458.401 Process & Product Design

07

Estimation of Manufacturing Costs

Jong Min Lee
School of Chemical and Biological Engineering
Seoul National University

Estimation of Manufacturing Costs

- Direct Costs
  - Vary with ____________ but not necessarily directly proportional
- Fixed Costs
  - Do not vary with _____________ but relate “directly” to production function
- General Expenses
  - Functions to which operations must contribute – overhead burden

Direct Costs

- Raw Materials (RM)
- Waste Treatment (WT)
- Utilities (UT)
- Operating Labor (OL)
- Supervisory and Clerical Labor
- Maintenance and Repairs
- Operating Supplies
- Laboratory Charges
- Patents and Royalties

Fixed Costs

- Depreciation - cover as a separate topic in Chapter 9
- Local taxes and insurance
- Plant overhead costs

General Expenses

- Administration costs
- Distribution and selling costs
- Research and development

Manufacturing Costs

- Table 8.1
  - Description of items
- Table 8.2
  - Factors for estimating costs
- We relate (historically) the relationship between items in Table 8.1 to direct costs A (RM - raw materials) , B (WT - waste treatment) , C (UT - utilities) , D (OL - operating labor), and FCI (fixed capital investment) of plant

Manufacturing Costs - Examples

- Maintenance and repairs
  - 2 – 10 % FCI (Fixed Capital Inv. C_{TM} or C_{GR})
  - Proportional to size of plant
- Supervisory and clerical labor
  - 10 – 25 % C_{OL}
  - Proportional to op. lab
- Depreciation
  - some % of FCI

Use (   ) from Table 8.2

Note: using the mid-point values from Table 8.2 is a non-biased way of estimating COM but actual COM may be quite different depending on the plant and industry sector

Manufacturing Costs

$$COM = 0.280FCI + 2.73C_{OL} + 1.23(C_{UT} + C_{WT} + C_{RM}) \qquad (8.1)$$

with depreciation as 10% FCI

$$COM_d = 0.180FCI + 2.73C_{OL} + 1.23(C_{UT} + C_{WT} + C_{RM}) \qquad (8.2)$$

COM without depreciation – we use this since we calculate depreciation more accurately in Chapter 9

How Do We Get…

- FCI – Chapter 7 C_{TM} or C_{GR}
- C_{OL}
- C_{RM}
- C_{UT}
- C_{WT}

Look at these separately

Cost of Operating Labor

$$N_{OL} = (6.29 + 31.7P^2 + 0.23N_{np})^{0.5}$$

N_{OL}: the # of operators per shift
P: particulate processing steps
N_{np}: non-particulate processing steps - compression, heating/cooling, mixing, separation, and reaction

Important note – Above equation based on data from chemical plants and refineries where number of particle processing steps is low. For units with more than 2 solids processing steps ignore middle term and add 1 operator per solids step

Example - acetone process

Operating Labor - Acetone Facility

Equipment	Number of	N_{np}
Compressors	0	
Exchangers	8	
Fired Heaters	1	
Pumps	5	
Reactors	1	
Towers	3	
Vessels	4	
Total		13

Pumps and vessels are not counted in evaluating N_{np}

Operating Labor - Acetone Facility

$N_{OL} = [6.29 + (31.7)(0)^2 + (0.23)(13)]^{0.5} = 3.05$

Number of operators required for one operator per shift = 4.5

= (49 wks/yr)(5 shifts/operator/wk)

= 245 shifts/year/operator

Total shifts per year = (365)(3 shifts per day) = 1095 shifts/year

1095/245 = ___________ operators (for a single shift)

Operating Labor - Acetone Facility

Total Operators = (3.05)(4.5) = 13.75 → 14

Salary = $59,580/yr (2010 Gulf-Coast average)

C_{OL} = (59,580)(14) = $834K

Cost of Raw Materials, Utilities, and Waste Treatment

Stream factor (SF) = (# of days plant operates per year) / 365

- Flowrates
  - Get these from PFD - use stream factor
- Costs
  - Utilities and waste treatment - Table 8.3 - See Section 8.6 for utilities estimation
  - Common chemicals - Table 8.4, Chemical Market Reporter, http://www.icis.com/StaticPages/a-e.htm#top

Stream Factor

- Operating hours per year divided by total hours per year
  - Typical 8000 operating hours
  - 0.9 - 0.96 typical
    8000/8760 = 0.913
- Flows on PFD are kmol/operating hour not kmol/hour - why?

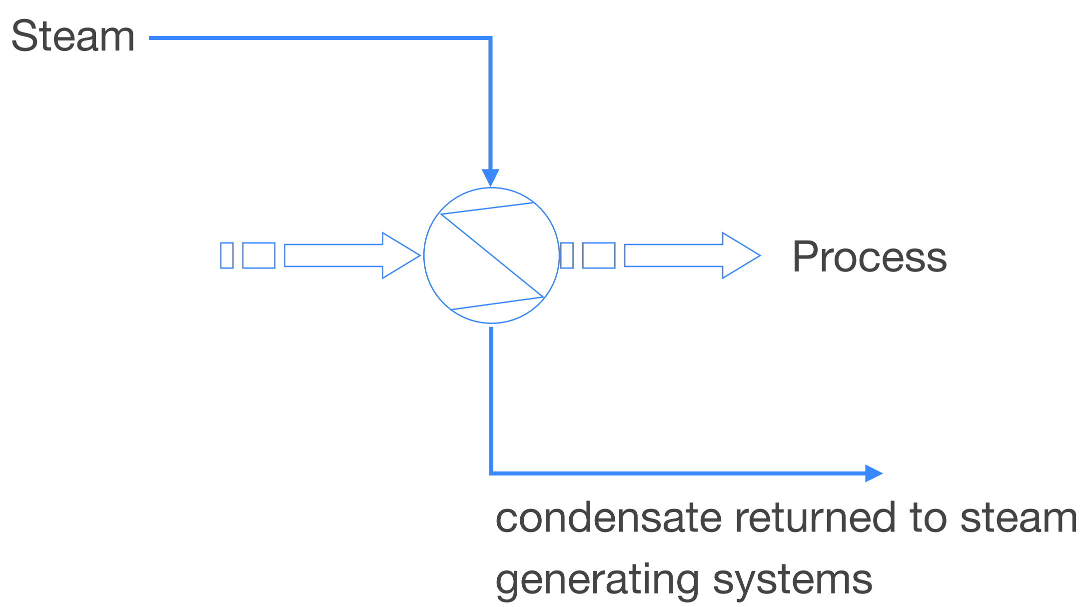
Utilities - Fuel and Electricity

- Fuel for Fired Heaters
  - PFD gives process load (energy balance) but total flow is more due to efficiency: 70 - 90% from Table 11.11 - item 13.
  - Fuel costs may vary wildly - Figure 8.1
- Electricity for pumps and compressors - Figure 8.7
  - Shaft power - fluid power / efficiency
  - Power to drive - shaft power / drive efficiency
- PFD usually gives shaft power - but be careful

Utilities - Steam

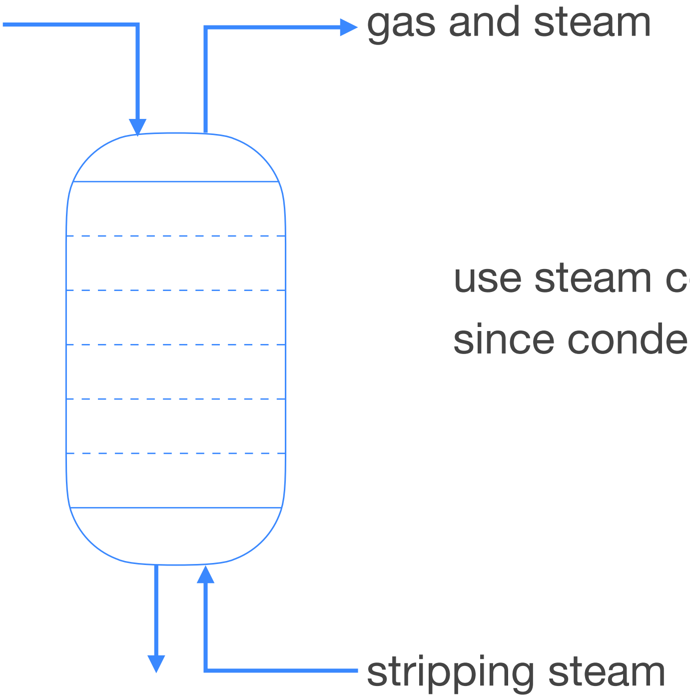
- Pressure levels
  - Low (30 - 90 psi)
  - Medium (150 - 250 psi)
  - High (525 - 680 psi)
- Available saturated but sometimes superheated
- Large chemical complexes generate high-pressure steam and use excess pressure to generate electricity - Figure 8.6
- Steam can be used as a drive medium for compressors and pumps
  - Thermodynamic efficiency: Table 8.5
  - Drive efficiency: Figure 8.7

Utilities - Condensate Return and Boiler Feed Water



*just use steam costs

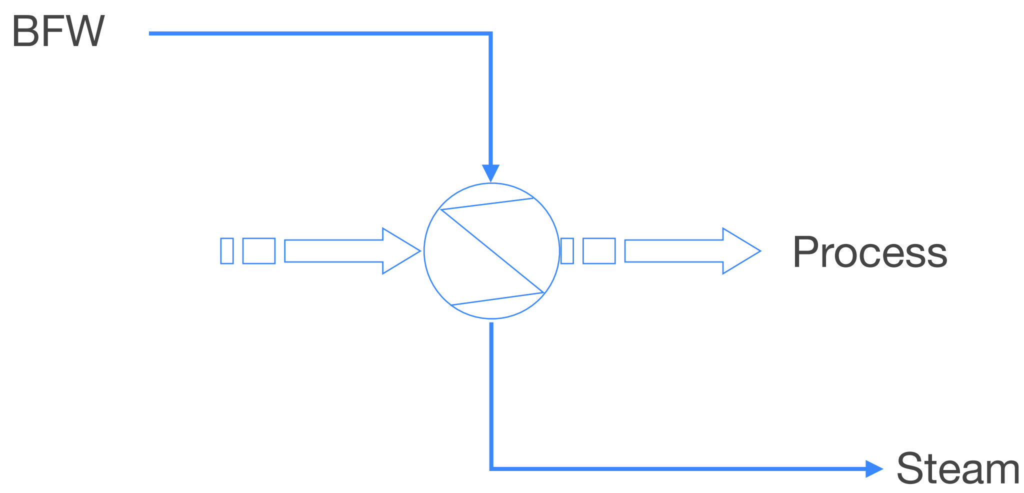
If Steam Lost in Process



use steam cost + bfw
since condensate is not returned

07 Estimation of Manufacturing Costs

Steam Generated in Process



*just take credit for (steam - bfw) unless steam is lost in process

Example 8.9

Estimate the quantities and yearly costs of the appropriate utilities for the following pieces of equipment on the HDA PFD (Fig. 1.5) Assume the stream factor of 0.95.

E-101: Duty is 15.19 GJ/h

Cost of HPS = \$5.66/GJ

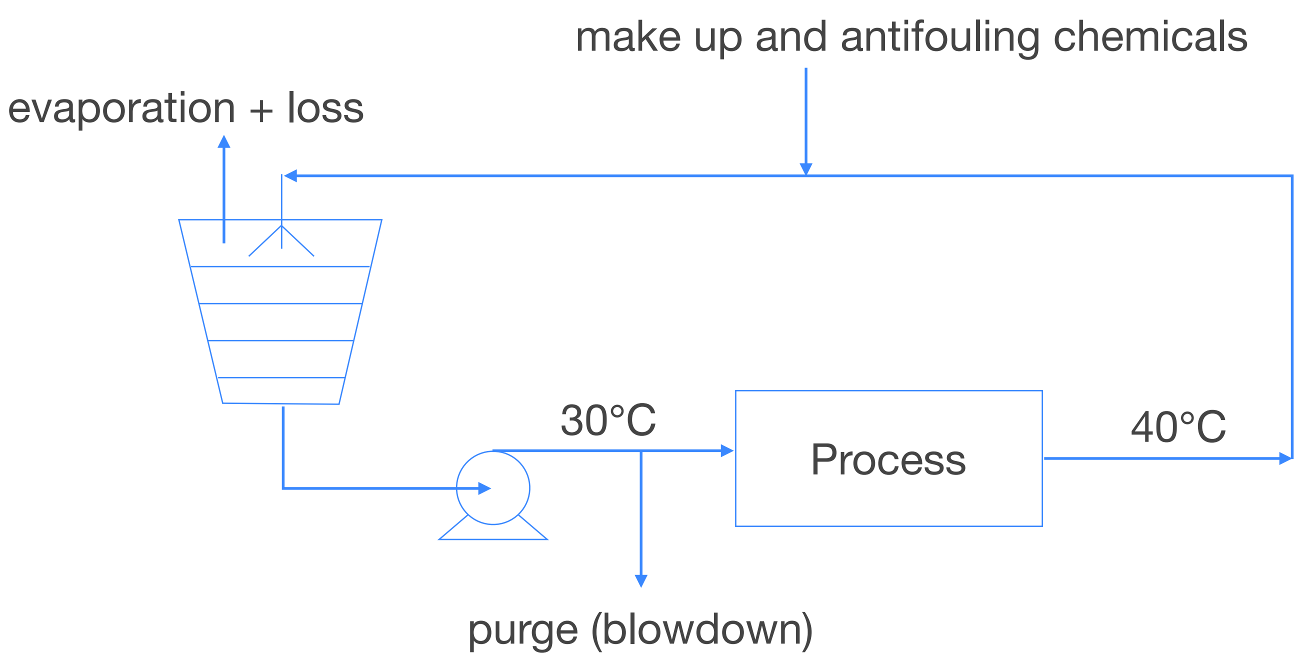
ΔH_{vap} = 1699.3 kJ/kg

Table 1.7

→ m_{steam} = 2.48 kg/s

Yearly Cost
= (15.19 GJ/h)(\$5.66/GJ)(24)(365)(0.95) = \$715,500/yr

Utilities - Cooling Water



Utilities - Cooling Water

- Make-up based on ΔT (40-30)!
- Should charge cw based on energy used
  - Table 8.3
- Does not matter (much) if cw returned at 40°C or 45°C - same energy
- 45°C is absolute max - due to fouling

Example 8.3

Estimate the utility cost for producing a circulating cooling water stream using a mechanical draft cooling tower. Consider a basis of 1 GJ/h of energy removal from the process units. Flow of cooling water required to remove this energy = m kg/h

Energy Balance

$$\dot{m}C_p\Delta T = 1\times10^9 = \dot{m}\left(4180\left[\frac{J}{kg}\right]\right)(40-30) \qquad \dot{m} = 23,923\ \mathrm{kg/h}$$

Amount of water evaporated from tower, W_{tower}

$$W_{tower} = \frac{\text{Heat Load}}{\Delta H_{vap}} = \frac{1\times10^9}{\boxed{2417\times10^3}} = \boxed{413.7\ \mathrm{kg/h}}$$

→( )%

@ ( )°C

Example 8.3 (Continued)

Windage loss: 0.1~0.3%

We use 0.3%

Water blowdown: maximum allowable salt conc. factor, s assumed to be 5

$$s = \frac{\text{conc. salts in cooling water loop}}{\text{conc. salts in makeup water}} = \frac{s_{loop}}{s_{in}}$$

$$W_{MU} = W_{tower} + W_{wind} + W_{BD}$$

$$s_{in}W_{MU} = s_{loop}W_{wind} + s_{loop}W_{BD}$$

$$W_{BD} = 0.133\%,\ W_{MU} = 2.163\% = 517\ kg/h$$

07 Estimation of Manufacturing Costs

Example 8.3 (Continued)

Pressure drop: pump

15 psi (pipe losses) + 5 psi (exchanger losses) + 10 psi (control valve loss) + 8.7 psi (static head - 20 ft above pump inlet) = 38.7 psi = 266.7 kPa

$$\text{Pump power} = \frac{1}{\epsilon}\dot{V}\Delta P = \frac{1}{0.75}\frac{23,923}{(1000)(3600)}(266.7) = 2.36\ \text{kW}$$

Power for fan

required surface area in the tower = 0.5 ft^2/gpm

fan horse power per square foot of tower area = 0.041 hp/ft^2

$$\text{Power for fan} = \frac{(23,923)\overset{\text{lbs/kg}}{(2.2048)}}{(60)\underset{\text{lbs/gal}}{(8.337)}}(0.5)(0.0041) = 1.61\ \text{kW}$$

Example 8.3 (Continued)

Cost of cooling water = cost of electricity + cost of chemicals for makeup water + cost of makeup water

electricity cost = \$0.0674/kWh

process water cost = \$0.176/1000 kg

cost of chemicals (from Nalco Water) = \$0.0347/1000 kg

Cooling water cost = (0.0674)(2.36+1.61) + (517.3)(0.176)/1000 + (517.3)(0.0347)/1000 = \$0.378/h = \$0.378/GJ

Utilities - Refrigerated Water

- Same as previous slide in that energy costs are not ΔT dependent - but cost based on 5°C supply temperature
- Other refrigerants are possible and cost↑ as Temperature ↓
- Generation of refrigeration requires a refrigeration cycle
- Figure 8.4 shows cost of refrigeration as a function of temperature

Refrigeration Cycles

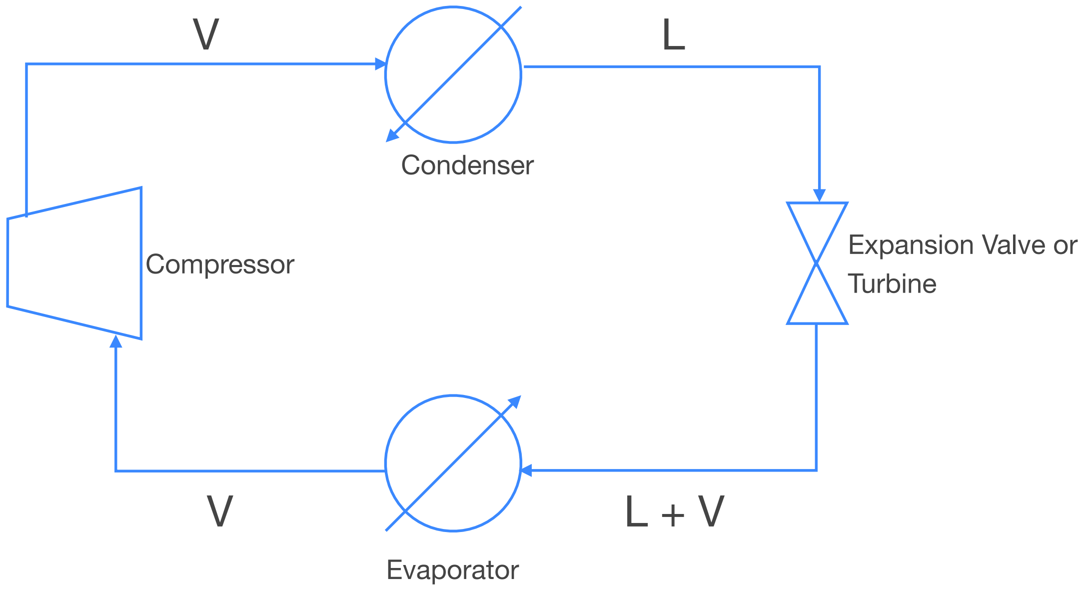


Figure 8.3 Process Flow Diagram for a Simple Refrigeration Cycle