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| | | Rev 01 June 2014 |
| <p>KLM Technology Group P. O. Box 281 Bandar Johor Bahru, 80000 Johor Bahru, Johor, West Malaysia</p> | <p>Kolmetz Handbook of Process Equipment Design</p> <p>GENERAL PROCESS PLANT COST ESTIMATING</p> <p>(ENGINEERING DESIGN GUIDELINE)</p> | Co Author: Reni Mutiara Sari |
| | | Author / Editor Karl Kolmetz |

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INTRODUCTION

Scope

Many engineering design projects are developed to provide sizing information from which estimates of capital and operating costs can be made. Chemical plants are built to make a profit, and an estimate of the investment required and the cost of production is needed before the profitability of a project can be assessed. Cost estimation is a specialized subject and a profession in its own right, but the design engineer must be able to make rough cost estimates to decide between project alternatives and optimize the design.

Cost estimation may be defined as the process of forecasting the expenses that must be incurred to manufacture a product. These expenses take into consideration all expenditures involved in design and manufacturing with all the related service facilities such as pattern making, tool making as well as portion of the general administrative and selling costs. Cost estimates are the joint product of the engineer and the cost accountant.

Estimating is of great importance to a concern because it enables the factory owner to decide about the manufacturing and selling policies. It is obvious that too high of an estimate will not get any jobs for the firm quoting higher rates. Under estimating will put the engineering firm owner with a loss and may lead the engineering firms failure. Therefore, estimation must be carried out accurately.

This design guideline covers the how to estimate capital investment, total product cost and economic and profitability analysis of cost estimating used in the typical process industries. It assists engineers to understand the basic design of cost estimation.

This design guideline covers the basic elements in the field of cost estimation in sufficient detail to allow an engineer to design a cost estimate with the suitable economic analysis; depreciation, net profit after tax, percentage of return of investment, payout period of project net present value with interest rate and cash flow, etc.

The design of cost estimation may be influenced by factors, including equipments size, process requirements, location, labor cost, and complexity level of process. .All the important parameters use in the guideline are explained in the definition section which help the reader more understand the meaning of the parameters or the terms utilized.

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In the application section of this guideline, five case studies are shown and discussed in detail, highlighting the way to apply the theory for the calculation. Example Calculation Spreadsheets are part of this guideline. This Example Calculation Spreadsheets are based on case studies in the application section to make them easier to understand.

INTRODUCTION

General Consideration

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.

A. Sources of Price Data

The revenues and variable costs of production are obtained by multiplying the product, feed, or utility flow rates from the flowsheet by the appropriate prices. The difficult step is usually finding good price data.

In many large companies the marketing or planning department develops official forecasts of prices for use in internal studies. These forecasts sometimes include multiple price scenarios, and projects must be evaluated under every scenario. Company forecasts are occasionally made available to the public.

Other sources of price data are based on trade journals. Other companies also can be hired as consultants to provide economic and marketing information or contact online brokers and suppliers directly and last source, get price data from reference books^[9].

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B. Capital Requirement

The cost of capital is what it costs a company to borrow money from all sources, such as loans, bonds, and preferred and common stock. It is an important consideration in determining a company's minimum acceptable rate of return on an investment. A company must make more than the cost of capital to pay its debts and make a profit.

From profits, a company pays dividends to the stockholders. If a company ignores the cost of capital to increase dividends to the stockholders, then management is not meeting its obligations to pay off outstanding debts. The following explanations are principal to build cost estimating of a plant.

C. 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.

I. Fixed Capital Investment

About 85 to 90 percent of total capital is comprised generally of fixed capital. Fixed capital may be defined as the total cost of processing installations, buildings, auxiliary services, and engineering involved in the creation of a new plant. Several methods to obtain fixed capital investment can be described as follow.

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i. Method 1

This method requires the cost factors by consider the proportional costs of each component. The cost factors presented are based on modern industrial experience. The typical variation in component costs as percentages of fixed capital investment for multiprocess grass-roots plants or large battery limit additions are summarized in table 1. A grass-roots plant is defined as a complete plant erected on a new site.

Table 1: Percentage of Fixed capital Investment (Peters, 1990)

| Typical percentages of fixed-capital investment values for direct and indirect cost segments for multipurpose plant or large additions to existing facilities | |
|---|----------|
| Component : | Range, % |
| Direct costs | |
| Purchased equipment | 15-40 |
| Purchased equipment installation | 6-14 |
| Instrumentation and controls (installed) | 2-8 |
| Piping (installed) | 3-20 |
| Electrical (installed) | 2-10 |
| Buildings (including services) | 3-18 |
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ii. Method 2

This method looks like first method but, there is contained difference in the application. The used of this method requires initially that the cost of purchased process equipment. All components of direct cost are then estimated individually as equivalent to percentages of the equipment cost.

iii. Method 3

A simple technique to estimate the capital cost of a chemical plant is the Lang Factor method. The Lang factor method has a tendency to produce high results. The total cost is determined by multiplying the total purchased cost for all the major items of equipment by a constant. The multipliers, depending on the type of plant are given in table 2^[10].

Table 2: Lang factor

| Type of chemical plant | Lang factor, F_{Lang} |
|--------------------------|-------------------------|
| Solid processing | 3.10 |
| Solid – fluid processing | 3.63 |
| Fluid processing | 4.74 |

The capital cost calculation is determined using Equation 1.

$$C_T = F_{Lang} \sum_{i=1}^n C_{p,i} \quad \text{Eq (1)}$$

Where,

- C_T = Capital cost of the plant
- $C_{p,i}$ = Purchased cost for the major equipment units
- n = Total number of individual units
- F_{Lang} = Lang Factor

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II. Working Capital

Working capital is the amount of capital required to start up the plant and finance ordinarily amounts to the production cost for 1 month of operation before revenues from the process start. In general it will be found to be amount equal to 15 to 20% of the fixed capital investment or 25% of annual product sales value^[3].

The working capital for an industrial plant consists of the total amount of money invested in raw materials and supplies carried in stock, finished products in stock and semifinished products in the process of being manufactured, accounts receivable, cash kept on hand for monthly payment of operating expenses, such as salaries, wages, and raw-material purchases, accounts payable, and taxes payable^[7].

D. Total Production Cost

Important part of a complete cost estimate besides capital investment is the estimation of costs for operating the plant and selling the products. Capital expenditures occur once during the life of a project but operating expenses are recurring expenses and, as such, significantly affect the cash flow and profitability of a venture. These costs can be grouped under total production cost. Total production cost is generally divided into the categories of manufacturing costs and general expenses.

I. Manufacturing Costs

The manufacturing expense will be interpreted to mean all expenses required to make a product and to ready it for shipment. These expenses, as considered here, are divided into three classifications as follows: direct production costs, fixed charges, and plant-overhead cost.

II. General Expenses

In addition to the manufacturing costs, other general expenses are involved in any company's operations. These general expenses may be classified as administrative expenses, distribution and marketing expenses, research and development expenses, and financing expenses.

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E. Classification of Cost Estimates

An estimate of the capital investment for a process may vary from a predesign estimate based on little information except the size of the proposed project to a detailed estimate prepared from complete drawings and specifications. The American National Standards Institute (ANSI) defines five categories represent the accuracy range and designation normally used for design purposes:

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Table 3 : Classification of Cost Estimates^[11]

| Phase of estimating cycle | Typical process industry accuracy range and contingency | Typical data input available | Typical end uses | Typical techniques |
|---|---|---|---|---|
| Class V (Order of magnitude, guessestimate) | -30% to +50% before contingency | Engineering <2% complete; general fuction; rough capacities and outputs | Project screening; brain-storming | Judgement or parametric including : capacity factoring, parametric cost models, gross unit costs/ratios |
| | Typical contingency : 15 – 40% | | | |
| Class IV (Study, conceptual) | -15% to +30% before contingency | Engineering 1-5% complete; capacities and outputs; block layouts and diagrams; preliminary equipment list; soils data assumed | Project screening; concept evaluation; feasibility studies; budget previews | Parametric including : equipment factored, gross unit costs/ratios, parametric cost models |
| | Typical contingency : 10 – 20% | | | |
| Class III (Preliminary, budget authorization) | -10% to +20% before contingency | Engineering 10-40% complete; preliminary layouts and diagrams; equipment list and specifications; partial soils data | Design development; cost control; detailed feasibility | Mixed parametric and unit: battery limit, cascading; parametric unit cost models; some unit costs |
| | Typical contingency : 8 – 12% | | | |

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| Phase of estimating cycle | Typical process industry accuracy range and contingency | Typical data input available | Typical end uses | Typical techniques |
|--|---|--|---|--|
| Class II (Definitive, project control) | -5% to +15% before contingency | Engineering 30-60% complete; final layouts and diagrams; final equipment list and quotes; preliminary design drawings; complete soils data | Check or comparison; bid or tender (soft \$); detail cost control | Unit cost or line item with minor parametric application |
| | Typical contingency : 5 – 10% | | | |
| Class I (Detailed, firm) | -5% to +5% before contingency | Engineering >90% complete; design essentially complete; approved for construction; full quantity take off | Bid or tender (hard \$), material procurement | Unit cost or line item |
| | Typical contingency : 3 – 5% | | | |

It should be noted that the predesign estimates may be used to provide a basis for requesting and obtaining a capital appropriation from company management. Later estimates, made during the progress of the job, may indicate that the project will cost more or less than the amount appropriated. Management is then asked to approve a variance which may be positive or negative.

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F. Estimating Procedure

Committees within the firm are formed to plan for the future and prepare capital budgets. The economic evaluation of a process proceeds in several steps. These are:

1. preparing a process flow diagram
2. calculating mass and energy flows
3. sizing major equipment
4. estimating the capital cost
5. estimating the production cost
6. forecasting the product sales price
7. estimating the return on investment

The difficulty in a process evaluation is not the computations, but the variability in the terminology that appears in the literature, which is a result of differences in company practice^[8].

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DEFINITION

After-tax cash flow - the net profit after taxes plus depreciation.

Breakeven point the operating - condition, such as output, at which two alternatives are equal in economy.

Cost estimating - A predictive process used to quantify, cost, and price the resources required by the scope of an asset investment option, activity, or project.

Cost index (price index) - a number that relates the cost of an item at a specific time to the corresponding cost at some arbitrarily specified time in the past.

Direct costs - the portion of the operating costs that is generally assignable to a specific product or process area.

Escalation - the provision in actual or estimated costs for an increase in the cost of equipment, material, labor, etc., over that specified in the purchase order or contract due to continuing price level changes over time.

Indirect costs - costs not directly assignable to the end product or process, such as overhead and general purpose labor, or costs of outside operations, such as transportation and distribution.

Interest rate - the ratio of the interest payment to the principal for a given unit of time, usually expressed as a percentage of the principal.

Operating cost (or manufacturing cost) - the expenses incurred during the normal operation of a facility, or component, including labor, materials, utilities, and other related costs.

Overhead - a cost or expense inherent in the performing of an operation, plant overhead is also called factory expense.

Payout period - the time required to recover the original fixed investment from profit and depreciation.

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Present value - the value of the asset in its condition at the time of valuation.

Profit – the excess of income over expenditure

Royalty - compensation for the use of a property, usually a patent, copyrighted material, or natural resource; often expressed as a percentage of receipts from using the property.

Salvage value - the market value of a capital asset at the time it is retired (often assumed to be zero in economic analysis).

Service life - the useful life of an asset.

Stockholder - an investment group or individual holding legal ownership of a business by virtue of investing equity capital and entitled to any profits generated.

Straight line (SL) depreciation - provides that an asset be depreciated in equal annual installments over its useful (book) life or its tax life.

Taxable income - cash earnings minus cash expense minus noncash expenses for depreciation, depletion, or amortization.

Taxes - cash payments to governmental agencies, including excise taxes, property taxes, capital gains taxes, and income taxes.

Time value of money - recognizes that money shifts in purchasing power over time to reflect inflation and uncertainty in investment returns.

Time zero - a single reference point in time set by the analyst as a starting point for economic analysis.

Working capital - cash that is tied up in an operation in addition to capital invested in facilities. Includes cash cost of inventories, net accounts receivable, spare parts or supplies, and cash-on-hand.

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NOMENCLATURE

| | |
|-----------|---|
| A | Uniform end-of-period payment or receipt, dimensionless |
| C_1 | Estimated cost at previous time, \$ |
| C_2 | Cost at expected time, \$ |
| C_a | Capacity of equipment a |
| C_b | Capacity of equipment b |
| CF_n | Cash flow in year n |
| D | Depreciation, \$ |
| E_a | Purchased cost of equipment a, \$ |
| E_b | Purchased cost of equipment b, \$ |
| F | Future sum of money at the end of period, dimensionless |
| F_{DB} | Factor of declining-balance depreciation, dimensionless |
| F_{DDB} | Factor of double-declining-balance depreciation, dimensionless |
| i | interest rate per period |
| I_1 | Index value at expected time, dimensionless |
| I_2 | Index value at previous time, dimensionless |
| L | Salvage value, \$ |
| n | Depreciable life in years, year |
| N_{OL} | Number of operators per shift, dimensionless |
| N_{np} | Number of nonparticulate processing steps (compressors, towers, reactors, heaters, and exchangers) , dimensionless |
| P | Present value, a single amount (may be used fixed capital investment) |
| P | Number of processing steps involving the handling of particulate solid (e.i distribution, particulate size control, and particulate removal). In general, the value of P is zero, dimensionless |
| t | Project life in years, year |
| T_b | Thickness of the shell at the bottom, in |
| T_p | Thickness required for the operating pressure, in |
| W | Weight of towers, lb |

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THEORY

A. 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.

Cost indexes are numerical values that reflect historical change in engineering costs. The cost index numbers are dimensionless, and reflect relative price change in either individual cost items such labor, material, utilities; or groups of costs such consumer prices, producer prices. Indexes can be used to update historical costs with the basic ratio relationship as follows^[6].

$$C_2 = C_1 \left(\frac{I_2}{I_1} \right) \quad \text{Eq (2)}$$

where,

C_1 = Estimated cost at previous time

C_2 = Cost at expected time

I_1 = Index value at expected time

I_2 = Index value at previous time

There are several cost indexes used by the chemical industry to adjust for the effects of inflation.

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Several of these cost indices are shown in Table 4.

Table 4: Cost Indexes

| Year | Chemical Engineering Plant Cost 1957-1959 = 100 | Eng.News-Record Construction Cost index 1967 = 100 | Marshall and Swift Equipment Cost Index 1926 = 100 | Nelson-Farrar refinery Cost index 1946 = 100 |
|---------------|--|---|---|---|
| 1995 | 381.1 | 5471 | 1027.5 | 1392.1 |
| 1996 | 381.8 | 5620 | 1039.2 | 1418.9 |
| 1997 | 386.5 | 5826 | 1056.8 | 1449.2 |
| 1998 | 389.5 | 5920 | 1061.9 | 1477.6 |
| 1999 | 390.6 | 6059 | 1068.3 | 1497.2 |
| 2000 | 394.1 | 6221 | 1089.0 | 1542.7 |
| 2001 | 394.3 | 6343 | 1093.9 | 1579.7 |
| 2002 | 395.6 | 6538 | 1104.2 | 1642.2 |
| 2003 | 401.7 | 6694 | 1123.6 | 1710.4 |
| 2004 | 444.2 | 7115 | 1178.5 | 1833.6 |
| 2005 | 468.2 | 7446 | 1244.5 | 1918.8 |
| 2006 | 499.6 | 7751 | 1302.3 | 2008.1 |
| 2007 | 525.4 | 7967 | 1373.3 | 2106,7 |
| 2008 | 575.4 | 8310 | 1449.3 | 2251,4 |
| 2009 | 521.9 | 8570 | 1468.6 | 2217.7 |
| 2010(midyear) | 555.3 | 8837 | 1461.3 | 2337.6 |

Current and past values of several of the indexes may be obtained from each published sources, as such the Marshall & Swift Index (M&S) and the Chemical Engineering (CE) Index is found in *Chemical Engineering* under Economic Indicators; Nelson Farrar (NF) index is published in the first issue each month of the *Oil and Gas Journal* quarterly; and the Engineering News Record (ENR) Index may be found weekly in *Engineering News Record*.

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The choice of the index to use is based upon the industry in which the person works. If it is general construction, the ENR Index is the best. An engineer in the petroleum or petrochemical business might find the NF Index suitable. In the chemical process industries, either the CE or the M&S are adequate. Although these latter two indexes have different bases, both of these give similar results^[3].

As a rule of thumb, cost indexes permit accuracy may be limited by applying indexes over a 4 to 5 year period at best. The development of the cost index requires the actual cost at different times for a prescribed quantity and quality of the item. The base period is a selected time when the index is defined with a basis value of 100. The index each year (period) is determined as the cost divided by the base year cost and multiplied by 100. Future index values may be forecast using simple extrapolation by plot historical cost index trends^[5].

B. Fixed Capital Investment

I. Component of Fixed Capital Investment

i. Estimation of Purchased Equipment Costs

To obtain an estimate of the capital cost of a chemical plant, the costs associated with major plant equipment must be known. The most accurate estimate of the purchased cost of a piece of major equipment is provided by a current price quote from a suitable vendor. The next best alternative is to use cost data on previously purchased equipment of the same type^[10].

a. Six-Tenths Factor

Six tenths factor rule is given when the estimator is faced with the problem of determining the cost of a piece of equipment at a capacity for which has no cost data immediately available. This rule states that 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.

$$E_b = E_a \left(\frac{C_b}{C_a} \right)^{0.6} \quad \text{Eq (3)}$$

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where,

- ca = Capacity of equipment a
 cb = Capacity of equipment b
 Ea = Purchased cost of equipment a
 Eb = Purchased cost of equipment b

ii. Equipment Instalation

Analyses of the total installed costs of equipment in a number of typical chemical plants indicate that the cost of the purchased equipment varies from 65 to 80 percent of the installed cost depending upon the complexity of the equipment and the type of plant in which the equipment is installed. The installation cost of process equipment may be estimated as being an amount equivalent to 43 percent of the purchased equipment cost. Futher detail may be made based upon the listing in table 5^[1].

Table 5 : Installation cost

| Parameter | Material, % | Labor, % | Total, % |
|------------------------|-------------|----------|----------|
| Foundations | 4 | 3 | 7 |
| Platforms and supports | 7 | 4 | 11 |
| Erection of equipment | - | 25 | 25 |
| Total installation | 11 | 32 | 43 |

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iii. Piping

The cost for piping covers labor, valves, fittings, pipe, supports, and other terms involved in the complete erection of all piping used directly in the process. The cost of piping depending upon the type of process involved, may be estimated at amounts equal to percentages of the purchased equipment value.

Table 6: Piping cost

| Type of process plant | Percent of purchased equipment | | | Percent of fixed capital investment |
|-----------------------|--------------------------------|-------|-------|-------------------------------------|
| | Material | Labor | Total | Total |
| Solid | 9 | 7 | 16 | 4 |
| Solid-fluid | 17 | 14 | 31 | 7 |
| Fluid | 36 | 30 | 66 | 13 |

iv. Instrumentation

Instrumentation is the major part of the capital investment which actually includes not only the instruments but also all auxiliaries for a complete system. There are three parameters depend required of automatic controls which are installed in equipments. Instrumentation costs may be calculated from the purchased equipment as equivalent percentages that shown in table 7.

Table 7: Instrumentation cost

| Parameter | Material, % | Labor, % | Total, % |
|------------------------|-------------|----------|----------|
| Few or no controls | 4 | 1 | 5 |
| Some specific controls | 12 | 3 | 15 |
| Extensive controls | 24 | 6 | 30 |

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