

SKF4153- PLANT DESIGN

CAPITAL COST ESTIMATION

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Cost Indexes

- ✓ Equipment cost is obtained from charts, equations or quotes from vendors, and only valid for a certain period of time.
- ✓ The cost changes (increases) from year to year primarily due to inflation.
- ✓ To estimate purchase Cost, C_p at a later date,
- ✓ The Chemical Engineering (CE) Plant Cost Index, The Marshall & Swift (MS) Equipment Cost Index, The Nelson-Farrar (NF) Refinery Construction Cost Index, The Engineering News-Record (ENR) Construction Cost Index.

$$Cost = Base Cost \left(\frac{I}{I_{base}} \right)$$

Total Capital Investment (TCI)

- ✓ One-time expense for design, construction and start-up for new or a revamp of an existing plant.
- ✓ Grass-roots plants vs. Plant expansions.
- ✓ Components of TCI:
 - ❖ C_{TBM} : Total Bare-Module Cost
 - ❖ C_{DPI} : Direct Permanent Investment
 - ❖ C_{TDC} : Total Depreciable Capital
 - ❖ C_{TPI} : Total Permanent Investment
 - ❖ C_{W} : Working Capital Investment

Estimation of TCI

- ❖ Methods (Levels of accuracy),
 - ❖ *Order-of-magnitude estimate ($\pm 50\%$)* based on production rate and major equipments as determine from bench-scale laboratory data.
 - ❖ *Study estimate ($\pm 35\%$)* based on a preliminary process design.
 - ❖ *Preliminary estimate ($\pm 20\%$)* based on detailed process design studies leading to an optimized process design.
 - ❖ *Definitive estimate* based on a detailed plant design, including detailed drawings and cost estimates, sufficient to apply cost accounting.

METHOD 1: Order-of-Magnitude Estimate

- ❖ To know whether a process is worth pursuing or not?
- ❖ Suitable for low pressure process (<100psi)
- ❖ Need production rate and flowsheet showing major equipment
- ❖ Calculation are based on:
 - ❖ A base production rate of 10,000,000 lb/yr of main product
 - ❖ Based on **Marshall and Swift Index (I_{MS})**
 - ❖ Carbon steel construction
 - ❖ Design pressure < 100 psi

Step 1 of METHOD 1

- Using six-tenths rule compute production rate factor F_{PR} :

$$F_{PR} = \left(\frac{Capacity_2}{Capacity_b} \right)^m = \left(\frac{\text{Main product flowrate, } lb / yr}{10,000,000} \right)^{0.6}$$

Step 2 of METHOD 1

- Calculate individual *module cost* C_M for compressors, blowers, separators (distillation, absorber, etc.), reactor, but not for pump, flash, reflux drum and heat exchanger.

$$\sum C_M = F_{PR} \left[\sum F_M \left(\frac{\text{design pressure, } psia, \text{ if } > 100 \text{ } psia}{100} \right)^{0.25} \right] \times \$160000$$

F_M is material factor; Carbon steel ($F_M=1.0$), Copper ($F_M=1.2$), Stainless steel ($F_M=2.0$), Nickel Alloy ($F_M=2.5$), Titanium clad ($F_M=3.0$).

Step 3 of METHOD 1

- Calculate *total bare-module investment* C_{TBM} for current year,

$$C_{TBM} = F_{PI} \left(\frac{I_{MS}}{I_{MS,base}} \right) \sum C_M$$

F_{PI} is factor to account for piping, instrumentation, automatic control as well as indirect costs. For solid handling ($F_{PI}=1.85$), solid & fluids ($F_{PI}=2.0$) and for fluids handling ($F_{PI}=2.15$).

Step 4 of METHOD 1

- Calculate direct permanent investment C_{DPI}

$$C_{DPI} = (1 + F_1 + F_2) C_{TBM}$$

F_1 and F_2 are factors to account site preparation, service facilities, utility plants. For outdoor construction ($F_1=0.15$), Indoor & outdoor ($F_1=0.4$) and indoor only ($F_1=0.8$). For minor addition to existing facilities ($F_2=0.10$), major addition to existing facilities ($F_2=0.3$) and for grass-roots plant ($F_2=0.8$).

Step 5 of METHOD 1

- ❖ Calculate total permanent investment C_{TPI}
- ❖ Add 40% to cover for contingencies and another 10% for land, royalties and start-up (total of 50%, thus multiply by 1.5).

$$C_{TPI} = 1.5C_{DPI}$$

- Calculate total capital investment C_{TCI}
- Add 15% to the total permanent investment C_{TPI}

$$C_{TCI} = 1.15 C_{TPI}$$

METHOD 2: Study Estimate

- ❖ Here the method is based on overall factor method of Lang (1947, 1948).
- ❖ Refer Table 22.16 for Lang factors of TPI and CPI, $f_{L,TPI}$ and $f_{L,TCP}$, respectively.
- ❖ Purchase cost, C_p for a particular base year ($I_{b,i}$) should already be known.
- ❖ The purchase cost of equipment was based on year 1977, and the corresponding MS index for that year is 514.

Summary of steps in Method 2

- ❖ Prepare an equipment list including their purchase cost for a particular base year.
- ❖ Update to the current cost index (I_i) and sum the updated purchase cost.
- ❖ Multiply by 1.05 to account for delivery cost to the plant site.

$$C_{TPI} = 1.05 f_{L,TPI} \sum_i \left(\frac{I_i}{I_{b,i}} \right) C_{P,i}$$

$$C_{TCI} = 1.05 f_{L,TCI} \sum_i \left(\frac{I_i}{I_{b,i}} \right) C_{P,i}$$

METHOD 3: Preliminary Estimate

- ✓ Based on Individual Factors Method of Guthrie (1969, 1974).
- ✓ Best carried out after;
 - ❖ Optimal process design,
 - ❖ Complete M&E balances, Equipment sizing and decision on materials of construction,
 - ❖ Process control configuration developed as in P&ID.

Steps 1 & 2 of METHOD 3

- Prepare an equipment list including their purchase cost for a particular base year.
- Update to the current cost index (I).
- The purchase cost is based on near ambient design pressure, carbon steel material and a base design.

Step 3 of METHOD 3

- For each piece of equipment, determine bare-module cost (C_{BM}) using bare-module factors (F_{BM}) and apply appropriate factors for design (F_d), pressure (F_p) and material (F_m).

$$C_{BM} = C_{P,b} \left(\frac{I}{I_b} \right) [F_{BM} + (F_d F_p F_m - 1)]$$

Steps 4 & 5 of METHOD 3

- ❖ Obtained the total bare-module cost C_{TBM} .

$$C_{TBM} = \sum C_{BM}$$

- ❖ Calculate total permanent investment C_{TPI} , (note: not including start-up and royalties)

$$C_{TPI} = 1.18(C_{TBM} + C_{site} + C_{building} + C_{offsite\ facilities})$$

- ❖ Add working capital to calculate total capital investment C_{TCI}

$$C_{TCI} = C_{TPI} + C_{WC}$$

Purchase Cost, C_p

- Table 22.19 gives sources of widely used equipment cost data and the corresponding base cost index.
- Usually presented in the form of graphs and/or equations.
- Could be generated using Aspen Icarus Process Evaluator (Aspen-IPE).
- Aspen-IPE: more accurate, consistent and periodically updated.

C_p of Centrifugal Pump

- ✓ Determine size factor, $S = Q(H)^{0.5}$
- ✓ Q is flowrate in gpm and H is the pump head in ft
- ✓ Calculate base f.o.b. purchase cost,

$$C_B = \exp\{9.7171 - 0.6019[\ln(S)] + 0.0519[\ln(S)]^2\}$$

- ✓ Purchase cost (C_B has already taken into account) of a single-stage, 3600 rpm, vertical split case (VSC), and made of cast iron centrifugal pump for S between 400 and 100000 can be estimated from Figure 22.3.

- ✓ For other specifications, purchase cost of centrifugal pump,

$$C_p = F_T F_M C_B$$

- ✓ F_M is material factor from Table 22.21.
- ✓ F_T is pump type factor from Table 22.20.
- ✓ This price does not include electric motor.

C_p of Shell & Tube HEX

- ✓ Base f.o.b. purchase cost data of HEX are correlated in terms of surface area.
- ✓ Fig. 22.10 is only valid for carbon steel tubes, $\frac{3}{4}$ in. or 1 in. OD, wall thickness of tube is 16 BWG (Birmingham Wire Gage), 20 ft long, square or triangular pitch, carbon steel with shell side pressure up to 100psig, and surface area between 150 to 12000ft².
- ✓ For other specifications, use Equation 22.43, and C_B of particular design from Equations 22.39-22.42.

- ✓ Equation 22.43;

$$C_p = F_p F_M F_L C_B$$

- ✓ F_L is tube-length correction factor (see page 571)
- ✓ F_M is material factor (Equation 22.44 and Table 22.25)
- ✓ F_p is pressure factor (Equation 22.45), P in psig.
- ✓ Read also on purchase costs for double-pipe HEX and fired heater.

C_p of Pressure vessel and Towers

- ❖ Size factor = Weight (lb)
- ❖ For other specifications, use Equation 22.52.

$$C_p = F_M C_V + C_{PL}$$

- ❖ Obtain cost of empty vessels, C_V ; in Equations 22.53 (horizontal), 22.54 (vertical) and 22.57 (towers).
- ❖ Additional cost for platform and ladder, C_{PL} ; in Equations 22.55 (Horizontal), 22.56 (Vertical) and 22.58 (towers).
- ❖ Use appropriate units for the equations
- ❖ Values of F_M are given in Table 22.26.

$$W = \pi(D_i + t_s)(L + 0.8D_i)t_s\rho$$

- ρ is density of carbon steel.
- t_s is thickness of shell and elliptical heads.
 - ✓ At high internal pressure (operating pressure); use Equation 22.60, where $t_s = t_p$.
 - ✓ Minimum wall thickness at low pressures are given at page 575.
- Effect of wind and earthquake on a vertical vessel/tower, use Equations 22.60 and 22.62. $t_s = t_v = t_p + t_w$
- At low internal pressure (vacuum), use Equations 22.63-22.65.
 $t_s = t_v = t_e + t_{ec}$.

C_p of Tray and Packed Tower

- ❖ Add cost of installed trays (inclusive all downcomers), C_T to cost of vessel.

$$C_p = F_M C_V + C_{PL} + C_T$$

$$C_T = N_T F_{NT} F_{TT} F_{TM} C_{BT}$$

- ❖ Base cost, C_{BT} (CE 394, year 2000) is given by Equation 22.67.
- ❖ N_T is tray number, F_{NT} is given by Equation 22.68, F_{TT} is tray type factor, F_{TM} is tray material factor, see page 577.
- ❖ For Packed column, self-learn from page 578.

References

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