Preliminary Design Equipment Sizing Use the following suggested equipment sizing and costing procedures for this level of design. The numbers refer to steps in the procedure - the letters refer to different cases. The method will vary depending on the information required to use the cost correlation. **Use Table 6.6 in T&S to estimate cost.**

Equipment Item	**Sizing Method**	**Heuristics**
Pump	Need power delivered to fluid to size and cost pump. • Need mass flow rate of liquid. • Use pressure change and 30 ft of friction head in ME balance. Assume overall pump efficiency to determine electric motor size. • Cost pump and electric motor separately.	Assume overall pump efficiency of 70%.
Furnace	Furnace size and cost based on heat load. • Use heat of combustion of burning material and overall furnace efficiency to determine heat load. • If fuel fired, used lower heating value of fuel (water is in vapor form) and overall furnace efficiency to determine heat load. Cost is based on heat load.	Assume furnace efficiency of 70%
Vessel mixer and motor	Mixer size is based on geometry of vessel. Operating cost based on power to electric drive motor. Almost always electric motor driven, but may be pneumatic. Most electric motors have an rpm speed of 1750 rpm, but this must be geared down to about 1 - 5 rpm for the stirring bar. Power requirements given in Perry's 7th ed., pp. 19-9 to 19-10 – use rpm of 1 to 5 – not motor rpm!	

D. A. Crowl, January, 2010

Compressor	Size is based on pressure increase and gas mass flow rate. Cost if based on power delivered to fluid. Use adiabatic compression equations to estimate work required. Compression ratio must not exceed 5 for oiled piston compressors. If compression ratio > 5, need interstage coolers. Assume compression ratio across each stage is equal. From work and mass flow rate determine power. Cost compressor using Table 6.6 in T&S.	Most compressors have efficiencies of from 65% to 85% (based on overall work delivered to gas). Assume 70% overall efficiency.
Heat Exchanger	Size and cost is based on heat transfer area. 1. Determine duty from required temperature change in stream and mass flow. 2. Determine mass flow rate of other stream. 3. Use typical overall heat transfer coefficient for exchanger, see tables in Perry's (11-21, 11-25) or Geankopolis (4.9-2) . 4. Calculate area required for heat exchange using published correlations. 5. Estimate size - need max. temperature and pressure. 6. Cost heat exchanger from Table 6.6 in T&S using heat exchanger area.	• Shell and tube gives most area for volume. • For a double pipe exchanger, area must be less than 150 ft^2 • For a 1-shell, 2 tube pass exchanger, want correction factor, *F*, to be greater than 0.75 to 0.80. • Put corrosive fluid on tube side. • Put higher pressure fluid on tube side. • Put fouling liquid on tube side. • Put more viscous material on shell side. Design velocities (ft/sec): Tubes Shell Water: 3-6 2-4 Non-viscous liq.: 2-5 2-3 Viscous liquid: 2-4 1-2 Gas, low den.: 50-150 30-60 Gas, high den.: 20-80 20-40

Pressure vessel (Pressure vessel code begins for pressure greater than 15 psig)	Size based on volume of contents. Cost based on shell mass. 1. Estimate volume from material balance. 2. Use max. temperature and material of construction to determine allowable shear stress from handout figure or Table 13.2 in T&S. 3. Use max. pressure to calculate wall thickness of vessel. 4. Estimate mass of vessel ends (if applicable) using equations in section 13.5.4 in T&S. 5. Determine volume of metal shell. 6. Use density of material of construction to determine shell mass. 7. Use Table 6.6 in T&S to estimate costs.	• See section 13.5 in T&S. • Wall thickness not larger than 4 to 5 inches, generally. • For non-spherical vessel, use hemispherical, ellipsoidal or torispherical ends – see section 13.5.4 in T&S. • Max. normal operating pressure = 0.8 time MAWP.
Vacuum vessels	Use same procedure as for pressure vessels. See section 13.7 in T&S	Very approximate rule of thumb: A pressure vessel rated for an internal pressure of greater than 50 psig is generally capable of withstanding a full vacuum
Atmospheric Storage vessel or tank	Need only total volume and geometric configuration. Use Table 6.6 in T&S to estimate cost.	• Vessel at atmospheric pressure. • Max. storage = 0.8 total vessel volume. • Max. pressure = 8" of water gauge.

Distillation column	Need to determine number of trays and reflux ratio required. Several approaches: 1. If ideal (rare) use FUEM method to determine number of trays, reflux ratio. 2. If non-ideal (usual) have several choices. If VLE known (x-y), use VLE in simulator to determine number of trays. If VLE not known, use carefully selected VLE model in simulator. Compare with any known data to confirm. Determine number of trays and reflux ratio. Procedure: 1. Use vapor density at average T & P and nominal vapor velocity to estimate column width. 2. Use nominal tray height to estimate total column height. 3. Use pressure vessel sizing method to determine wall thickness. 4. Use vertical pressure vessel equation in Table 6.6 of T&S to cost vessel. 5. If trays are used, need diameter of column to estimate costs. If packing used, need volume of packing. See guidelines in section 11.14.2 to estimate packing height, then use column diameter to estimate volume. Use equation in Table 6.6 of T&S to cost packing. 6. Use heat exchanger sizing to cost reboiler and condenser. 7. Total column cost = sum of 4 thru 6.	• Use nominal vapor velocity of 3 ft/s • Use average tray height of 16 - 24 inches. • Condenser duty about equal to reboiler duty. • Tray efficiency of from 50 to 75% - use nominal 70%

Reactors (batch)	Need reactor residence time and reactor output composition. Several approaches available: 1. If detailed kinetics and thermo properties know, use reactor design equations to determine max. T and P, reaction time and output composition. 2. If patent information available, this usually only contains information on batch reactor composition after a fixed time and temperature sequence. It is likely that actual time is shorter, but this is not know. 3. If production capacity and reactor size of a plant is known, can estimate size from this. Use equilibrium program to estimate reactor output composition. 4. If nothing is known about kinetics, can use an equilibrium program to estimate output composition from reactor. Use reaction time as a parameter. 5. Assume nominal values for output composition and reaction time. Procedure: Knowing output composition, reaction time, and required production rate, determine reactor volume required. Use pressure vessel sizing to determine wall thickness. 1. Use Table 6.6 in T&S to estimate vessel cost. Might need to add cost for stirrer, motor, and connections (which is done separately) 2. If reactor is unpressurized, then reactor equations apply. If pressurized, used pressure vessel equations.	
Reactors (continuous)	Same procedure as for batch, but now continuous reactor equations are used.	
Reactors (tubular)	Same procedure as for batch, but tubular reactor equations are used. Reactor vessel in this case is a pipe. Determine pipe length from kinetics and pipe schedule from max. T and P. Pipe costs not shown in Table 6.6 in T&S – see Crowl.	

Additional comments:

1. Need to document in final report the reference used and the exact figure, table, equation used for the cost estimation. This is required for each equipment piece. Example: Perry's (2002), Figure 12-35.
2. If your unit size is outside the ranges on Table 6.6 in T&S, then you equipment piece is probably too large or too small. Use multiple smaller units, or increase size and decrease flow rates.
3. Cost values must be converted to current values using an equipment index, i.e. Chemical Engineering.

$$\left(\frac{\text{Cost 1}}{\text{Cost 2}}\right) = \left(\frac{\text{Index 1}}{\text{Index 2}}\right)$$

4. Cost values are usually based on carbon steel. The cost for a different material will be factored into the FCI calculation.
5. Need detailed equipment specification sheet for each major equipment piece in your plant.
6. Most companies today have their own cost database, based on the purchases they actually made. These can be very reliable.
7. Commercial cost estimating programs are available, i.e. ICARUS. Some are just the equivalent of what we are doing here. A more involved program uses the cost of carbon steel sheet since everything is fabricated from this raw material. This program will include detail, including cost of walkways, lighting, and so forth, and will print a very detailed summary sheet.
8. If your equipment item does not appear anywhere, you can build it from the basic components. For instance, an absorption column can be built from a pressure vessel with internals added.
9. If the cost of an item is known at one size, then the "0.6 rule" can be used to estimate the cost at another size:

$$\left(\frac{\text{Cost 1}}{\text{Cost 2}}\right) = \left(\frac{\text{Size 1}}{\text{Size 2}}\right)^{0.60}$$