Equipment Sizing and Capital Cost Estimation

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Selection of Topics - depends on previous exposure to process economics

Can begin with cost accounting – gives a good view of corporate finances and considerations when evaluating a potential design.

Given limited time – begin with equipment sizing and capital cost estimation.

Again, coverage depends on previous exposure to sizing of:

Pressure vessels, heat exchangers, pumps, compressors, etc.

Many sources on selection and sizing of many kinds of equipment

Ulrich, G. D., and P. T. Vasudevan, *Chemical Engineering Process Design & Economics: A Practical Guide*, Second Edition, 2004.

Peters, M. S., K. D. Timmerhaus, and R. West, *Plant Design and Economics for Chemical Engineers,* Fifth Edition, McGraw-Hill, 2003.

Sandler, H. J., and E. T. Luckiewicz, *Practical Process Engineering*, XIMIX, Philadelphia, PA, 1993.

Turton, R., R. C. Bailie, W. B. Whiting, and J. A. Shaeiwitz, *Analysis, Synthesis, and Design of Chemical Processes,* Second Edition, Prentice-Hall, 2003.

Seider, W. D., J. D. Seader, and D. R. Lewin, *Product and Process Design Principles: Synthesis, Analysis, and Evaluation*, Second Edition, Wiley, 2004.

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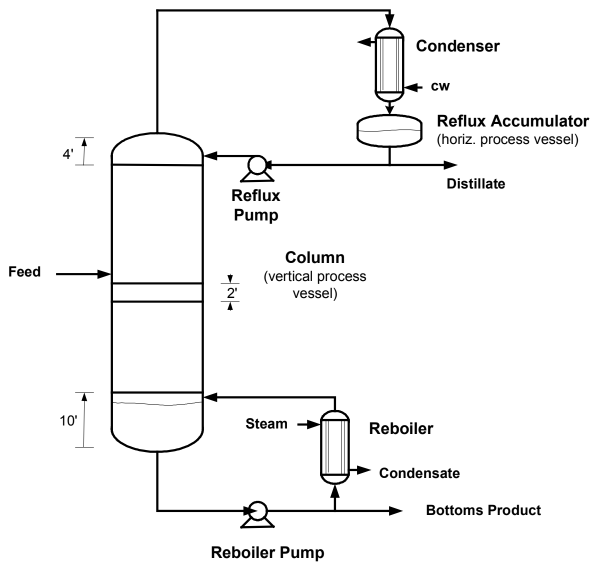
One Popular Option – Distillation Complex



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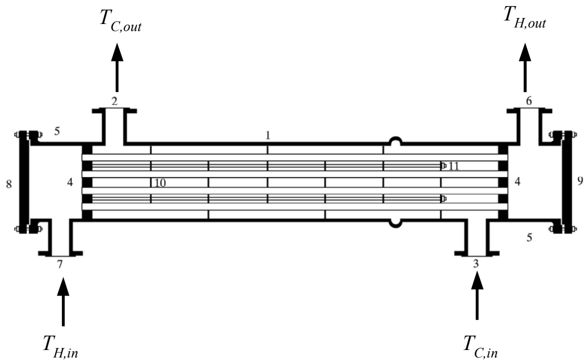
Shell-and-Tube Heat Exchanger



$$Q = UA\Delta T_{LM}$$

$$A = \frac{Q}{U\Delta T_{LM}}$$

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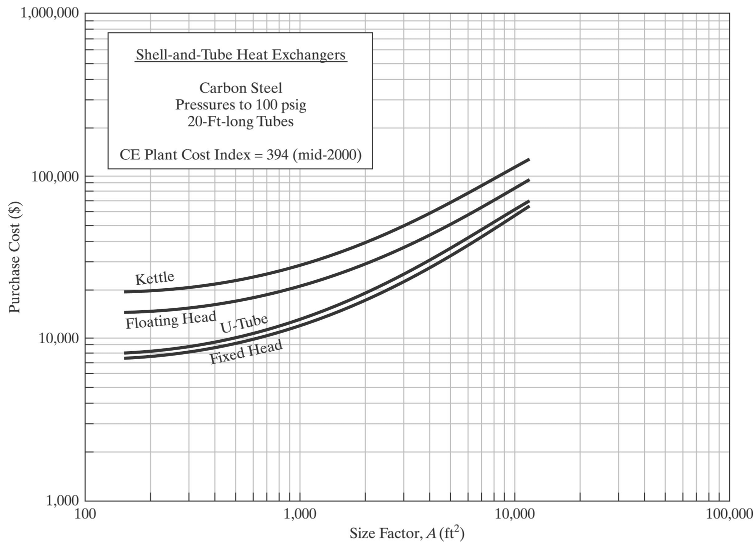
Purchase Costs – Shell-and-tube Heat Exchangers



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Floating Head

$$C_B = \exp\left\{11.667 - 0.8709\left[\ln(A)\right] + 0.09005\left[\ln(A)\right]^2\right\}$$

Fixed Head

$$C_B = \exp\left\{11.0545 - 0.9228\left[\ln(A)\right] + 0.09861\left[\ln(A)\right]^2\right\}$$

U-tube

$$C_B = \exp\left\{11.147 - 0.9186\left[\ln(A)\right] + 0.09790\left[\ln(A)\right]^2\right\}$$

Kettle Vaporizer

$$C_B = \exp\left\{11.967 - 0.8709\left[\ln(A)\right] + 0.09005\left[\ln(A)\right]^2\right\}$$

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Purchase Cost

$$C_P = F_P F_M F_L C_B$$

Pressure factor (F_P), Materials factor (F_M), Tube-length correction (F_L)

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Materials of Construction Factors, F_M, for Shell-and-Tube Heat Exchangers

$$F_M = a + \left(\frac{A}{100}\right)^b$$

Material of construction Shell/Tube	*a* in Eq. (16.44)	*b* in Eq. (16.44)
Carbon steel/Carbon steel	0.00	0.00
Carbon steel/Brass	1.08	0.05
Carbon steel/Stainless steel	1.75	0.13
Carbon steel/Monel	2.1	0.13
Carbon steel/Titanium	5.2	0.16
Carbon steel/Cr-Mo steel	1.55	0.05
Cr-Mo steel/Cr-Mo steel	1.70	0.07
Stainless steel/Stainless steel	2.70	0.07
Monel/Monel	3.3	0.08
Titanium/Titanium	9.6	0.06

Pressure Factor

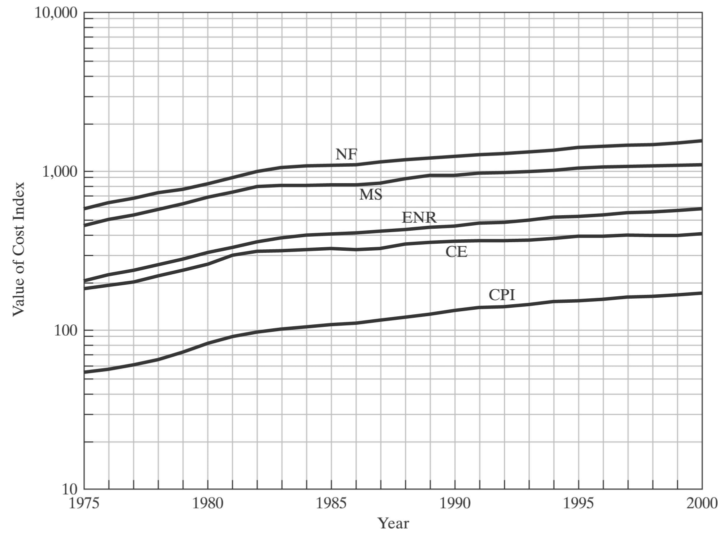
psia

$$F_P = 0.9803 + 0.018\left(\frac{P}{100}\right) + 0.0017\left(\frac{P}{100}\right)^2$$

Tube-length Correction Factor

Tube length, ft	F_L
8	1.25
12	1.12
16	1.05
20	1.00

Cost Indexes



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Bare Module Cost – Heat Exchanger – Table 16.10 (SSL, 2004)

	Cost ($)	Total Costs ($)	Fraction of f.o.b. Purchase Cost (C_P)
Direct module expenses			
Equipment purchase price, f.o.b., C_P		10,000	1.00 C_P
Field materials used for installation			
Piping	4,560		
Concrete	510		
Steel	310		
Instruments and controllers	1,020		
Electrical	200		
Insulation	490		
Paint	50		
Total of direct field materials, C_M		7,140	C_M = 0.714 C_P
Direct field labor for installation			
Material erection	5,540		
Equipment setting	760		
Total of direct field labor, C_L		6,300	C_L = 0.63 C_P
Indirect module expenses			
Freight, insurance, taxes, C_{FIT}	800		C_{FIT} = 0.08 C_P
Construction overhead, C_O	5,710		C_O = 0.571C_P
Contractor engineering expenses, C_E	2,960		C_E = 0.296 C_P
Total indirect expenses, C_{IE}		9,470	C_{IE} = 0.947 C_P
Bare-module cost, C_{BM}		32,910	C_{BM} = 3.291 C_P
			F_{BM} = 3.291

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Bare Module Factors - Table 16.11 (SSL, 2004)

	Bare-module Factor (F_{BM})
Furnaces and direct-fired heaters, Shop-fabricated	2.19
Furnaces and direct fired heaters, Field-fabricated	1.86
Shell-and-tube heat exchangers	3.17
Double-pipe heat exchangers	1.80
Fin-tube air coolers	2.17
Vertical pressure vessels	4.16
Horizontal pressure vessels	3.05
Pumps and drivers	3.30
Gas compressors and drivers	2.15
Centrifuges	2.03
Horizontal conveyors	1.61
Bucket conveyors	1.74
Crushers	1.39
Mills	2.30
Crystallizers	2.06
Dryers	2.06
Evaporators	2.45
Filters	2.32
Flakers	2.05
Screens	1.73

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Total Capital Investment – Table 16.9 (SSL, 2004)

Total bare-module costs for fabricated equipment	C_{FE}					
Total bare-module costs for process machinery	C_{PM}					
Total bare-module costs for spares	C_{spare}					
Total bare-module costs for storage and surge tanks	$C_{storage}$					
Total cost for initial catalyst charges	$C_{catalyst}$					
Total bare-module investment, TBM		C_{TBM}				
Cost of site preparation		C_{site}				
Cost of service facilities		C_{serv}				
Allocated costs for utility plants and related facilities		C_{alloc}				
Total of direct permanent investment, DPI			C_{DPI}			
Cost of contingencies and contractor's fee			C_{cont}			
Total depreciable capital, TDC				C_{TDC}		
Cost of land				C_{land}		
Cost of royalties				C_{royal}		
Cost of plant startup				$C_{startup}$		
Total permanent investment, TPI					C_{TPI}	
Working capital					C_{WC}	
Total capital investment, TCI						C_{TCI}

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Cost Equations

SSL (2004) – Purchase Cost Equations for numerous process units – see Table 16.32 for "other" equipment items.

- Available literature sources back to 1960 consulted.
- After determining a suitable equipment size factor, all of the cost data were plotted.
- When a wide spread in the data was evident, which was not uncommon, an attempt was made to assess the validity of the data by comparison with costs of similar equipment.
- When the validity could not be determined, the data were averaged.
- In some cases, cost data were obtained from vendors.

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Table 16.32 contains cost equations for:

Agitators, autoclaves, crystallizers, dryers, dust collectors, evaporators, fired heaters, heat exchangers, liquid-liquid extractors, membrane separations, mixers, turbines, screens, size enlargers, size reducers, solid-liquid separators, solids handling systems, storage tanks, vacuum systems, waste-water treaters.

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Aspen Icarus Process Evaluator (IPE)

Extends results of process simulations

Generates rigorous size estimates for processing equipment and estimates costs based upon extensive data

Performs preliminary mechanical designs

Estimates purchase and installation costs, indirect costs, the total capital investment, the engineering-procurement-construction schedule, and profitability analysis

Aspen IPE uses five key steps

1. Simulation results are ***loaded*** into Aspen IPE.
2. Process simulation units are ***mapped*** into more descriptive models of process units and associated ***plant bulks*** – including installation items, such as piping, instrumentation, paint, etc.
3. Equipment items are ***sized*** and ***re-sized*** when modified.
4. Capital costs, operating costs, and the total investment are ***evaluated*** for a project.
5. Results are presented to be ***reviewed***, with modifications as necessary.

Aspen IPE Features

Numerous default *design basis* parameters are built in for use in rigorous equipment-sizing routines – for many equipment types.

Bare module factors are ***not*** used. Extensive data are used to estimate the costs of materials, labor, and construction equipment –

based upon detailed design calculations for foundations, platforms, piping, instrumentation, electrical connections, insulation, painting, …

See

Section 16.7 (SSL, 2004) – Equipment Sizing and Capital Cost Estimation Using The Aspen Icarus Process Evaluator (IPE)

Course Notes (SSL, 2004) – Aspen Icarus Process Evaluator (IPE) – Equipment Sizing and Costing Using ASPEN PLUS to Initiate Evaluation.