Table 17.1 Cost Sheet Outline[a]

Cost factor	Typical factor in American engineering units	Typical factor in SI units
Feedstocks (raw materials)		
Utilities		
Steam, 450 psig	\$5.50/1,000 lb	\$12.10/1,000 kg
Steam, 150 psig	\$4.00/1,000 lb	\$8.80/1,000 kg
Steam, 50 psig	\$2.50/1,000 lb	\$5.50/1,000 kg
Electricity	\$0.040/kW-hr	\$0.040/kW-hr
Cooling water (CW)	\$0.050/1,000 gal	\$0.013/m^3
Process water	\$0.50/1,000 gal	\$0.13/m^3
Boiler feed water (BFW)	\$1.50/1,000 gal	\$0.40/m^3
Refrigeration, −150°F	\$3.20/ton-day	\$10.50/GJ
Refrigeration, −90°F	\$2.60/ton-day	\$8.55/GJ
Refrigeration, −30°F	\$2.00/ton-day	\$6.60/GJ
Refrigeration, 10°F	\$1.40/ton-day	\$4.60/GJ
Chilled water, 40°F	\$1.00/ton-day	\$3.30/GJ
Natural gas	\$2.70/1,000 SCF	\$0.113/SCM
Fuel oil	\$0.75/gal	\$200/m^3
Coal	\$40/ton	\$44/1,000 kg
Wastewater treatment	\$0.10/lb organic removed	\$0.22/kg organic removed
Landfill	\$0.06/dry lb	\$0.13/dry kg
Operations (labor-related) (O) (See Table 17.3)		
Direct wages and benefits (DW&B)	\$30/operator-hr	\$30/operator-hr
Direct salaries and benefits	15% of DW&B	15% of DW&B
Operating supplies and services	6% of DW&B	6% of DW&B
Technical assistance to manufacturing	\$52,000/(operator/shift)-yr	\$52,000/(operator/shift)-yr
Control laboratory	\$57,000/(operator/shift)-yr	\$57,000/(operator/shift)-yr
Maintenance (M)		
Wages and benefits (MW&B)		
Fluid handling process	3.5% of C_{TDC}	3.5% of C_{TDC}
Solid–fluid handling process	4.5% of C_{TDC}	4.5% of C_{TDC}
Solid handling process	5.0% of C_{TDC}	5.0% of C_{TDC}
Salaries and benefits	25% of MW&B	25% of MW&B
Materials and services	100% of MW&B	100% of MW&B
Maintenance overhead	5% of MW&B	5% of MW&B
Operating overhead		
General plant overhead	7.1% of M&O-SW&B	7.1% of M&O-SW&B
Mechanical department services	2.4% of M&O-SW&B	2.4% of M&O-SW&B
Employee relations department	5.9% of M&O-SW&B	5.9% of M&O-SW&B
Business services	7.4% of M&O-SW&B	7.4% of M&O-SW&B
Property taxes and insurance	2% of C_{TDC}	2% of C_{TDC}
Depreciation (see also Section 17.6)		
Direct plant	8% of ($C_{TDC} - 1.18C_{alloc}$)	8% of ($C_{TDC} - 1.18C_{alloc}$)
Allocated plant	6% of $1.18C_{alloc}$	6% of $1.18C_{alloc}$
COST OF MANUFACTURE (COM)	Sum of above	Sum of above
General Expenses		
Selling (or transfer) expense	3% (1%) of sales	3% (1%) of sales
Direct research	4.8% of sales	4.8% of sales
Allocated research	0.5% of sales	0.5% of sales
Administrative expense	2.0% of sales	2.0% of sales
Management incentive compensation	1.25% of sales	1.25% of sales
TOTAL GENERAL EXPENSES (GE)		
TOTAL PRODUCTION COST (C)	COM + GE	COM + GE

[a]DW&B = direct wages and benefits; MW&B = maintenance wages and benefits; M&O-SW&B = maintenance and operations salary, wages, and benefits. See Table 16.9 for C_{TDC} and C_{alloc}. 1 ton of refrigeration = 12,000 Btu/hr

Source: Busche (1995) with modifications.

Labor-Related Operations, O

One of the most difficult annual costs to estimate is direct wages and benefits (DW&B) for operating the plant. It and the other annual costs that are proportional to it are often an important fraction of the cost of manufacture. Table 17.1 lists the labor-related charges associated with operations. These include *direct wages and benefits* (DW&B), calculated from an hourly rate for the operators of a proposed plant. To estimate all labor-related operations, it is necessary to estimate the number of operators for the plant per shift and to account for three shifts daily. Typically, each shift operator works 40 hr per week, and, hence, for each operator required during a 7(24) = 168-hr week, 4.2 shifts must be covered. In practice, due to illness, vacations, holidays, training, special assignments, overtime during startups, etc., it is common to provide for 5 shifts for each operator required.

Estimates of the number of plant operators needed per shift are based on the type and arrangement of the equipment, the multiplicity of units, the amount of instrumentation and control for the process, whether solids are handled, whether the process is continuous or batchwise or includes semicontinuous operations, and company policy in establishing labor requirements, particularly as it relates to operator unions. For preliminary estimates of the number of operators required per shift, the process may be divided into sections as discussed in Chapter 7 and shown in Figures 7.1 and 7.3. These sections may include: (1) feed preparation system using separation steps, (2) reactor system, (3) vapor recovery system, (4) liquid-separation system, (5) solids separation and purification system, and (6) pollution abatement system. When a process includes two or more reactor systems and/or two or more liquid-separation systems, each is counted separately. As given in Table 17.3, for a continuously operating, automatically controlled, fluids-processing plant with a low-to-medium capacity of 10 to 100 ton/day of product, one operator/shift is assigned to each section. For solids–fluids processing and solids processing, the number of operators per shift is increased as noted in Table 17.3. For large capacities, for example, 1,000 ton/day of product, the number of operators/shift in Table 17.3 are doubled for each section. Batch and semicontinuous processing also require more operators than a continuous process, as indicated in Table 17.3. A process should always have at least two operators present per shift. Each shift operator is paid for 40 hr/week and 52 weeks/yr or a total of 2,080 hr/yr. The annual cost of direct wages and benefits (DW&B) is obtained from:

$$\text{DW\&B, \$/yr} = (\text{operators/shift})(5\ \text{shifts})(2{,}080\ \text{hr/yr-operator})(\$/\text{hr}) \tag{17.2}$$

Table 17.3 Direct Operating Labor Requirements for Chemical Processing Plants
Basis: Plant with Automatic Controls and 10–100 Ton/Day of Product

Type of process	Number of operators per process section[a]
Continuous operation	
Fluids processing	1
Solids–fluids processing	2
Solids processing	3
Batch or Semibatch operation	
Fluids processing	2
Solids–fluids processing	3
Solids processing	4

[a]Note: For large continuous-flow processes (e.g., 1,000 ton/day of product), multiply the number of operators by 2.

where the \$/hr covers wages and benefits, and depends on locality and whether operators are unionized. In Table 17.1, a figure of \$30/hr is typical in the United States.

To obtain the total annual labor-related operations cost, O, direct salaries and benefits for supervisory and engineering personnel at 15% of DW&B and operating supplies and services at 6% of DW&B are added to DW&B. In addition, \$52,000/(operator/shift)-yr for technical assistance to manufacturing and \$57,000/(operator/shift)-yr for control laboratory are added. An estimate of the total annual cost of labor-related operations is illustrated in the following example.

EXAMPLE 17.8

The vinyl chloride process discussed in Sections 3.4 and 3.5 and shown in Figures 3.8 and 3.19 produces 100,000 lb/hr of vinyl chloride or 1,200 ton/day. Estimate the annual cost of labor-related operations, O.

SOLUTION

This is a continuous fluids process of large capacity. Assume it is automatically controlled. From the block flow diagram, the process is comprised of two reactor sections and one liquid separation section. Therefore, from Table 17.3, three operators per shift are required for a moderate-capacity plant. However, this is a large-capacity plant, requiring twice that number or 6 operators per shift and five shifts or a total of 30 shift operators. Also, a large-capacity plant requires one labor-yr each for technical assistance and control laboratory. Using Eq. (17.2), the annual costs are

$$\text{Annual DW\&B} = (30 \text{ operators})(2{,}080 \text{ hr/yr})(\$30.00/\text{hr}) = \$1{,}872{,}000$$

Using Table 17.1, the other annual labor-related operation costs are

$$\text{Direct salaries and benefits} = 0.15(\$1{,}872{,}000) = \$280{,}800$$
$$\text{Operating supplies and services} = 0.06(\$1{,}872{,}000) = \$112{,}300$$
$$\text{Technical assistance to manufacturing} = \$52{,}000(5) = \$260{,}000$$
$$\text{Control laboratory} = \$57{,}000(5) = \$285{,}000$$

The total labor-related operations annual cost, O, is

$$O = \$1{,}872{,}000 + \$280{,}800 + \$112{,}300 + \$260{,}000 + \$285{,}000 = \$2{,}810{,}100/\text{yr}$$ ■

Maintenance, M

A second category of labor-related costs is associated with the maintenance of a proposed plant. Processing equipment must be kept in acceptable working order, with repairs and replacement of parts made as needed. Annual maintenance costs, M, are sometimes greater than the cost of labor-related operations, O. Included in Table 17.1, under annual maintenance costs, M, is the main item, maintenance wages and benefits (MW&B), which is estimated as a fraction of the total depreciable capital, C_{TDC}, depending on whether the process handles fluids, solids, or a combination of fluids and solids. The range is from a low of 3.5% for fluids to 5.0% for solids, with 4.5% for solids–fluids processing. Salaries and benefits for the engineers and supervisory personnel are estimated at 25% of MW&B. Materials and services for maintenance are estimated at 100% of MW&B, while maintenance overhead is estimated at 5% of MW&B. Thus, the total annual cost of maintenance varies from 8.05 to 11.5% of C_{TDC}. Maintenance costs can be controlled by selecting the proper materials of construction for the processing equipment, sparing pumps, avoiding high rotation speeds of shafts, restricting the highest fouling streams to the tube side of heat exchangers, selecting long-life catalysts for reactors, scheduling routine maintenance, and practicing preventative maintenance based on experience, supplier information, and record-keeping. Routine maintenance includes cleaning of heat exchanger tubing and lubrication and replacement of packing and mechanical seals in pumps, compressors, blowers, and agitators. A main goal should be to provide most of the maintenance during scheduled plant shutdowns, which might be during a two- or three-week period each year.

PRODUCT AND PROCESS DESIGN PRINCIPLES

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Second Edition

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