Chemical Engineering

Plant Design and Economics

Comprehensive Theory

with Solved Examples and Practice Questions

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Plant Design and Economics

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CHAPTER 1

Cost Estimation

LEARNING OBJECTIVES

The reading of this chapter will enable the students

- To understand the types of investment and different costs.
- To understand the cost index, their types and lang factor for cost estimation.

1.1 Introduction

An acceptable plant design must present a process that is capable of operating under conditions which will yield a profit. Since net profit equals total income minus all expenses, it is essential that the chemical engineer be aware of the many different types of costs involved in manufacturing processes. Capital must be allocated for direct plant expenses, such as those for raw materials, labor, and equipment. Besides direct expenses, many other indirect expenses are incurred, and these must be included if a complete analysis of the total cost is to be obtained. Some examples of these indirect expenses are administrative salaries, product-distribution costs, and costs for interplant communications.

A capital investment is required for any industrial process, and determination of the necessary investment is an important part of a plant-design project. The total investment for any process consists of fixed-capital investment for physical equipment and facilities in the plant plus working capital which must be available to pay salaries, keep raw materials and products on hand, and handle other special items requiring a direct cash outlay. Thus, in an analysis of costs in industrial processes, capital-investment costs, manufacturing costs, and general expenses including income taxes must be taken into consideration.

1.2 Cost Indexes

Most cost data which are available for immediate use in a preliminary or predesign estimate are based on conditions at some time in the past. Because prices may change considerably with time due to changes in economic conditions, some method must be used for updating cost data applicable at a past date to costs that are representative of conditions at a later time? This can be done by the use of cost indexes.

A cost index is merely an index value for a given point in time showing the cost at that time relative to a certain base time. If the cost at some time in the past is known, the equivalent cost at the present time can be determined by multiplying the original cost by the ratio of the present index value to the index value applicable when the original cost was obtained.

$$\text{Present cost} = \text{Original Cost}\left(\frac{\text{Index value at present time}}{\text{Index value at time original cost was obtained}}\right)$$

Cost indexes can be used to give a general estimate, but no index can take into account all factors, such as special technological advancements or local conditions. The common indexes permit fairly accurate estimates if the time period involved is less than 10 years.

The main indexes available for industries include :

- Chemical Engineering Index, CE composed of 4 major components – equipment, construction labour, buildings and engineering and supervision – the index is employed primary as a process plant construction index, was established using a base period of 1957-59 as 100. The CE index is updated monthly and it lags in time by about 3 months. The CE index was revised in 1982, to account for changes in labor productivity and again in 2002.
- Marshall and Swift Cost Index, M&S (originally known as Marshall and Stevens Index) : a composite of two major components – process-industry equipment average and all-industry equipment average - was established in 1926 with a value of 100. Some industries considered in the process-industry equipment average are chemicals, petroleum products, rubber and paper. The all-industry average encompasses 47 different types of industrial, commercial and housing equipment.
- Intratec Chemical Plant Construction Index, IC a process plant construction index developed by Intratec, a chemical consulting company. Although cost indexes do not usually forecast future escalation, the IC index stands out for presenting a smaller delay between release date and index date, besides a 12 months forecast.
- Nelson-Farrar Indexes, NF (originally known as the Nelson Refinery Construction Indexes) established in 1946 with a value of 100, the index is more suitable for petroleum or petrochemical business.

Estimating Equipment Costs by Scaling

It is often necessary to estimate the cost of a piece of equipment when no cost data are available for the particular size of operational capacity involved. Good results can be obtained by using the logarithmic relationship known as the six-tenth factor rule, if the new piece of equipment is similar to one of another capacity for which cost data are available. According to this rule, if the cost of a given unit at one capacity is known, the cost of a similar unit with X times the capacity of the first is approximately $(X)^{0.6}$ times the cost of the initial unit.

$$\text{Cost of equipment, } a = \text{cost of equipment } b\left(\frac{\text{capacity equipment } a}{\text{capacity equipment } b}\right)^{0.6}$$

1.3 Lang Factor for Cost Estimation

Factorial Method

(i) For chemical process plant chemical cost estimate are often based on an estimate of major process equipment purchase cost. Other cost being estimated as a factor of the equipment cost.

(ii) By using Lang factor we can make quick estimate of capital cost in the early stage of project design.

(iii) The project fixed capital is given by as a function of total purchase equipment cost by following relation:

Fixed capital investment or total capital investment to an existing plant = Lang factor × delivered equipment cost.

(iv) Lang factor for different type of plant are given below :

Types of Plant	Lang Factor	
	Fixed Capital Investment	Total Capital Investment
(i) Solid processing plant	3.9	4.6
(ii) Solid-fluid processing plant	4.1	4.9
(iii) Fluid-processing plant	4.8	5.7

1.4 Capital Investments

Before an industrial plant can be put into operation, a large sum of money must be supplied to purchase and install the necessary machinery and equipment. Land and service facilities must be obtained and the plant must be erected complete with all piping, controls and services. In addition, it is necessary to have money available for the payment of expenses involved in the plant operation.

The capital needed to supply the necessary manufacturing and plant facilities is called the **fixed capital** investment, while that necessary for the operation of the plant is termed the **working capital**. The sum of the fixed-capital investment and the working capital is known as the total capital investment. The fixed capital portion may be further subdivided into manufacturing fixed capital investment and non-manufacturing fixed capital investment.

1.4.1 Fixed Capital Investment (F.C.I.)

1. Fixed capital means total cost of plant needed for start up. It is the cost paid to the contractors. It is a once – only cost that is not recovered at the end of the project life, other than scrap value. Fixed capital investment can be divided into :
   (a) Manufacturing fixed capital investment
   (b) Non-manufacturing fixed capital investment
2. Manufacturing fixed capital investment represents the capital necessary for installed process equipment with all auxiliaries that are needed for complete process operation. Examples are piping, instrument, insulation, foundation and site operations.
3. Fixed capital required for construction, overhead and all plant components that are not directly related to the process operation is called non-manufacturing. Examples of fixed capital investment are land, processing building, administration and other office warehouses, laboratories, transportation, shipping and receiving facility utility and waste disposal facilities. Constrution overhead cost consists of field office and supervision expenses, home office expenses, engineering expenses, miscellaneous construction cost, contractors fees and contingencies.
4. In some cases, construction overhead is proportioned between manufacturing and non-manufacturing fixed capital investment.

1.4.2 Working Capital Investment

1. Working capital is the additional investment needed over and above the fixed capital to start the plant up and operate plant to the point where profit is earned.

2. The working capital for an industrial plant consists of the total amount of money invested in:
   (a) Raw materials and supplies carried in stock.
   (b) Finished product in stock and semi-finished product in the process of being manufactured.
   (c) Accounts receivable.
   (d) Cash kept on hand for monthly payment of operating expenses such as salaries, wages and raw material purchase.
   (e) Accounts payable and taxes payable.
   (f) Start up cost, catalyst charges.
3. The ratio of working capital to total capital investment varies with different companies but most chemical plant use an initial working capital amount 10 to 20 percent of the total capital investment.
4. Most of the working capital is recovered at the end of the project.

1.5 Direct Costs

1. Purchased Equipment :
   - All equipment listed on a complete flow sheet.
   - Spare parts and non installed equipment spares.
   - Surplus equipment, supplies and equipment allowance.
   - Inflation cost allowance.
   - Freight charges.
   - Taxes, insurance, duties.
   - Allowance for modification during start-up.
2. Purchased Equipment Installation :
   - Installation of all equipment listed on complete flow sheet.
   - Structural supports.
   - Equipment insulation and painting.
3. Instrumentation and Controls :
   - Purchase, installation, calibration, computer control with supportive software.
4. Piping :
   - Process piping utilizing suitable structural materials.
   - Pipe hangers, fiting, valves.
   - Insulation.
5. Electrical Systems :
   - Electrical equipments.
   - Electrical material and labor.
6. Building (including services)
   - Process buildings.
   - Auxiliary buildings.
   - Maintenance shops.
   - Building services.

7. Yard Improvements :
   Site development-site clearing. Grading, roads, walkways etc.
8. Service Facilities :
   - Utilities : Steam, water, power, refrigeration, compressed air, fuel, waste disposal.
   - Facilities : Boiler plant incinerator, wells, river intakes, water treatment, cooling tower, storage tank etc.
   - Non-process equipments : Office furniture, cafeteria installment, medical equipment, etc.
   - Distribution and packaging : Law material and product storage and handling equipment, product packaging etc.
9. Land :
   - Surveys and Fees
   - Property Cost

1.6 Indirect Cost

1. Engineering and Supervision :
   - Engineering cost : Administrative, process, design and general engineering etc.
2. Legal Expenses
3. Construction Expenses :
   - Constrution, operation and maintenance of temporary facilities, offices, etc.
   - Construction tools and equipment
   - Construction supervision
   - Warehouse expenses
   - Safety expenses
   - Permits and licenses
   - Taxes, insurance, interest
4. Contractor's fees
5. Contingency

Example 1.1 Direct costs component of the fixed capital consists of

(a) contingency (b) onsite and offsite costs
(c) labour costs (d) raw material costs

Solution : (b)

Direct costs component of the fixed capital consists of onsite and offsite costs.

Example 1.2 For a solid processing plant, the delivered equipment cost is Rs. 10 lakhs. Using lang multiplication method, the total capital investment, in lakhs of rupees, is

(a) 46 (b) 57 (c) 100 (d) 200

Solution : (a)

For solid processing plant, Lang factor = 4.6

Total capital investment = 10×4.6 = Rs. 46 lakhs

Example 1.3 Which relation gives total capital investment?

(a) Total capital investment = Fixed capital investment + Working capital

(b) Total capital investment = Fixed capital investment + scrap value

(c) Total capital investment = Working capital + Depreciation

(d) Total capital investment = Salvage value + Depreciation

Solution : (a)

Example 1.4 In a desalination plant, an evaporator of area 200 m^2 was purchased in 1996 at a cost of Rs. 3,00,000. In 2002, another evaporator of area 50 m^2 was added. What was the cost of the second evaporator (in Rs.)? Assume that the cost of evaporators scales as $(\text{capacity})^{0.54}$. The Marshall and Swift index was 1048.5 in 1996 and 1116.9 in 2002.

Solution : (151166)

$$\text{Cost of 200 m}^2\text{ evaporator in year 2002} = \text{Cost in year 1996}\left(\frac{\text{Cost Index in year 2002}}{\text{Cost Index in year 1996}}\right)$$

$$= (3{,}00{,}000)\left(\frac{1116.9}{1048.5}\right)$$

Now use capacity scale,

$$\text{The cost of 50 m}^2\text{ evaporator in 2002} = (3{,}00{,}000)\left(\frac{1116.9}{1048.5}\right)\left(\frac{50}{200}\right)^{0.54}$$

$$= \text{Rs. } 151166.$$

Example 1.5 If cost of a distillation column in the year 2000 is Rs. x. What is the cost of the column in Rs. in the year 2010? Given the cost indices for the years 2000 and 2010 are 480 and 520 respectively.

Solution :

$$\text{Cost in year 2010} = \text{Cost in year 2000} \times \left(\frac{\text{Cost Index in year 2010}}{\text{Cost Index in year 2000}}\right)$$

$$\Rightarrow \quad \text{Cost in year 2010} = x\left(\frac{520}{480}\right) = x\left(\frac{13}{12}\right)$$

Example 1.6 The purchased cost of a shell-and-tube heat exchanger with 10 m^2 of heating surface was Rs. 4200 in 1990. What will be the purchased cost of a similar heat exchanger with 100 m^2 of heating surface in 2000? Use both Marshal and Swift Index and Chemical Engineering Plant Cost Index for comparison.

Given : The purchased cost capacity exponent for this type of heat exchanger is :
0.60 for surface areas ranging from 10 to 40 m^2
0.81 for surface areas ranging from 40 to 200 m^2

Year	Marshal and Swift Index	Chemical Engineering Plant Cost Index
1990	929.3	357.6
2000	1097.7	394.1

Solution :

First make capacity correction, then inflation correction.

$$\text{Cost in 1990 for 100 m}^2 = (\text{Cost in 1990 for 10 m}^2)(\text{Capacity correction})$$

$$= \text{Rs. } 4200 \times \left(\frac{40}{10}\right)^{0.60} \left(\frac{100}{40}\right)^{0.81} = \text{Rs. } 20268$$

Marshal and Swift Index :

$$\text{Cost in 2000 for 100 m}^2 = (\text{Cost in 1990 for 100 m}^2)(\text{Inflation correction})$$

$$= \text{Rs. } 20268\left(\frac{1097.7}{929.3}\right) = \text{Rs. } 23941$$

Chemical Engineering Plant Cost Index :

$$\text{Cost in 2000 for 100 m}^2 = \text{Rs. } 20268\left(\frac{394.1}{357.6}\right) = \text{Rs. } 22337$$

Example 1.7 In the year 2005, the cost of a shell and tube heat exchanger with 68 m^2 heat transfer area was Rs. 12.6 lakh. Chemical Engineering Index for cost in 2005 was 509.4 and now the index is 575.4. Based on index of 0.6 for capacity scaling, what will be the present cost (in lakhs of rupees) of a similar heat exchanger having 100 m^2 heat transfer area?

Solution :

$$\text{Cost in 2005 for 100 m}^2 = (\text{Cost in 2005 for 10 m}^2)(\text{Capacity correction})$$

$$= 12.6 \times \left(\frac{100}{68}\right)^{0.60} = 15.88 \text{ lakh}$$

$$\text{Current cost for 100 m}^2 = (\text{Cost in 2005 for 100 m}^2)(\text{Inflation correction})$$

$$= 15.88\left(\frac{575.4}{509.4}\right) = 17.94 \text{ lakh}$$

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Student's Assignments

Q.1 A heat exchange of area 10 m^2 costed Rs. 50,000 in the year 1985. What is estimated cost of a 15 m^2 exchanger in 1988. Assume that the cost index in 1985 was 270 and in 1988 it is 320.

Q.2 If the delivered cost of equipments of a fluid processing plant is 4×10^6. What is the capital cost of the plant in lakh?

Q.3 In a desalination plant, an evaporator of area 200 m^2 was purchased in 1996 at a cost of $3,00,000. In 2002, another evaporator of area 50 m^2 was added. What was the cost of the second evaporator (in $)? Assume that the cost evaporators scales as $(\text{capacity})^{0.54}$. The marshall and swift index was 1048.5 in 1996 and 1116.9 in 2002.

(a) 1,30,500 (b) 1,39,100
(c) 1,41,900 (d) 1,51,200

Q.4 The cost of a drum dryer is Rs. 10 lakhs. The cost of a drum dryer with double the surface area in lakhs of rupees is

(a) 2×10 (b) $3^{0.6} \times 10$
(c) $5^{0.6} \times 10$ (d) $2^{0.6} \times 10$

Q.5 Which of the following cost is related to Non-Manufacturing Fixed Capital Investment?

(a) Site preparation (b) Land
(c) Taxes payable (d) Insulation

Q.6 Which type of cost estimate is used when we have no design information about the project and estimate is based on the similar previous cost data?

(a) Definitive estimate
(b) Order of magnitude estimate
(c) Preliminary estimate
(d) Study estimate

Q.7 The purchased cost of a 50-gal glass-lined, jacketed reactor (without drive) was $8350 in 1981. Estimate the purchased cost of a similar 300-gal, glass-lined, jacketed reactor (without drive) in 1986. Use the annual average Marshall and Swift equipment-cost index (all industry) to update the purchase cost of the reactor.

Q.8 The cost of a Shell and Tube Heat Exchanger with 100 ft^2 heating surface was Rs. 3000 in 1980. The cost (in Rs.) of a Heat Exchanger with 1000 ft^2 of heating surface in 1985 is _____.
Data : Cost index in 1985 = 813
Cost index in 1980 = 675

Q.9 In the year 1995, the cost of a Shell and Tube heat exchanger with 70 m^2 heat transfer area was Rs. 10 lakh. Chemical Engineering Index for cost in 1995 was 381.1 and the index in 2002 was 390.4. Based on index of 0.6 for capacity scaling, the cost (in Lakhs of Rupees) of a similar heat exchanger having 90 m^2 heat transfer area in 2002 will be _____.

Q.10 What will be the purchased cost of a similar 360 gal Jacketed reactor in 2013. If the purchased cost of 50 gal glass lined jacketed reactor was Rs. 7000 in 2002.
Cost index for 2002 : 710 and 2013 : 780.

(a) 20110 (b) 20250
(c) 25140 (d) 22330

Q.11 Present cost relation is

(a) $\text{P.C.} = \text{Original cost} \times \dfrac{\text{Index value at present time}}{\text{Index value at time original cost was obtained}}$

(b) $\text{P.C.} = \dfrac{\text{Index value at present time}}{\text{Index value at time original cost was obtained}} \times \dfrac{1}{\text{Original cost}}$

(c) $\text{P.C.} = \text{Original cost} \times \dfrac{\text{Index value at time original cost was obtained}}{\text{Index value at present time}}$

(d) $\text{P.C.} = \dfrac{\text{Index value at time original cost was obtained}}{\text{Index value at present time}} \times \dfrac{1}{\text{Original cost}}$

ANSWERS

1. (75580.71) 2. (22.8) 3. (d) 4. (d)
5. (b) 6. (b) 7. (24300)
8. (17278.10) 9. (11.9) 10. (d) 11. (a)

Explanation

1. (75580.71)

Capacity of heat exchanger $(\text{HE})_1 = 10\ \text{m}^2$

Capacity of $(\text{HE})_2 = 15\ \text{m}^2$

Hence from six – tenth rule we know that

$$\frac{\text{Cost of (HE)}_1}{\text{Cost of (HE)}_2} = \left(\frac{\text{Capacity of (HE)}_1}{\text{Capacity of (HE)}_2}\right)^{0.6}$$

$$\text{Cost of (HE)}_2 \text{ in 1985} = 50000 \times \left(\frac{15}{10}\right)^{0.6}$$

$$= 63771.23$$

Cost index in 1985 = 270

Cost index 1987 = 320

Hence, we know from given relation :

$$\text{Present cost} = \left(\frac{\text{Index value at present time}}{\text{Index value at time original cost was obtained}}\right)$$

$$\text{Present cost} = 63771.23 \times \left(\frac{320}{270}\right)$$

$$= \text{Rs. } 75580.71$$

2. (22.8)

We know that :

Fixed capital investment or total capital investment = Lang Factor × delivered cost

Total capital cost of the plant $= (4 \times 10^6) \times 5.7$

$= 22.8 \times 10^6$

Total capital cost of the plant = Rs. 22.8 lakh

3. (d)

Evaporator cost of 50 m^2 in 1996

$$= \$\left(\frac{50}{200}\right)^{0.54} \times 300{,}000 = \$141909$$

Evaporated cost of 50 m^2 in 2002

$$= \$141909 \times \frac{1116.9}{1048.5} = \$151166 \simeq \$151200$$

4. (d)

By six tenth rule

$$\frac{C_2}{C_1} = \left(\frac{S_2}{S_1}\right)^{0.6}$$

$$\frac{C_2}{10} = (2)^{0.6} \Rightarrow C_2 = 10 \times (2)^{0.6}$$

7. (24300)

Marshall and Swift equipment-cost index (all industry)

(From Table 3) For 1981 : 721

(From Table 3) For 1986 : 798

From Table 5, the equipment vs. capacity exponent is given as 0.54 :

In 1986, cost of reactor

$$= (\$8350)\left(\frac{798}{721}\right)\left(\frac{300}{50}\right)^{0.54}$$

$$= \$24{,}300$$

8. (17278.10)

Cost of H.E. with 1000 ft^2 =

Cost of H.E. with 100 ft^2 ×

$$\frac{\text{C.I. 1985}}{\text{C.I. 1980}} \times (\text{Capacity Ratio})$$

$$= 3000 \times \frac{813}{675} \times \left(\frac{400}{100}\right)^{0.6} \times \left(\frac{1000}{400}\right)^{0.8}$$

= Rs. 17278.10

9. (11.9)

Cost in year 2002 (x)

$$x = (\text{Cost in year 1995}) \times \frac{\text{Cost Index in 2002}}{\text{Cost Index in 1995}} \times (\text{Capacity Ratio})^{0.6}$$

$$x = 10 \times 10^5 \times \frac{390.4}{381.1} \times \left(\frac{90}{70}\right)^{0.6}$$

$$x = 11.91 \times 10^5 \simeq 11.9 \text{ lakhs}$$

10. (d)

In 2013 cost of reactor

$$= 7000 \times \left(\frac{360}{50}\right)^{0.6} \times \frac{780}{710} = \text{Rs. } 25138.18$$

11. (a)

$$\text{P.C.} = \text{Original cost} \times \frac{\text{Index value at present time}}{\text{Index value at time original cost was obtained}}$$

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