Bid/Tender	Primarily Deterministic	1 to 3	5 to 20
Class 1	50% to 100%	Check Estimate or Bid/Tender	Deterministic	1	10 to 100

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Example-01

The estimated capital cost for a chemical plant using the study estimate method (Class 4) was calculated to be $2 million. If the plant were to be built, over what range would you expect the actual capital estimate to vary?

Solution-01

Lowest Expected Cost Range

Example-01

The estimated capital cost for a chemical plant using the study estimate method (Class 4) was calculated to be $2 million. If the plant were to be built, over what range would you expect the actual capital estimate to vary?

Solution-01

Highest Expected Cost Range

Capital Cost Estimate

- Order of Magnitude (Rule of Thumb)
  - Based on the plant capacity
    - Production rate or feed processing rate
  - Typical figure (example)
    - $2,500/kW for coal fired power plant
    - $25,000/bpsd of crude oil processing in the refinery complex plant
- Cost Curve
  - Capacity of process unit as the x-axis and the cost as the y-axis in the log-log chart
  - Cost calculation basis: the scope of plant

Capacity Factored Estimate (CFE)

The plant capital cost (by Lang): based on the variation in the plant size

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

n: between 0.5 and 0.85, and 0.6 in average (Accuracy: 25~50%)

exponent, n	Type of Chemical Plant
0.8~0.9	Gas compression plant with many machineries (Methanol plant)
0.7	Petrochemical plant
0.4~0.5	Small plant, but instrumentation is well provided
0.6	Average value for most chemical plants

Capacity Factored Estimate (CFE)

CFE Formula for Refinery Process Units

$$\text{Capital Cost (MM\$)} = \alpha \times \text{capacity}^{\beta}$$

Process Unit	α	β	Unit
ADU	8.20	0.510	1,000 bpsd
VDU	8.34	0.493	1,000 bpsd
Delayed Coker, 10 bbl feed/ton coke	17.56	0.657	1,000 bpsd
Delayed Coker, 30 bbl feed/ton coke	24.42	0.644	1,000 bpsd
FCC	24.67	0.461	1,000 bpsd
RFCC	32.98	0.510	1,000 bpsd
Hydrocracker, 1000 scf/bbl H2	15.65	0.719	1,000 bpsd
Hydrocracker, 3000 scf/bbl H2	26.18	0.714	1,000 bpsd
NHT	4.96	0.524	1,000 bpsd
DHT	8.62	0.576	1,000 bpsd
ARDS	8.61	0.834	1,000 bpsd
CCR	12.19	0.547	1,000 bpsd

Capacity Factored Estimate (CFE)

CFE Formula for Refinery Process Units

$$\text{Capital Cost (MM\$)} = \alpha \times \text{capacity}^{\beta}$$

Process Unit	α	β	Unit
C4 Isomerization	9.57	0.514	1,000 bpsd
C5/C6 Isomerization, once through	3.11	0.565	1,000 bpsd
C5/C6 Isomerization, recycle	6.17	0.599	1,000 bpsd
Alkylation	12.19	0.606	1,000 bpsd
H2 Production, Steam methane reforming	3.35	0.599	MMscfd
Partial oxidation	5.44	0.601	MMscfd
Gas Processing, 1 gal/Mscf	1.91	0.627	MMscfd
Gas Processing, 10 gal/Mscf	4.38	0.593	MMscfd
Gas Processing, 20 gal/Mscf	5.83	0.610	MMscfd
Amine Gas Treating	0.064	0.746	MMscfd
SRU	0.064	0.746	ton/day

Capacity Factored Estimate (CFE)

CFE Formula for Chemical Process Unit

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

Chemical Process Unit	Exponent (n)
AN	0.6
BD	0.68
Chlorine	0.45
Ethanol	0.73
EO	0.78
HCl	0.68
Hydrogen Peroxide	0.75
Methanol	0.60
Nitric Acid	0.60

Chemical Process Unit	Exponent (n)
Phenol	0.75
PP	0.70
PVC	0.60
Sulfuric Acid	0.65
Styrene	0.60
Urea	0.65
Vinyl Acetate	0.80

Estimating Purchased Equip. Costs

- Vendor quote
  - Most accurate
    - based on specific information
    - requires significant engineering
- Use previous cost on similar equipment and scale for time and size
  - Reasonably accurate
    - beware of large extrapolation
    - beware of foreign currency
- Use cost estimating charts and scale for time
  - Less accurate
  - Convenient

Effect of Size: Equipment Factored Estimate (EFE)

Note: 본 방법이 플랜트 전체 투자 비용 산정에 쓰인다면 Capacity Factored Estimate (CFE)으로 불리운다.

$$\frac{C_a}{C_b} = \left(\frac{A_a}{A_b}\right)^n \qquad (7.1)$$

Cost Exponent (n)

Cost (C)

Equipment Cost Attribute - Size (A)

a: equipment with the required attribute

b: equipment with the base attribute

n: varies between 0.30 and 0.84. often around 0.6 (six-tenth rule)

$$C_a = K A_a^n \qquad (7.2)$$

where $K = \frac{C_b}{A_b^n}$

Table 7.3

With the six-tenths rule, the % increase in purchased cost when the capacity of a piece of equipment is doubled will be

$$C_a/C_b = (2/1)^{0.6} = \square$$

Even though the equipment capacity was doubled, the purchased cost of the equipment increased by only ☐

________________: The larger the equipment, the lower the cost of equipment per unit of capacity

Example-02

A new plant ordered a set of floating head heat exchangers (area = 100 m^2) cost $92,000. What would cost be for a heat exchanger for similar service if area = 50 m^2 and n = 0.44?

Solution-02

$$K = \frac{C_b}{A_b^n} = \frac{92,000}{100^{0.44}} = 12,128$$

Effect of Time

- Time increases - cost increases (inflation)
- Inflation is measured by cost indexes (Fig. 7.3)
  - Chemical Engineering Plant Cost Index (CEPCI); our textbook uses this
  - Marshall and Swift Process Industry Index (generally accepted)
- Numbers based on basket of goods typical for construction of chemical plants (Table 7.5)

Location Factor

- Transportation cost
- Taxes
- Labor supply and local productivity
- Codes and local inspection

Country	Region	Location Factor
Russia		1.53
India		1.02
ME		1.07
China	Imported	1.12
	Indigenous	0.61
US	Gulf Coast	1.00

Equation for Time Effect

$$C_2 = C_1 \left(\frac{I_2}{I_1} \right)$$

C = Cost

I = Value of cost index

1, 2 = Represents points in time at which costs required or known and index values known

Example-03

Cost of vessel in 1996 was $25,000, what is estimated cost in 2010?

Solution-03

$$\$25,000 \times \left(\frac{551}{382} \right) = \$36,000$$

Example-04

2 heat exchangers, 1 bought in 1990 and the other in 1995 for the same service

	A	B
Area	70 m^2	130 m^2
Time	1990	1995
Cost	17,000	24,000
I	358	381

What is the cost of a 80m^2 heat exchanger today? (I = 582)

Solution-04

$$\begin{aligned} \text{Cost today (A)} &= (\text{Cost in 1990}) \times (\text{Capacity Correction}) \times (\text{Inflation Correction}) \\ &= 17,000 \times (80/70)^{0.59} \times (582/358) \\ &= 29,900 \end{aligned}$$

$$\begin{aligned} \text{Cost today (B)} &= (\text{Cost in 1995}) \times (\text{Capacity Correction}) \times (\text{Inflation Correction}) \\ &= 24,000 \times (80/130)^{0.59} \times (582/381) \\ &= 27,500 \end{aligned}$$

Total Cost of Plant

- Purchased cost - equipment f.o.b. (free on board)
- Installed cost - often 3 to 8 times larger than purchased cost
- Installed cost of equipment (Table 7.6)
  - 1. Direct Project Expenses
    - Equipment
    - Material for installation
    - Labor for installation
  - 2. Indirect Project Expenses
    - Freight, insurance, and taxes
    - Construction overhead
    - Contractor engineering expenses

Total Cost of Plant

- Installed cost of equipment (Table 7.6)
  - 3. Contingency and Fee
    - Contingency
    - Contractor fee
  - 4. Auxiliary Facilities
    - Site development
    - Auxiliary buildings
    - Off-sites and utilities

Lang Factors (Table 7.7)

- The cost to build a major expansion to an existing chemical plant
- Use multiplier depending on type of plant to escalate equipment costs to installed costs
- F_{lang} = 4.74 Fluid processing plant
  = 3.63 Solid-fluid processing plant
  = 3.10 Solid processing plant

Note: Equipment Factored Estimate (EFE) 의 한 방법이다. cf) CFE

$$C_{TM} = F_{lang} \sum_{i=1}^{n} C_{pi}$$

Capital (total module) cost

Purchased cost of major equipment from preliminary PFD (pumps, compressors, vessels, etc.)

Module Factor Approach (Table 7.8)

- A common technique to estimate the cost of a new chemical plant introduced by Guthrie
- Also referred to as “Module Costing Technique”
- Relates all costs back to the purchased cost of equipment of base conditions
- Multiplying factors depend on
  - Equipment type, Pressure, MOC
- Direct, indirect, contingency, and fees are expressed as functions (multipliers) of purchased equipment cost (C_p^0) at base conditions (1 bar and CS)
- Details given in Appendix A
- Bare module cost = direct and indirect costs for each unit

Module Factor Approach (Table 7.8)

$$C_{BM} = C_p^0 F_{BM}$$

F_{BM} ← Bare module factor (sum of all multipliers)

C_{BM}: Bare Module Cost

C_p^0: Purchased equipment cost for CS and 1 atm pressure (Appendix A)

$$F_{BM} = B_1 + B_2 F_p F_M \leftarrow F_{BM}^0 = B_1 + B_2$$

F_P = pressure factor

F_M = material of construction factor (= 1 for CS)

$$C_p = C_p^0 F_p F_M$$

Example-04

The purchased cost for a carbon steel heat exchanger operating at ambient pressure is $10,000. For a heat-exchanger module, Guthrie provides the following cost information:

Item	**% of Purchased Equip. Cost**
Equipment	100.0
Materials	71.4
Labor	63.0
Freight	8.0
Overhead	63.4
Engineering	23.3

Using the information given above, determine the equivalent cost multipliers given in Table 7.8, bare module cost factor, and bare module cost.

Solution-04

Good News! Appendix A

Direct Cost: Materials

$$C_M = \alpha_M C_p^0 \qquad 71.4 = \alpha_M 100 \qquad \alpha_M = 0.714$$

Direct Cost: Labor

$$C_L = \alpha_L(C_p^0 + C_M) = \alpha_L(1+\alpha_M)C_p^0 \qquad 63.0 = \alpha_L(1+0.714)100$$

$$\alpha_L = 0.368$$

Similarly, multiplying factors for indirect costs (freight, overhead, and engineering) can be obtained.

$$F_{BM}^0 = (1 + 0.368 + 0.047 + (1.005)(0.368) + 0.136)(1 + 0.714) = 3.291$$

$$C_{BM}^0 = (3.291)(\$10,000) = \$32,910$$

Example-05

Find the bare module cost of a floating-head, shell-and-tube heat exchanger with a heat transfer area of 100m² at the end of 2011. The operating pressure of the equipment is 1.0 bar, with both shell-and-tube sides constructed of CS. From the cost curve given in Appendix A, we find that

$$C_p^0(2001) = (\$250)(100) = \$25,000$$

The bare module cost for shell-and-tube heat exchangers is given by Eq. (A.4).

$$C_{BM} = C_p^0[B_1 + B_2 F_p F_M]$$

The values of B_1 and B_2 for the heat exchangers from Table A.4 are 1.63 and 1.66, respectively.

The pressure factor is obtained from Eq. (A.3). From Table A.2, for pressures < 5 bars, $C_1 = C_2 = C_3 = 0$, and thus $F_p = 1$

From Table A.3, we also find that $F_M = 1$ for CS.

$$C_{BM}(2001) = C_p^0(2001)[1.63 + 1.66 \cdot 1 \cdot 1] = 3.29 C_p^0 = (3.29)(\$25,000) = \$82,300$$

$$C_{BM}(2011) = C_{BM}^0(2001)(582/397) = \$82,300(582/397) = \$120,650$$

$$\log_{10} C_p^0 = K_1 + K_2 \log_{10} A + K_3(\log_{10} A)^2$$

Equipment cost vs. capacity (area)

Equipment Factored Estimate의 한 방법 (Cost Curve를 이용한 C_p^0 구하기)

log-log 차트에서 2차함수: 꽤 정확함

Equipment Cost: a useful software tool in a book by Peters, Timmerhaus, …

CAPCOST: more accurate estimating software by Turton et al.

Figure 7.4

Calculation Algorithm of BMC

- Obtain C_p^0 (Appendix A)
- Obtain F_p and F_m (Appendix A)
- Obtain F_{BM} (Appendix A)
- Calculate C_{BM}
- Update cost from Sept. 2001 (CEPCI = _______)

Module Factor Approach - Pressure Factors

- Basis: ASME code
- Pressure parameter $F_{p,vessel}$ for a vessel having diameter D and operating pressure P (barg)
- Assuming allowable stress of carbon steel as 944 bar and welding efficiency as 90%, minimum allowable vessel thickness as 1/4" (0.0063m) and an additional thickness for allowable corrosion as 1/8" (0.00315)

$$F_{\mathrm{p,vessel}} = 1.0$$

when, $t < t_{\min}(0.0063\ \mathrm{m})$ and $P > -0.5\ \mathrm{barg}$

Module Factor Approach - Pressure Factors

$$F_p = \frac{(P+1)D/(2\cdot 944\cdot 0.9 - 1.2(P+1)) + CA}{t_{\min}}$$
$$= \frac{(P+1)D/(2\cdot 850 - 1.2(P+1)) + 0.00315}{0.0063}$$

when, $t > t_{\min}$ and $P > -0.5\ \mathrm{barg}$

$$F_{p,\mathrm{vessel}} = 1.25$$

when, pressure < -0.5 barg

* For equipment other than pressure vessel,

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

Module Factor Approach - Material Factors

Material Factor, F_M

Material	F_M
Carbon Steel	1.0
Stainless Steel Clad	1.7
Stainless Steel	3.1
Nickel Clad	3.6
Nickel	7.1
Titanium Clad	4.7
Titanium	9.4

Example-06

Compare costs for shell-and-tube heat exchanger in 2011 with an area = 100m² for

- Carbon Steel at 1 bar
- Carbon Steel at 100 bar
- Stainless Steel at 1 bar
- Stainless Steel at 100 bar

Solution-06

$$F_m = 2.73, \quad F_p = 1.383$$

P	MOC	C_p^0	C_p $(=C_p^0 F_p F_m)$	C_{BM}^0	C_{BM}
1 bar	CS	36.6	36.6	120.7	120.7
1 bar	SS	36.6	99.9	120.7	225.8
100 bar	CS	36.6	50.6	120.7	143.8
100 bar	SS	36.6	138.2	120.7	289.3

Total-Module Costs & Grass-Roots Costs

TM – Includes Contingency and Fees at 15% and 3% of BM

$$C_{TM} = 1.18 \sum_{\text{all equip.}} C_{BM}$$

GR – grass-roots cost includes costs for auxiliary facilities

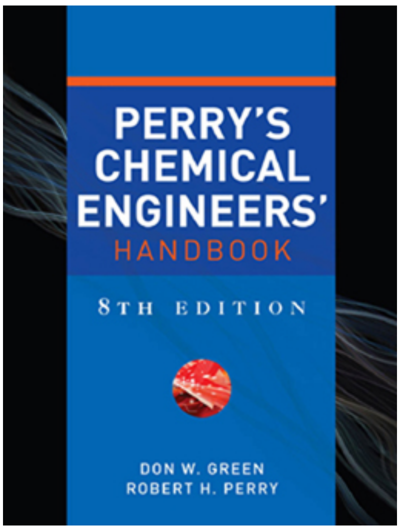
Auxiliary facilities = 50% of C_{BM}

$$C_{GR} = 0.50 \sum_{\text{all equip.}} C^0_{BM} + C_{TM}$$

Use base BM costs in GR cost (1 atm and CS) since auxiliary facilities should not depend on pressure or M.O.C.

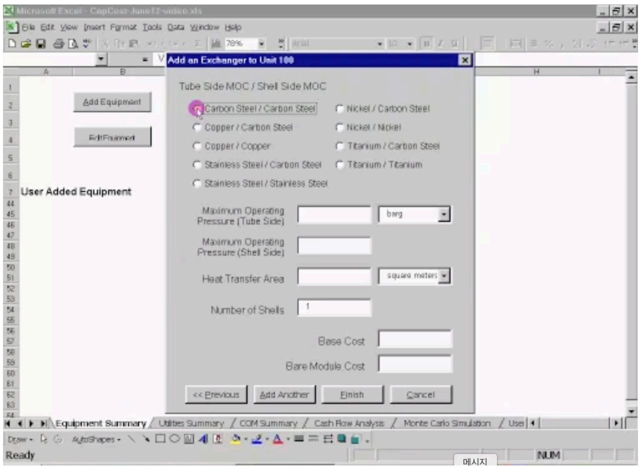
Materials of Construction

- Very important
- Table 7.9 - rough guide
- Perry's Chemical Engineer's Handbook - good source



Capcost

- Calculates costs based on input
- CEPCI – use current value of 542 or latest from *Chemical Engineering*
- Program automatically assigns equipment numbers



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