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Rules of Thumb

Rules of thumb are numerical values and suggestions that are reasonable to assume based on experience. They are based on the application of fundamentals and practical experience. They do not replace fundamentals but rather they enrich the correct use of fundamentals to solve problems. Rules of thumb:

- help us judge the reasonableness of answers;
- allow us to assess quickly which assumptions apply;
- are used to guide our better understanding of complex systems and situations; and
- allow us to supply rapid order-of-magnitude estimates.

Rules of thumb important for process design and engineering practice include those about

- the chemical process equipment,
- the context in which the equipment functions (properties of materials, corrosion, process control, batch versus continuous and economics),
- the thinking process used as engineers design and practice their skills (problem solving, goal setting, decision making, thermal pinch, “systems’ thinking, process design, process improvement, trouble shooting and health-safety-environment issues),
- the people part of engineering (communication, listening, interpersonal skills and team work) and
- the context in which engineers function (performance review, leadership, entrepreneurship, entrepreneurship and e-business).

In this book, the focus is on rules of thumb about process equipment. Chapters 2 to 10 provide details of equipment for transportation, energy exchange, separations, heterogeneous separations, reactions, mixing, size reduction, size enlargement and process vessels, respectively.

In this chapter, we give an overview, in Section 1.1, of how the rules of thumb are presented in the rest of the book. Then, we emphasize the contexts in which engineers work: the context for the process (Sections 1.2 to 1.7), the thinking used (Sections 1.8 to 1.16), the people dimension of our practice (Sections 1.17 to 1.20)

and the organizational context in which we work (Sections 1.21 to 1.25). Finally, suggestions about mentoring and self management are given in Section 1.26. Consider each in turn.

1.1

Rules of Thumb about Process Equipment

The rest of this book, Chapters 2 to 10, considers rules of thumb for different types of equipment. Here we give an overview of how the information is organized and presented. Rules of thumb are based on different types of experience. These different types of experience include (together with their code):

- generalized physical, thermal, environmental and safety properties of solids, liquids or gases (P),
- generalized fundamental concepts (F),
- generalized operating conditions: transfer coefficients, efficiencies (O),
- generalized manufacturers limitations (M),
- generalized natural or legal constraints: wind load, size of equipment shipped through rail tunnels (N)
- economic optimization: approach temperature, minimum reflux ratio (\$),
- generalized engineering judgement: max temperature for cooling water, operating location for pumps (J)
- hazard or safety consideration (H).

The rules of thumb are organized by prime function and within each function are listed the usual types of equipment. Each piece of equipment is assigned a code because some equipment is multifunctional. For example, a fluidized bed is primarily a method of mixing a gas–solid mixture. However, it is also used as a dryer, a heat exchanger, a reactor and an agglomerator.

For each piece of equipment are listed the following:

- *Area of Application*

How to select: when would you use this piece of equipment? What is the usual available size range?

- *Guidelines*

How to size: rules of thumb and short cut sizing for estimating the size of the equipment. In general these work within a factor of ten but usually a factor of four.

- *Capital Cost Guidelines*

Costs should be included with any rules of thumb because costs are such vital information to engineering practice. But these are guidelines – not data! The cost

estimates are ball park ideas. The guideline FOB cost is in US \$ for a value of the *Chemical Engineering Index* (1957–59 = 100), CEPCI Index = 1000. The value of CEPCI Index for the year 2003 was 395.6 so that the costs reported here are more than double the value in 2003. Costs are usually correlated in terms of a base cost multiplied by a ratio of sizes raised to the power “ n ”. $\text{Cost}_2 = \text{Cost}_{\text{ref}} (\text{size}_2/\text{size}_{\text{ref}})^n$. The cost is usually the FOB cost although sometimes it is the field erected cost. The size should be a “cost-dependent” parameter that is characteristic of the specific type of equipment. The size parameter that provides the least accurate estimate is the *flow* or *capacity*. In this book, sometimes several different parameters are given; use the size parameter *flow* or *capacity* as a last resort.

Although the FOB cost of equipment is of interest, usually we want to know the cost of a fully installed and functioning unit. The “bare module”, BM, method is used in this book. In the BM method, the FOB cost is multiplied by factors that account for all the concrete, piping, electrical, insulation, painting, supports needed in a space about 1 m out from the sides of the equipment. This whole space is called a module. The module is sized so that by putting together a series of cost modules for the equipment in the process we will account for all the costs required to make the process work. For each module we define a factor, $L+M^*$, that represents the labor and material costs for all the ancillary materials. Some of these may be shown as a range, for example, 2.3–3. This means that for the installation of a single piece of equipment (say, one pump), the higher value should be used; the lower value is used when there are many pumps installed in the particular process. The $L+M^*$ factor includes the free-on-board the supplier, FOB, cost for carbon steel and excludes taxes, freight, delivery, duties and instruments unless instruments are part of the package. The $*$ is added to remind us that the instrumentation material and labor costs have been excluded, (whereas most $L+M$ values published in the 60s, 70s and 80s included the instrumentation material and labor costs). The alloy corrections are given so that $L+M^*$ for carbon steel can be reduced appropriately for the alloy used in the equipment. For some unit operations the equipment is built of concrete or is a lagoon. For such equipment the reported cost is the Physical Module, PM cost, that represents the FOB plus $L+M^*$ plus instruments plus taxes and duties. The cost excludes offsite, home office expense, field expense and contractor’s fees and contingencies. Rules of thumb to account for the other cost items are given in Section 1.7. The costs are given in Appendix D.

- *Good Practice*

Suggestions may be given for good operability, and suggestions for sustainability, waste minimization, safety and environmental concerns.

- *Trouble Shooting*

For many units, likely causes of malfunction are given under “trouble shooting”. For trouble shooting, the symptom is given “*Temperature > design*” followed by a prioritized list of possible causes separated by “/”. Sometimes it is convenient to

identify a cause and list, in turn, the sub causes. An example is [fouling]* which then has a separate listing under [Fouling]*. This is used when elaboration about the “cause” is needed to identify a cause that we can actually correct. For example, the cause might be “fouling” but what do we change to prevent the fouling? What causes the fouling?

1.2

Rules of Thumb about the Context for a Chemical Process: Physical and Thermal Properties

Here are 17 rules of thumb:

1. Vapor pressure doubles every 20 °C.
2. The latent heat of vaporization of steam is five times that of most organics.
3. If two liquids are immiscible, the infinite dilution activity coefficient is > 8 .
4. 10 % salt in water doubles the activity coefficient of a dissolved organic.
5. Infinite dilution is essentially < 1000 ppm of dissolved organic.
6. Freezing temperature may be suppressed 1 °C for every 1.5 mol % impurity present.
7. A ratio of impurity concentration between a solid/liquid phase > 0.2 is probably due to solid solution.
8. Dissolving 2–20 % organic solute usually reduces the interfacial tension.
9. The Prandtl number for gases is approximately 1; for liquids 1 to 3.
10. The thermal conductivity of hydrogen = $10 \times$ value for most organic vapors.
11. For distillation, the condenser cooling water usage is 15 L/kg of steam to the reboiler.
12. Polymer melts can be classified based on their viscosity: *low viscosity melts* for polyacrylamide; polyethylene, polypropylene and polystyrene; *medium viscosity melts* for ABS, cellulose acetate, POM and styrene butadiene; and *high viscosity melts* for polycarbonate, polymethylmethacrylate, polypropylene oxide and polyvinyl chloride.
13. Surface tension for most organics (and for organic-water surfaces) at 25 °C = 15–40 mN/m and decreases almost linearly to 0 at the critical temperature. The surface tension decreases with temperature as approximately -0.1 mN/m °C. For water the surface tension at 25 °C is 72 mN/m.

14. The variation in surface tension with surface concentration of surface active materials is about 2.5 mN m/mol.
15. The surface concentration of a surfactant A, $\Gamma_A = \beta c_A$ where the latter is the bulk concentration of A and $\beta = 2 \times 10^{-5}$ m for octanol water with the value of β increasing by a factor of 3 for every CH_2 added to the hydrocarbon chain.
16. The Hamaker constant for liquid surfaces is about 10^{-20} J and is relatively independent of temperature.
17. The disjoining pressure for films is negligible for fluid films $> 0.1 \mu\text{m}$ thick.

1.3

Rules of Thumb about the Context for a Chemical Process: Corrosion

1. The strength of materials depends totally on the environment in which the materials function and not on the handbook values.
2. All engineering solids are reactive chemicals – they corrode.
3. The eight usual forms of materials failure by corrosion (and the frequency of failure due to this form of corrosion) are: (i) uniform corrosion: uniform deterioration of the material (32 %); (ii) stress corrosion: simultaneous presence of stress and corrosive media (24 %); (iii) pitting: stagnant areas with high halide concentration (16 %); (iv) intergranular corrosion: most often found in stainless steels in heated areas (14 %); (v) erosion: sensitive to high flowrates, local turbulence with particles or entrained gas bubbles; for flowing gas–solids systems the rate of erosion increase linearly with velocity and depends on abrasiveness of particles (9 %); (vi) crevice corrosion: concentration cells occur in stagnant areas (2 %); (vii) selective leaching or dealloying: removal of one species from a metallic alloy (1 %) and (viii) galvanic corrosion: dissimilar metals coupled in the presence of a solution with electrolyte (negligible).
4. Stress corrosion (the second form of corrosion) can start from perfectly smooth surfaces, in dilute environments with material stresses well below the yield stress.
5. $> 70\%$ of stress corrosion cracking is related to residual – not applied – stresses.
6. The penetration of stress corrosion cracking as a function of time depends on the alloy composition, structure, pH, environmental species present, stress, electrochemical potential and temperature.

- *Trouble Shooting*

“High concentration of metals (Fe, Cr, Ni, Cu) in solution”: [corrosion]*/contaminants from upstream processing.

“Ultrasonic monitoring shows thin walls for pipes, internals or vessels”: faulty ultrasonic instrument/[corrosion]*/faulty design. *“Failure of supports, internals, vessels”*: [corrosion]*/faulty design/unexpected stress or load.

“Leaks”: [corrosion]*/faulty installation/faulty gasket/faulty alignment.

[Corrosion]*: [corrosive environment]*/inadequate stress relief for metals/wrong metals chosen/liquid flows at velocities > critical velocity for the system; for **amine** circuits: > 1 m/s for carbon steel and > 2.5 m/s for stainless steel/large step changes in diameter of pipes/short radii of curvature/flange or gasket material projects into the pipe/[cavitation in pumps]*/improper location of control valves.

[Corrosive environment]*: temperature too hot; **for amine solution**: > 125 °C/high dissolved oxygen content in liquid/liquid concentration differs from design; **for steam**: trace amounts of condensate or condensate level in condensers > expected; **for 316 stainless steel**: trace amount of sodium chloride; **for sulfuric acid**: trace amounts of water diluting concentrated acid to < 90%; **for amine absorption**: total acid gas loadings > 0.35 mol acid gas/mol MEA, > 0.40 mol acid gas/mol DEA, > 0.45 mol acid gas/mol MDEA; makeup water exceeds specifications; **for amine absorption** units exceeds: 100 ppm TDS, 50 ppm total hardness as calcium ion, 2 ppm chloride, 3 ppm sodium, 3 ppm potassium and 10 ppm dissolved iron; **for sour water scrubbers**: cyanides present/pH change/acid carry-over from upstream units/high concentration of halide or electrolyte/presence of heat stable salts/bubbles present/particulates present/invert soluble precipitates with resulting underlying corrosion/sequence of alternating oxidation–reduction conditions.

[Cavitation in pumps]*: pump rpm too fast/suction resistance too high/clogged suction line/suction pressure too low/liquid flowrate higher than design/entrained gas/no vortex breaker.

1.4

Rules of Thumb about the Context for a Chemical Process: Process Control

(based on communication from T.E. Marlin, McMaster University, 2001)

- *Area of Application*

For all processes, provide the four levels of control: (i) the basic control system, (ii) an alarm system, (iii) a safety interlock system, SIS, and (iv) a relief system.

- *Guidelines*

Sensors: What to measure? Variables are measured by sensors to achieve the following objectives, in hierarchical sequence:

safety/environmental protection/equipment protection, *for example this could include redundant temperature sensing and alarms on reactors and reboilers handling*

corrosive chemicals such as HF/smooth operation/product quality/profit/monitoring/diagnosis and trouble shooting. Identify the objective and select a pertinent variable. Direct measurement of the variable is preferred. If direct measurement is impractical, select an inferential or calculated variable. For example, temperature can infer conversion and composition.

Variables must be measured that might quickly deviate from the acceptable range such as (i) non-self-regulating variables, example *level*, (ii) unstable variables, example *some temperatures in reactors* and (iii) sensitive variables that vary quickly in response to small disturbances, example *pressure in a closed vessel*.

How to measure? Select a sensor to balance accuracy and reproducibility, to cover the range of normal and typical disturbed operations and that provides minimum interference with the process operation and costs. *For example, prefer a low pressure loss flow sensor when compression costs are high.* Use a second sensor for extremely large ranges due to startup, large disturbances or different product specifications. The sensors should be consistent with the process environment, *for example, for flow measurements the instrument should be located downstream of sufficient straight pipe to stabilize the flow patterns reaching the instrument, at least 10 diameters upstream and 5 diameters downstream of straight pipe.* The sensors should be located to assist operators in performing their tasks and engineers in monitoring and diagnosing performance.

Sensors for control: should compensate for known nonlinearities before the measurement is used for monitoring or control. Prefer sensors that do not need calibration.

Specifics:

Temperature: prefer resistance temperature detectors, RTD. Prefer narrow span transmitters instead of thermocouples. Expected error: thermocouples, $\pm 0.5\%$ of full scale or $0.3\text{--}3^\circ\text{C}$; RTD, $\pm 0.2\text{--}0.5\%$ of full scale; thermistor, $\pm 0.5\%$ of full scale or $0.2\text{--}1^\circ\text{C}$.

Pressure: expected error: Bourdon gauge, $\pm 0.1\text{--}2\%$ of full scale; pressure transmitter, $\pm 1\%$ full scale; linear variable differential transmitter, $\pm 0.5\%$ full scale.

Differential pressure: prefer precision-filled diaphragm seals or remote heads for Δp because signal depends, in part, on the density of the fluid in the sensing lines.

Flow: prefer coriolis, vortex or magnetic flow meters over orifice or venturi. Keep fluid velocity $> 0.3\text{ m s}^{-1}$. Expected error: orifice meter, $\pm 1\text{--}5\%$ of full scale; coriolis, $\pm 0.2\%$ of full scale; magnetic, $\pm 0.5\text{--}1\%$ of full scale; venturi, $\pm 0.25\text{--}3\%$ of full scale.

Level: prefer tuning fork, radar or nuclear or consider radio frequency admittance if the composition changes. Expected error: nuclear, $\pm 1\text{--}2\%$; ultrasonic, $\pm 3\%$; vibrating probe, $\pm 1\text{ cm}$.

Composition: expected error: relative humidity, $\pm 2\text{--}3\%$; pH, $\pm 0.005\text{--}0.05\text{ pH units}$; dissolved oxygen, $\pm 1\text{--}5\%$; oxygen, $\pm 3\%$; TOC, $\pm 2\text{--}10\%$; gas chromatograph, $\pm 0.5\text{--}1\%$.

Manipulated variables and final elements: The manipulated variable, usually flow-rate, has a causal effect on a key controlled variable, can be manipulated by an automated final element, provides fast feedback dynamics, has the capacity to compensate for expected disturbances and can be adjusted without unduly upsetting other parts of the plant. The final element, usually a valve, has a causal effect on the controlled variable. The number of *final elements* should be equal to or greater than the number of measured variables to be controlled *and* we must provide an independent means for controlling every variable.

Final elements must provide the desired capacity with the required precision of flow throttling over the desired range, *usually 10–95% of maximum flow*. The valve characteristic should provide a linear closed-loop gain *except* use a linear or quick-opening characteristics for valves that are normally closed but that must open quickly. Select the valve failure position for safety. The valve body should satisfy such requirements as required flow at 0% stem position, plugging, pressure drop or flashing. The non-ideal final element behavior such as friction and dead-band should be small, as required by each application. Control valves should have manual bypass and block valves to allow temporary valve maintenance when short process interruptions are not acceptable, however, the bypass should never compromise the SIS systems. The gain on a control valve should be > 0.5 . Avoid using the lower 10% and the upper 5, 20 or 35% of the valve stroke. Generally select a control valve body one size less than the line size. Allow sufficient Δp across the control valve when selecting pumps (Section 2.3), compressors (Section 2.1), steam lines (Section 3.13) or flow because of Δp (Section 2.7).

For pump selection: allow the greater value of 33% of the dynamic loss or 100 kPa.

For compressor selection: allow the greater value of 5% of the absolute suction pressure or 50% of the dynamic loss.

For steam lines: allow the greater value of 10% of the absolute pressure at the steam drum or 35 kPa.

For pipe sizing with flow caused only by Δp : allow the greater value of 10% of the pressure of the lower terminal vessel or 50% of the dynamic loss.

For the throttling valve on the bypass for manual control, a tapered plug valve is recommended (especially for steam or erosive fluids).

Specifics

Include the same length of upstream straight run piping before control valves as is recommended for orifices. This is particularly important for rotary valves.

Globe valves: permissible stroke range: 10–90%; sliding stem gives highest sensitivity and the actuator stem feedback position more closely represents the final element position but not for fouling or solids.

Rotary ball valves: permissible stroke range: 20–80%. Δp across the valve is small but account for the pipe reducers needed for installation. Sensitive to the need for upstream straight pipes.

Rotary butterfly valves: permissible stroke range: 25–65 %.

Signal transmission: Use sensor-matched transmitters. All measurements used for control should be transmitted using high level 4–20 mA transmission.

Feedback controller: Match the type to the process requirements:

Manual: when close regulation of the variable near its desired value is not required and when knowledge is required that is not available in the control computer.

On/off: when the system responds slowly to disturbances and close regulation of the variable is not required.

Regulator: a self-contained P-only regulator offers low-cost and reliable control of noncritical variables that can be permitted to deviate for long periods from their set points.

PID: the proportional-integral-derivative algorithm is used for most single-loop applications.

PID control: Always determine the form of the PID algorithm being used. Select the PID modes:

P – always; *I* – when the controlled variable should return to its set point; *D* – for processes that are undamped, unstable or have a very large ratio of dead time/time constant.

Tuning: typical values are $K_c = 0.8/K_p$, $T_i = 0.75 (\theta + \tau)$ and $T_d = 0.0$. The proportional band ($100/K_c$) and the reset time ($1/T_i$) can be calculated from these. When fine tuning, observe the behavior of both the controlled and manipulated variables. Always use an implementation that includes anti-reset windup protection for when the manipulated variable encounters a constraint. Use an implementation that includes initialization that starts automatic control smoothly from the last manual condition. The digital execution period should be fast with respect to the feedback dynamics, with $\Delta t \leq 0.05 (\theta + \tau)$ where possible.

Filtering: For control variables: when filtering is needed, use a first-order filter to reduce the effects of high frequency noise. Do not excessively filter measurements unless absolutely necessary. The filter time constant (τ_f) should be \ll feedback dynamics.

For monitoring variables: use filters to reduce the noise at frequencies higher than the effects being observed. Recall that “averaging” is a filter that is often performed by the DCS historian features.

Loop pairing: Where options exist, pair the most important variables with manipulated variables that have fast feedback dynamics and large capacity. Select pairings that give good integrity. For example, select direct loop designs in which controllers will function when other controllers are not functioning. Usually avoid nested loops (a condition when some controllers will not function when other controllers are in manual or have their outputs saturated) that do not have

individual causal relationships. Select loop pairings that require little adjustment to controller tuning when the controllers switch from manual to automatic.

Tune the most important loops aggressively and the less important, loosely (when interaction is unfavorable).

DCS structure: All safety and basic regulatory controls should be highly reliable and executed in the lowest level digital processes with direct input and output wiring contact signals with the process. Should the LAN fail, the control system should provide means for the personnel to operate the process, possibly through displays and adjustable parameters at the digital processor. The system should provide redundancy (with automatic switching) for key elements such as processors, power supplied and LANs. The operator consoles should provide sufficient access to displays and adjustments for off-normal operations like startup and disturbances.

Implementation hierarchy: Implement process control in a hierarchy based on frequency of decision making. First level is protection (safety, environment and equipment), the second level is smooth operation and stability (through control of flows, temperature, pressures and levels and through alarms). The third level is product quality. The fourth level is profitability. The final level is for monitoring and diagnosis.

- *Good Practice*

Mount probes and flow meters in vertical lines to prevent solids accumulation. Provide insertion lengths at least ten times the diameter for thermowells.

- *Trouble Shooting*

“Instrument readings do not make sense”: transmitter range specified incorrectly/range not set to specification/measured variable > 100 % of range/reported range does not include static conditions/flashing or two-phase flow through flow-meter or control valve/installed incorrectly/wrong sensor/air leaks/plugged purge lines/purge liquid boiling in purge line/wrong controller tuning.

Sensors: Most sensor faults are due to improper selection, incorrect installation or adverse environmental conditions. *“Wrong signal”:* fouled or abraded sensors/bubbles or solid in fluid/sensing lines plugged or dry/electrical interference or grounding/sensor deformed/process fluid flow < design or laminar instead of turbulent flow/contamination via leaky gaskets or O rings/wrong materials of construction/unwanted moisture interferes with measurement or signal/high connection or wiring resistance/nozzle flappers plugged or fouled/incorrect calibration. *“Wrong input”:* sensor at wrong location/insufficient upstream straight pipe for velocity measurement/feedback linkages shift or have excessive play/variations in pressure, temperature or composition of the process fluid.

Control valves: “Leaks”: erosion/[corrosion]*/gaskets, packing or bolts at temperatures, pressures and fluids that differ from design. “Cannot control low flowrate”: miscalibration/buildup of rust, scale, dirt. “Cannot stop flow”: miscalibration/damaged seat or plug. “Excessive flow”: excessive Δp . “Slow response”: restricted air to actuator/dirty air filters. “Noise”: [cavitation]*/compressible flow. “Poor valve action”: dirt in instrument air/sticky valve stem/packing gland too tight/faulty valve positioner. “Equipment suddenly underperforms”: bypass partially or fully open.

Transmitters: “Erratic or fluctuating output”: vibrations/improper orientation/loose connections.

1.5

Rules of Thumb about the Context for a Chemical Process:

Batch versus Continuous

1. Batch if < 0.1 kg/s product.
2. Batch if it is difficult to scale up process: design data missing.
3. Batch for multiproduct.

1.6

Rules of Thumb about the Context for a Chemical Process:

Heterogenous Phase contacting

Often two phases are needed in process equipment. It is convenient to summarize here some of the key characteristics of such two-phase systems. Here we consider gas–liquid, GL, liquid–liquid, LL, and particulate systems.

1.6.1

GL Systems

GL contactors are used for direct contact heat exchange, Sections 3.7, 3.8 and 3.9; for distillation, Section 4.2; absorption, Section 4.8; stripping, Section 4.9; gas scrubbers, Section 5.2; for a wide variety of reactors. For such contactors it may be useful to know the following:

1. the usual superficial gas velocity.
2. the mass transfer coefficient for the gas phase, for the liquid phase, mm s^{-1} ; or the mass transfer coefficient times the area, l/s.
3. the surface area per unit volume.
4. the liquid holdup $(1-\epsilon)$.
5. for the liquid phase, the bulk/film volume ratio = relative volume of bulk liquid to the mass transfer film at the sur-

face, δ^+ . For example, for a dry foam that consists mainly of film then $\delta^+ = 1$; whereas for bubbles rising in a bubble column $\delta^+ = 4000$ to $10\,000$. This parameter is important for reactor design with GL reactions.

6. the Sherwood number, Sh , for mass transfer, typically 10–25.
7. the oxygen transfer rate, OTR, for air–water systems. Typical air flow is $15\text{--}50 \text{ Nm}^3/\text{s}^1 \text{ m}^3 \text{ liquid}$. The symbol [] means that this value was calculated from other data given in the table.

Table 1.1 summarizes such values. The values given are general; for specific applications they will differ. For example, the area/volume for bubble columns varies depending on the direction of flow. The relationship between the bubble area, bubble diameter, gas concentration in the liquid phase and the power input are given in Figs. 1.1 and 1.2.

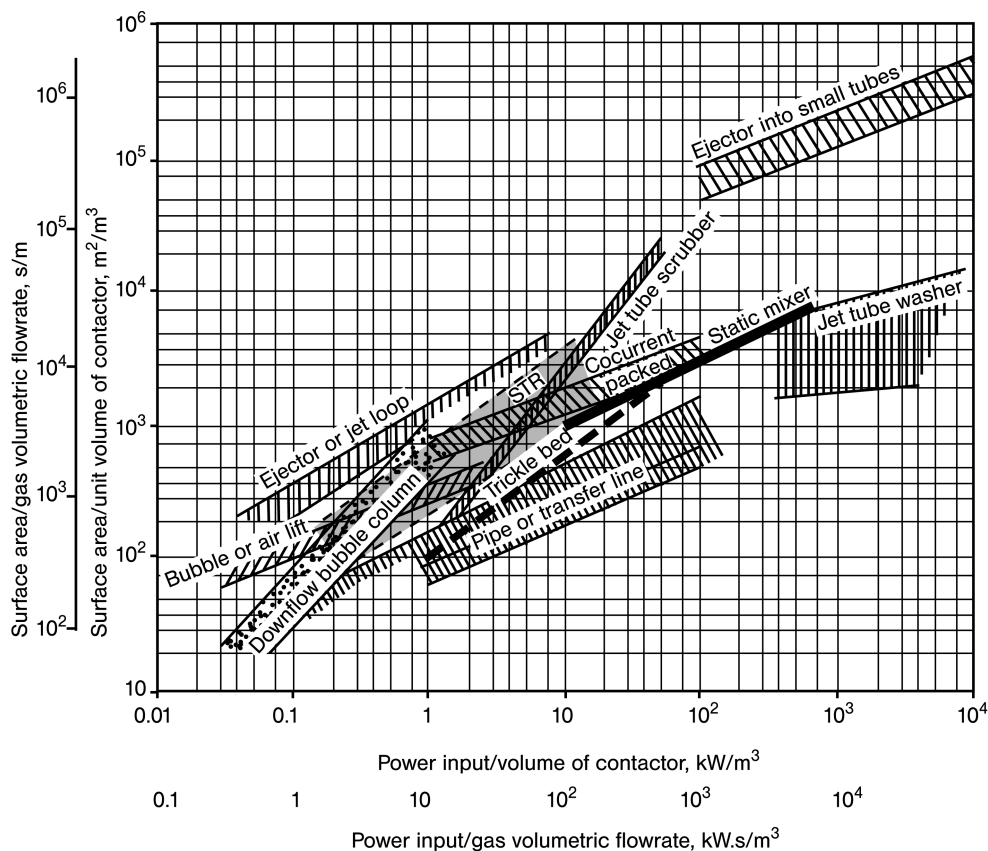


Figure 1.1 Surface area versus power input for gas–liquid contactors.

Table 1.1 Some characteristics of CL contactors.

	Gas vel. m/s	k_G ; mol/s $m^2 MPa$ (mm/s)	k_L , mm/s	$k_L a$, 1/s	a , m^2/m^3	L holdup (1- ϵ)	Bulk/ film vol. ratio, δ^+	Sh	OTR $g O_2$ $s^{-1} kW^{-1}$	mol O_2 $s^{-1} m^{-3}$	$g O_2$ $s^{-1} m^{-3}$
Pipe contactor, gas injection into liquid flowing in tube; vertical tube.	0.01–0.5	5–80	0.2–0.5	0.02–1	50–2000	0.05–0.95					0.28
Pipe contactor, horizontal and coiled tube		5–40	0.1–1	0.005–0.7	50–700	0.05–0.95					
Pipe contactor, gas into liquid via ejector into a tube					40000– 500000						
Static mixer in tube	1–2			0.1–3	1000– 7000				0.9		
Bubble column, with gas sparged at bottom; counter current. $H/D > 10$	0.01–0.3	5–20 (10–50)	0.1–0.6	0.005– 0.25 (0.05– 0.15)	20–1000 but usually 50–700	0.6–0.98	4000– 10^4	400–1000 (10^3 – 10^4)	0.2–0.66	0.03– 0.045	[0.9–1.3]
Bubble column, cocurrent. $H/D > 10$					50–400						
Bubble column, with gas diffuser at bottom; $H/D > 10$				0.0008					0.45		

Table 1.1 Continued.

Gas vel. m/s	k_G ; mol/s m^2 MPa (mm/s)	k_L , mm/s	$k_L a$, 1/s	a , m^2/m^3	L holdup ($1-\epsilon$)	Bulk/ film vol. ratio, δ^*	Sh	OTR $g\ O_2$ $s^{-1}\ kW^{-1}$	$mol\ O_2$ $s^{-1}\ m^{-3}$	$g\ O_2$ $s^{-1}\ m^{-3}$
Bubble column, with diffuser plus turbine $H/D > 10$			0.005– 0.08	200–600				0.2–0.66 [0.95]	0.06–0.12	1.6–3.3 [2.5–2.9]
Bubble column, packed ^[a]	0.01–0.2	5–20	0.005– 0.12	100–300	0.5–0.7					
Bubble column, air lift, internal loop	0.2–0.8		0.05–0.15	300–1000	0.7			0.3–1.2	0.03–0.3	2.8 [3.3]
Bubble column, air lift, external loop			0.01–0.06							
Bubble column, air lift, via jet loop (jet nozzle reactor)		0.4	0.2–1.2	200–5000 usually 1000– 2000	0.7			0.5–1.7 [0.55]	0.08–0.1	2.8 [2.5–3.2]
Spray, gravity	0.5–3	5–20	0.007– 0.015	10–150	0.05; 0.02–0.2	2–10	10–25			
Spray, Venturi scrubber	0.7–1	(10–50) (10–30)	0.7	1000– 7000	< 0.3					
Spray, plunging jet			0.2–1.2					0.25–0.9 [1.3]		3.3
Spray, circulating nozzle loop								0.6 [0.14]		0.8

Table 1.1 Continued.

	Gas vel. m/s	k_G ; mol/s $m^2 \text{ MPa}$ (mm/s)	k_L , mm/s	$k_L a$, 1/s	a , m^2/m^3	L holdup (1- ϵ)	Bulk/ film vol. ratio, δ^+	Sh	OTR $\frac{g \text{ O}_2}{s^{-1} \text{ kW}^{-1}}$	mol O_2 $s^{-1} m^{-3}$	$\frac{g \text{ O}_2}{s^{-1} m^{-3}}$
Tray column, without down- comers	0.5–3		0.10–0.40		100–200	0.15–0.7	40–100	200–600			
Tray column, sieve, with down- comers	0.3–2.5	5–60 (20–200)	0.10–0.50	0.01–0.4	75–500; usually 100–200	0.15–0.7			1–1.1 [0.92]		2.8
Tray column, bubble cap, with downcomers		5–20	0.1–0.5	0.01–0.2	100–400	0.1–0.95					
Packed ^[d] column, random, counter- current	1–2.2	0.3–20 (10–50)	0.06–0.2	0.0004– 0.07 (0.01–0.8)	20–350	0.05–0.15	10–100 (10–40)	10–100	[0.27]		0.14
Packed column, cocurrent		1–30	0.04–0.6	0.0004–1	400–3000	0.02–0.95					
Packed, trickling filter					45–115						
Packed, struc- tured					100–300	0.02					
Thin film, gravity	2		0.04–0.12		3–100	0.01–0.15	10–200	10–50	0.55	[0.025]	0.8
Thin film, trickle bed	> 0.01				100–3500	0.05–0.25					
STR, gas sparged into stirred tank	0.001– 0.02	(10–50)	0.03–0.5	0.003–0.8 (0.05–0.2)	50–4000 usually 300–600	0.2–0.95 usually > 0.7	150–800 (10^3 – 10^4)	100–500	0.3–0.66 [1.5]	0.06–0.12 [0.03–0.1]	1.6–3.3 [2.5–2.9]

Table 1.1 Continued.

	Gas vel. m/s	k_G ; mol/s m ² MPa (mm/s)	k_L , mm/s	$k_L a$, 1/s	a , m ² /m ³	L holdup (l-)	Bulk/ film vol. ratio, δ^+	Sh	OTR g O ₂ s ⁻¹ kW ⁻¹	mol O ₂ s ⁻¹ m ⁻³	g O ₂ s ⁻¹ m ⁻³
STR, tubular impeller									0.4		
STR, turbine									0.55–0.7		
STR, propeller									0.2–0.3		
STR, gassing tube									[0.7]		4.1

[a] Characteristics of packing are given in Table 1.2.

Table 1.2 Illustrative characteristics of packing.

		$a, \text{m}^2/\text{m}^3$	Void volume for gas, ϵ
Structured packing		100–300; usually 250	0.98
Raschig ring	ceramic	190–770	0.62–0.68
	metal	370	0.9
Saddle	ceramic	250–540	0.65–0.72
	plastic	80–120	0.9
Ring, slotted	ceramic	50–260	0.78–0.85
	metal	90–350	0.9–0.95
Tellerette		190	0.93
Intalox		120–620	0.78–0.8
Uniform spheres		depends on size	0.33–0.4

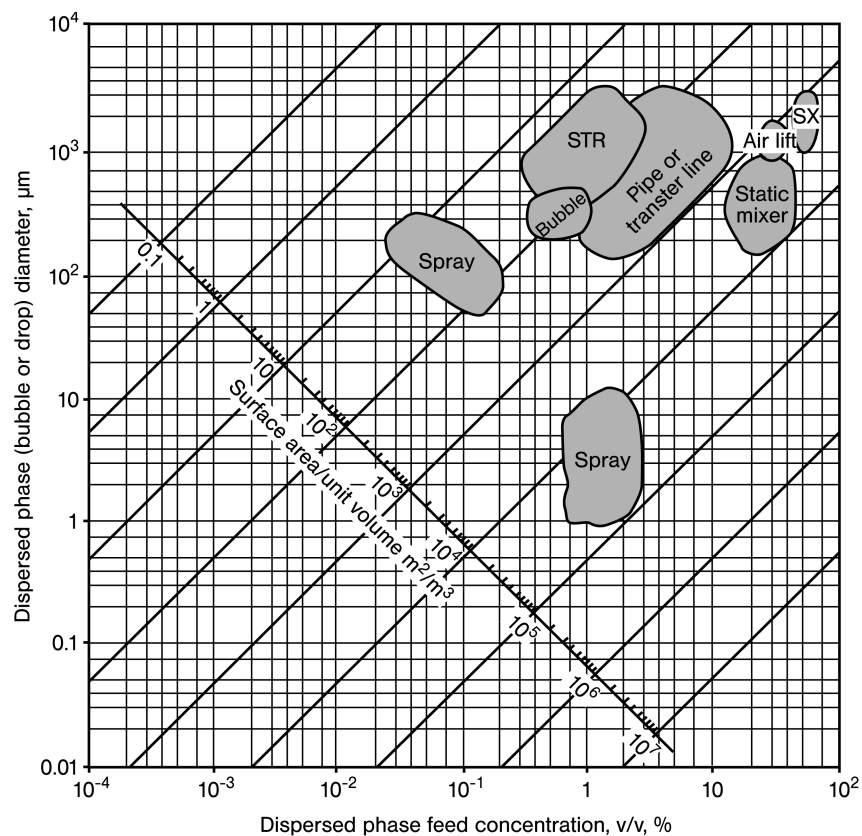
**Figure 1.2** Surface area per unit volume for dispersed systems.

Figure 1.1 shows the surface area generated as a function of power input per unit volume of “contactor” for a number of different GL contactors. Also shown in Fig. 1.1 is the surface area/gas volumetric flowrate as a function of the power per gas volumetric flowrate. Thus, the lowest values for an ejector or jet loop column correspond to a , the surface area/gas volumetric flowrate, = 1000 s/m and a power per gas volumetric flowrate = 1 kW s/m³.

1.6.2

LL Systems

LL contactors are used for direct contact heat exchange, Section 3.6; for solvent extraction, Section 4.10; for a wide variety of reactors; and for mixing, size decrease and size increase. For such contactors it is useful to know the following:

1. flow characteristics of the continuous and discontinuous phases: plug flow PF versus mixed flow MF or partial mixed flow PMF.
2. the residence time of the continuous phase.
3. the mass transfer coefficients.
4. holdup of the dispersed phase.

Table 1.3 summarizes this information.

Figure 1.2 shows the surface area as a function of the diameter of the dispersed phase bubbles, drops or particles and concentration. Also shown are illustrative regions for different contexts.

1.6.3

GLS Systems

For gas–liquid plus solids systems, the solids could be solid catalyst, inert solid or microorganisms. Most of the GL contacting systems given in Table 1.2 and Fig. 1.1 can handle the additional solid (although for Fig. 1.1, for GLS systems where a solid is suspended, about the same power input is needed for STR and cocurrent packed columns but about 1.2 to 2 times the power input is needed for suspension bubble columns). For GLS systems, additional contacting devices include fluidization, trickle beds and monolithic contactors. The diameter of catalytic or inert solid is usually about 1–200 μm . The amount of particulate catalyst or microorganisms in a reactor is 0.001–0.01 m³ catalyst/m³ reactor volume. For catalytic systems, the mass transfer coefficient across the liquid film to the solid, k_{La} , is as follows: bubble contactors: 0.25 1/s; jet loop and plunging jet: 0.1–1 1/s; trickling filter 0.06 1/s; sparged STR and fluidized bed: 0.1–0.5 1/s¹.

For GLS systems for bioapplications, the solid is a microorganism. Some conditions are given in Table 6.9. The biofilm areas for fluidized and trickle beds are 2000m²/m³ vessel and 200m²/m³ vessel, respectively.

Table 1.3 Characteristics of LL contactors.

	Continuous phase	Discontinuous phase	Residence time of continuous phase	Superficial velocity, mm/s		k_L , mm/s	a , m ² /m ³	Dispersed phase hold-up	Power input, kW/m ³
				dispersed	both				
Static mixer	PF	PF	limited			0.001–0.10	100–20000	0.05–0.2	
Spray column, gravity	MF		limited	3–8		0.001–0.10	7–75	0.05–0.1	
Gravity RTL					0.3–0.55	0.01–0.02			
Karr pulsed column; reciprocating plate					8–11	0.01–0.02			
Tray, sieve column					7.5–16	0.01–0.02			
Tray, pulsed sieve				2–20	3–4	0.01–0.02	75–3000		
Packed, random	PF	PF	limited	1–20	3–8	0.001–0.025	7–75	0.05–0.1	
Packed pulsed					3–4	0.01–0.02			
Stagewise packed with stirrer, Scheibel					3–4	0.01–0.02			
Thin film, gravity				0.02–0.8		0.01–0.02	5–120		
RDC					4–8	0.01–0.02			
STR with agitator	MF	PMF	wide variable	0.15–4		0.003–0.025	400–3500	0.01–0.5	0.2–3
Multistage STR				2–20		0.001–0.01	100–2500		
Inert gas agitation	MF	PMF	wide variable			0.001–0.003	1000–10000	0.05–0.3	

1.6.4

Particulate Systems

For particulate systems, the key characteristics are the surface area per unit volume (as shown in Fig. 1.2), the diameter of the particles (related to a commonly used method called Mesh size), the void volumes for a packed bed of particles and parameters to measure dry particle flowability.

Particle characterization includes measures of the size of particles and the flowability of dry powders. Size is frequently expressed as **Mesh size** (US Std is similar to Tyler). Mesh 325 = 44 μm ; 270 = 53 μm ; 230 = 63 μm ; 200 = 74 μm ; 170 = 88 μm ; 140 = 105 μm ; 120 = 125 μm ; 100 = 149 μm ; 80 = 177 μm ; 70 = 240 μm ; 60 = 250 μm ; 50 = 297 μm ; 40 = 420 μm ; 30 = 590 μm ; 20 = 840 μm ; 18 = 1000 μm ; 14 = 1410 μm ; 12 = 1680 μm ; 10 = 2000 μm ; 8 = 2380 μm ; 4 = 4760 μm .

Void volume between particles. For particulate systems it is useful to know the void space, or interstitial volume, ε , in particulate systems. For a loose pack of uniform spheres, $\varepsilon = 0.45$; for a tight pack of uniform spheres, $\varepsilon = 0.33$; for fresh catalyst bed $\varepsilon = 0.42$ decreasing to 0.38 as the bed ages; for uniform tower packing with sphericity of 0.4, $\varepsilon = 0.66$. The void volume decreases as the particle distribution deviates from uniformity. For example, for a log normal distribution with a geometric standard deviation of 3, then for a tight pack of spheres $\varepsilon = 0.18$.

For the flowability, use the Johanson indices to characterize dry particles: (see also related topics conveying solids, Section 2.6, storage bins, Section 10.3, mixing, Section 7.4) These indices are:

Arching index [m], **AI**, = diameter of the circular exit hole from a hopper that will ensure that an arch collapses in a conical bin or circular mixer, values range 0–1.2 m.

Ratholing index [m], **RI**, = diameter of the circular exit hole from a hopper that will ensure rathole failure and cleanout in a funnel-flow bin or mixer, values range from 0–9 m. (If **RI** > 3 then likely “lumps”.)

Hopper Index [degrees], **HI** = the recommended conical half-angle (measured from the vertical) to ensure flow at the walls. Usually add 3° to account for variability. Values range 14–33° with 304 s/s.

Flow ratio index [kg/s], **FRI** = maximum solids flowrate expected after deaeration of a powder in a bin. (Measures consistency: small **FRI** for fine, highly compressible particles; large **FRI** for particles > 400 μm , incompressible, very permeable.) Values range 0–90 kg/s.

Bin density index [Mg/m^3], **BDI** = bulk specific mass expected in a container full of solids or, in a mixer, when mixer stops and solid is allowed to deaerate. Values 0.3–1.6 Mg/m^3 .

Feed density index [Mg/m^3], **FDI** = bulk specific mass at the conical hopper or mixer's discharge outlet. Values are 1–60 % < **BDI**.

Chute index [degrees], **CI**, = recommended chute angle (with the horizontal) at points of solids impact. Values = angle of slide. values = 20–90°. High values suggest particles stick to sides of mixer or bins.

Rough wall angle of slide [degrees], **RAS** = angle (relative to the horizontal) that causes continual sliding on a solid on an 80-grit sandpaper surface with a pressure of 140 kPa-gauge. Values 20–35°. Approximately equal to the angle of repose.

Adhesion angle index [degrees], **AAI** = difference between angle of slide (with horizontal) after an impact pressure of 7 MPa or (**CI** –10°) and the angle of slide without impact pressure.

Spring back index [%], **SBI** = percentage of solids that spring back after consolidation.

From these definitions, we can quantify terms commonly used to describe particles.

Free flowing particles: **AI** < 0.06 m; **RI** < 0.3 m.

Moderately free flowing: **AI** < 0.18 m and mixtures of particles whose angle of repose or **RAS** differ by > 4°.

Moderately cohesive: 0.15 m < **AI** < 0.3 m; **RI** < 1 m; **FRI** > 0.225 kg/s and mixtures of particles whose angle of repose or **RAS** differ by < 3°.

1.7

Rules of Thumb about the Context for a Chemical Process: Economics

The rules of thumb refer to capital cost estimation, operating cost estimation, financial attractiveness and financial reports.

1. Total fixed *capital cost estimation*, total fixed capital investment = 3 to 10 (4 to 5 usual) × FOB major pieces of equipment. The factor decreases as more alloys are used in the process.
2. For capital cost estimation: for carbon steel fabrication: L+M factors are in the range 1.5 to 3 with corresponding L/M ratios of 0.15 to 0.65 with 0.4 being usual. The factor decreases for alloys.
3. For capital cost estimation: FOB equipment cost increases with sizeⁿ where *n* is usually 0.6 to 0.7. When *n* = 1 there is no capital cost advantage to building larger; increase size or capacity by duplicating equipment.
4. For capital cost estimates:
(FOB × L+M*) + installed instruments + buildings required within the battery limits = L+M cost.
L+M cost + taxes, freight and insurance at 15–25 % FOB cost = physical module cost, PM.
PM + offsites + indirects for home office and field expenses at 10–45 % of L+M with small values for large projects = bare module or BM cost.

BM cost + contractors fees (3–5 % BM) + contingency for unexpected delays (10–15 % BM) + design contingency for changes in scope during construction (10–30 % BM) = fixed capital investment or total module, TM, cost.

To the fixed capital investment might be added, as needed:

- (i) royalties and licenses.
- (ii) land (1–2 % TM).
- (iii) spare parts (1–2 % TM).
- (iv) legal fees (1 % TM).
- (v) working capital: for year-round commodities (15–20 % TM); for seasonal commodities (25–40 % TM). For specialties and pharmaceuticals (15–40 % of sales).
- (vi) startup expenses (15–40 % TM).
 5. *Operating cost*: for 1 laborer/shift, 4.2 laborers are needed.
 6. Operating cost: selling price = $1.3 \text{ to } 3 \times$ raw material cost with usual value of 2.
 7. For *financial attractiveness*: risk-free interest: 6 to 18 % depending on the industry, usually 6 %; additional incremental interest for risk: low risk = add 1 to 5 % to the risk-free value; medium = add 5 to 20 %; high = add 20 to 100 %.
 8. For financial attractiveness: Discounted Cash Flow, DCF, and payback time are approximately related as follows:
 $\text{DCF} = 100 \% \approx 1 \text{ year payback time}$; $50 \% \approx 2 \text{ years}$;
 $33 \% \approx 3 \text{ years}$; $16 \% \approx 5 \text{ years}$.
 9. For *financial reports*: current ratio: 1.5 to 2; cash ratio: 1; debt to assets: 0.35; times interest earned: 7 to 8; inventory sales: 7 to 9; average collection period: 45 days; fixed assets turnover: 2 to 3; total assets turnover: 1 to 2; profit margin on sales: 5 to 8 %.

1.8

Rules of Thumb about the Thinking Process: Problem Solving and Creativity

Here are 18 rules-of-thumb about the process of problem solving:

1. *Be able to describe your thought processes as you solve problems.*
2. *Know the systematic stages for each cycle of the problem solving process.* (i) **Engage** with the problem or dilemma, listen, read carefully and manage your distress well. Say “I want to and I can!” (ii) **Analyze** the data available and classify it: the “goal, the givens, the system, the constraints and the criteria”. (iii) **Explore**: build up a rich visual/mental picture of the problem and its environment; through simplifying assumptions and rules of thumb explore the problem to see what is really important; identify the *real* problem. (iv) **Plan** your approach to solving the problem. (v) **Carry out**

the plan and (vi) **Check** the accuracy and pertinence of your answer. Did it answer the problem? satisfy the criteria? Reflect on the problem solving process used to discover new insights about problem solving. Elaborate on the answer and the problem situation to discover answers to other problems, to extend the solution to other situations and to relate this problem experience to other technical problems you have solved in the past. This systematic approach is **not** sequential. Skilled problem solvers bounce back and forth between the stages. A typical approach would be engage, analyze, engage, explore, engage, explore, analyze, engage, explore, plan, engage and so on.

3. *Focus on accuracy* instead of speed.
4. *Actively write things down.* Make charts, draw diagrams, write down goals, list measurable criteria and record ideas in brainstorming.
5. *Monitor and reflect.* Mentally keep track of the problem solving process and monitor about once per minute. Typical monitoring thoughts are “*Have I finished this stage? What have I discovered so far? Why am I doing this: if I calculate this, what will this tell me? What do I do next? Should I reread the problem statement? Should I recheck the criteria?*” Typical reflections that look back on the process and attitudes used are: “*This didn’t work, so what have I learned? Am I focusing on accuracy or am I letting the time pressures push me to make mistakes? Am I managing my stress? I can do this! Am I monitoring the process?*”
6. *Be organized and systematic.*
7. *Define the “real” problem by creating a rich perspective of the problem.* During the **Explore** stage, see the problem from many different points of view. Be willing to spend at least half the total available time exploring the problem. Ask many *what if* questions. Try to bound the problem space. Identify the *real* problem, by asking a series of *why?* questions to generalize the situation. This **Explore** activity of identifying the *real* problem is the heart of the problem solving process. Rules of thumb are used extensively during this activity.
8. *Be flexible.*
9. *Use your creativity effectively.* Defer judgment; be succinct; list 50 ideas in 5 minutes; create a risk-free environment; encourage free and forced association of ideas; piggy back on previous ideas; use **triggers**, such as those listed below, to maintain the flow of ideas; don’t be discouraged, in the last two minutes of a ten minute brainstorming session, over 85 % of the ideas are not practical. But, spend time identi-

fying the treasures among the 15 %; use impractical and ridiculous ideas as “stepping stones” to innovative, practical options. Some **triggers** include: function, physical uses, chemical uses, personal uses, interpersonal uses, aesthetic uses, mathematical or symbolic properties, SCAMPER checklist (an acronym for Substitute, Combine, Adapt, Modify, minimize, and maximize, Put to other uses, Eliminate, and Reverse), wildest fantasy, how nature does it, *what if?* in the extremes, boundary exploration, functional analogy, appearance analogy, morphology, symbolic replacement, juxtaposition, personal analogy, reversal, book title, letter-word-sentence and famous paintings.

10. *Critically assess the knowledge and data used.* Too often we hope that the data are applicable. A colleague, in designing a petrochemical plant, was unable to locate the physical properties of the organics. He decided to assume they were the same as water and hope that they would work out. Just a short time spent in critical assessment of this assumption would have saved six months of wasted work. Too often we accept data from the published literature; yet about 8 % of data published are mistakes. “The temperature into the hydrodealkylation reactor is $> 1150^{\circ}\text{C}$ ” states one reference. This should read $> 1150^{\circ}\text{F}$. A major handbook published an incorrect value of the heat of vaporization through several editions. Check the data coming from computer programs and simulations. Check the physical property package estimates.
11. *See challenges and failure as opportunities for new perspectives.*
12. *Spend time where it benefits you the most.* Use Pareto’s principle (80 % of the results can be found from 20 % of the effort). Find the key 20 %.
13. *Be an effective decision maker.* Express the goal as *results* to be achieved rather than as *actions* to be taken. Make decisions based on written criteria that are explicit and measurable. Distinguish between *must* criteria (the process must have an internal rate of return of 35 %) and *want* criteria (the process might have the potential to be licensed). Reject options that do not meet the *must* criteria. Use a rating system to score the *want* criteria.
14. *Be willing to risk.*
15. *Manage stress well.* Solving problems is stressful. When we initially encounter a problem we experience distress because of the uncertainty. Such stress tends to immobilize us. When we successfully solve a problem we experience the joy and exhilaration of stress (that distracts us from checking and

double checking that our answer is the best). A certain level of stress motivates us. Excessive stress makes us make mistakes. Data suggest that operators with confidence and training working under high stress make 1 mistake in 10 actions. Operators with confidence and training who receive feedback about their actions and are under low stress make 1 mistake in 1000 actions. Although these data refer to plant operators, the same trends can be extended to suggest how stress, lack of reflection and feedback might interfere with engineering practice. High stress would be a rating of over 450 on the Holmes–Rahe scale (Holmes–Rahe, 1967).

Ten suggested approaches to managing stress include: worry only about things over which you have control, include physical exercise as part of your routine, have hobbies and destimulating activities in which you can lose yourself, plan ahead, avoid negative self talk, rename the events that are stressful to you, build a support system, be decisive, put the situation into perspective and use role models of others who have succeeded.

16. *Manage your time well.* Covey (1989) offers excellent suggestions on time management. Identify problems and decisions according to their importance and urgency. Shift the important situations to being nonurgent. Learn to say “No”.
17. *Understand your strengths, limitations and preferred style.*
18. *For problems involving people, use the 85/15 rule.* 85 % of the problems occur because of rules and regulations; 15 % of the problems are because of people.

1.9

Rules of Thumb about the Thinking Process: Goal Setting

Here are nine guidelines for setting goals:

1. We function better if we have goals about what we want to achieve, to prevent from happening and to preserve.
2. Carefully define specific goals; do not accept vague ideas of what you want to achieve, prevent or preserve.
3. Clearly differentiate between symptom, cause, issues, solutions and goals.
4. Know when your goal has been achieved by writing out measurable criteria when you create your goal.
5. Be willing to spend at least half the allotted time in defining the real goal. Be unwilling to impulsively replace a goal with an immediate answer.
6. Use eleven characteristics to describe goals: (i) are written; (ii) are in the context of **here and now**, and **now and then**;

(iii) are problems/goals and not symptoms; (iv) have owners; (v) have stakeholders (people affected by your goals); (vi) have three parts: goals, criteria and resources and these form an achievable, consistent set. (vii) are written in observable and unambiguous terms; (viii) have criteria that are written in measurable terms; (ix) are expressed as “results” and not actions; (x) are achievable in that the resources of time, talent and money are actually available; (xi) are flexible in that they can be changed when conditions change.

7. Use an approach, such as the *Why? Why? Why?* approach, to create the **here and now** context and provide the big picture in which the goal resides. Flexibly identify the **real** problem.
8. Put the goal in the context of **now and then** to ensure that it meets your overall long-term mission and vision.
9. List a range of stakeholders and classify them as being family, friends, fence-sitters, fighters, factions or foes. Rate how each is affected by your achievement of your goal.

1.10

Rules of Thumb about the Thinking Process: Decision Making

1. Consider what you want to achieve, avoid and preserve.
Focus on the results you want to achieve and not the actions.
Use the guidelines in Section 1.9 to create goals.
2. Generate many options to achieve the goals.
3. Decisions are made based on published, measurable criteria.
4. Criteria can usually be classified into “Must” and “Want”.
The Must criteria must be satisfied for the option to be viable.

1.11

Rules of Thumb about the Thinking Process: Thermal Pinch

1. Always add heat at the lowest possible temperature level;
always remove heat at the highest possible temperature level.
2. Above the pinch, supply heat; below the pinch reject heat.
3. Do not transfer heat across the pinch.

1.12

Rules of Thumb about the Thinking Process: “Systems” Thinking

Three elements contribute to system thinking: physical, chemical, thermal and information dimension; the financial dimension and the people dimension.

- *Physical, Chemical, Thermal and Information Dimension*

Each chemical process is a system in which individual pieces of equipment are hooked together to function effectively and efficiently to convert feedstocks into products.

1. Startup and shutdown: can the system be started up? Were cold startup conditions considered? What happens to the air inside all vessels? What happens to the liquid and vapor inside all vessels when we shut down? Were all the vessels and lines cleaned correctly? dirt removed? rust removed? liquid puddles removed? was junk left in the lines or vessels?
2. Failure occurs: how does the system respond when corrosion, cycling, leaks, catalyst breakdown occur? power failure? barrier failure?
3. Interaction with the environment: weather, elevations, leaks, environmental impact. See related topic Section 1.16.
4. Material carry over and impact on downstream and upstream operations: fouling, foaming, corrosion, cycling, leaks, recycle, and stable emulsion formation.
5. Information carry over and interaction: cycling.

- *Trouble Shooting*

In trouble shooting “systems”, some common issues include: solvent losses somewhere in the system; fouling; foaming or stable emulsion formation that causes equipment malfunction and carry over; corrosion; and/or recycle causing a buildup of species that may not be removed from the system without adequate bleeds or blowdown. Although, in this book, many of these are considered for specific pieces of equipment, we include a generic consideration of some of these here. In this listing, the concept or symptom is shown in parentheses and italics, for example, “*Foaming*”, followed by possible causes separated by/. If the cause is not a root cause, then it is represented in square bracket plus an *, [foam-promoting systems]*. These intermediate causes are then listed alphabetically .

“*Corrosion*” or corrosion products: see Section 1.3.

“*Foaming*”: [foam-promoting systems]*/[foam-promoting contaminants]*/[gas velocity too fast]*/[liquid residence time too low in GL separator]*/antifoam addition faulty (wrong type or incorrect rate of addition)/mechanical foam breaker not rotating/baffle foam breaker incorrectly designed or damaged/overhead disengaging space insufficient height/[liquid environment wrong]*.

“Fouling”: velocity too slow/[particulate fouling]* for example, rust, corrosion products from upstream, scale from upstream units, oil, grease, mud or silt/[precipitation fouling]* for example sodium sulfate, calcium sulfate, lignin/[biological fouling]* species present such as algae and fungi/[chemical reaction fouling]*, example coke formation and polymerization fouling/[flocculation fouling]* or destabilization of colloids, for example asphaltenes or waxes from hydrocarbons/corrosion products for this unit, see Section 1.3/[solidification fouling]* or incrustation such as the freezing on a solid layer on the surface or crystallization/[condensation fouling]* such as vaporization of sulfur.

“Solvent loss”: [physical losses]*/[entrainment]*/[solubility]*/[vaporization]*/[degradation]*/[solvent loss elsewhere]*/for **glycol dehydration** typical losses = 0.015 mL m^{-3} gas treated.

“Stable emulsion formation”: contamination by naturally occurring or synthetic surfactants: example, lubricating oils/contamination by particulates: example, products of [corrosion, see Section 1.3]*, amphoteric precipitates of aluminum or iron/pH far from the zpc/contamination by polymers/temperature change/decrease in electrolyte concentration/the dispersed phase does not preferentially wet the materials of construction/coalescence-promoter malfunctioning/improper cleaning during shutdown/[rag buildup]*/[Marangoni effects]*.

*[Amine concentration too high or too low]**: if too high, lack of equilibrium driving force/if too low, insufficient moles of amine for the feed concentrations.

*[Biological fouling]**: temperature, pH and nutrients promote growth of algae and fungi/biomaterials present.

*[Chemical reaction fouling]**: high temperature causing cracking/high wall temperatures/stagnant regions near the wall or velocity too slow $< 1 \text{ m/s}$ reactant droplets preferentially wet the solid surface/addition of “fouling suppressant” insufficient, for PVC polymerization oxalic acid or its salt or ammonium or alkali metal borate/pH change.

*[Column operation faulty]**: plugged tray or packing/poor distribution for packing/liquid flowrate $<$ minimum required for loading/[gas velocity too fast]*/collapsed trays or packing/plugged or broken distributors/[foaming]*/solvent – stripper overhead temperature too low. See also Section 4.2.

*[Condensation fouling]**: wall temperature too cold/contamination in the vapor.

*[Degradation]**: chemical reaction: for **amine**: reacts with CO_2 and O_2 ; forms stable salts: for **glycol**: reacts with O_2 /thermal decomposition: for **amine**: surface temperatures $> 175^\circ\text{C}$; for **glycol**: surface temperatures $> 205^\circ\text{C}$.

*[Electrokinetic effects]**: hydrocarbon liquid velocity too high/conductivity too low/pipes not grounded.

*[Entrainment: GL]**: demister plugged, missing, collapsed, incorrectly designed/[flooding]*/[foaming]*/inlet liquid line or distributor undersized or plugged/poor distribution for packing/liquid flowrate $<$ minimum required for loading/[gas velocity too fast]*/solvent feed temperature $>$ specifications/[column operation faulty]*/tray spacing $<$ design. See also GL separators Section 5.1.

*[Entrainment: L-L]**: fluid velocity too high; example $> 10 \text{ L/s}^1 \text{ m}^2$ /liquid distributor orifice velocity $>$ design; for **amine**: for amine $> 0.8 \text{ m s}^{-1}$; for hydrocarbon

$> 0.4 \text{ m/s}^1$ /faulty location of exit nozzles/interface level wrong location/faulty control of interface/no vortex breaker/exit fluid velocities $>$ design/insufficient residence time/[stable emulsion formation]*. See also decanters, Section 5.3.

[Flocculation fouling]*: pH at the zpc/low concentration of electrolyte/colloids present/[electrokinetic effects]*.

[Foam-promoting contaminants: soluble]*: naturally occurring or synthetic polymers/naturally occurring or synthetic organics $> \text{C}_{10}$; example lube oils, asphaltenes/naturally-occurring or synthetic surfactants; **for amine systems**: the surface active contaminants include condensed hydrocarbons, organic acids, water contaminants, amine degradation products/faulty cleaning before startup; surfactants left in vessels.

[Foam-promoting contaminants: solid]*: [corrosion products, see Section 1.3]*; **for amine systems**: iron sulfides; amine salts formed from organic acids + hydrocarbons/faulty cleanup before startup; rust left in vessel/dust/dirt/particulates.

[Foam-promoting systems]*: those that foam naturally: methyl ethyl ketone, aerobic fermentation, textile dyeing foam more readily than $>$ amine and glycol absorption systems and latex stripping $>$ amine, glycol and Sulfolane strippers $>$ slightly foam promoting: fluorine systems such as freon, BF_3 /systems operating close to the critical temperature and pressure/surface tension positive system/[Marangoni effects]*.

[Flooding]*: see Section 4.2.

[Gas velocity too fast]*: temperature too hot/design error/[foaming]*/vessel diameter too small for gas flow/column pressure $<$ design/trays or packing damaged or plugged giving excessive vapor velocity/upstream flash separator passing liquids: feed contaminated with excessive volatile species/stripping gas fed to column too high/input stripping gas flowmeter error/design error.

[Inaccurate sensing of the interface]*: instrument fault/plugged site glass.

[Liquid environment wrong]*: pH far from the zpc/electrolyte concentration too low.

[Liquid residence time too low in gas liquid separator]*: interface height decreases/[inaccurate sensing of interface]*/turbulence in the liquid phase/flowrate $>$ expected/sludge settles and reduces effective height of phase/inlet conditions faulty.

[Marangoni effects]*: nonequilibrated phases/local mass transfer leads to local changes in surface tension and hence stable interfacial movement.

[Particulate fouling]*: filter not working or not present/contaminant in feed/upset upstream/erosion.

[Physical losses]*: leak to atmosphere/purges for sampling/sampling/heat exchanger leak/pump seal flushes/filter changes/leaks in piping, fitting, valve stems, gaskets and pumps.

[Precipitation fouling giving scale or sludge]*: soluble species present in feed/temperature high for invertly soluble/temperature too low for incrustation or crystal formation.

[Rag buildup]*: collection of material at the interface: naturally-occurring or synthetic surfactants: example, lubricating oils/particulates: example, products of [corrosion, see Section 1.3]*, amphoteric precipitates of aluminum/naturally occurring or synthetic polymers.

[Solidification fouling]*: wall temperature too cold/missing insulation/cold spots on wall/sublimation.

[Solubility losses]*: liquid-liquid systems: system pressure < design/**for amine**: concentrations > 40 % w/w/system temperatures too high.

[Solvent contaminated]*: carryover from upstream equipment; example oil from compressor; brines, corrosion inhibitors, sand, [corrosion products, see Section 1.3]*/oxygen leaks into storage tank/inadequate corrosion control, example low pH causing corrosion/degradation via overheating, ex hot spots in reboiler tubes or fire tubes/ineffective filters/ineffective cleaning before startup/**for amine absorbers**: corrosion products/FeS/chemicals used to treat well.

[Solvent loss elsewhere]*: upstream units, for example **for glycol dehydration**: glycol dumped with hydrocarbons separated in upstream flash drum/loss in downstream solvent stripper.

[Solvent stripping inadequate]*: not enough steam in stripper/incorrect pressure in stripper/[foaming]*/[solvent contaminated]*/contaminated feed: **for amine strippers**: other sulfur species causing high partial pressure/leak in the feed preheater contaminating feed with stripped solvent.

[Vaporization losses]*: system pressure < design/**for amine**: concentrations > 40 % w/w/system temperatures too high.

- *The Financial Dimension*

The operation is a financial system: profit and attractive returns on investment occur because revenues brought in exceed payments for equipment, personnel, feedstocks and operating supplies. Processes are built and operate because the return on financial investment relative to the risk exceeds other investment opportunities of similar risk. See related topic Section 1.7.

- *The People Dimension*

The corporation is a system of people in which the specialized knowledge, skills and attitudes of individuals are used and rewarded. See related sections on performance review Section 1.21 and leadership, Section 1.22.

1.13

Rules of Thumb about the Thinking Process: Design

The six general guidelines are:

1. Decide batch versus continuous; Section 1.5.
2. Set goals, see suggestions in Section 1.9 about how to do this.
3. Preliminary scouting of reactor configuration and conditions.
4. Explore mass recycle.
5. Explore separations. Try to avoid adding separation agents.
6. Explore energy integration. Use the principles of thermal pinch, Section 1.11.

1.14**Rules of Thumb about the Thinking Process: Process Improvement**

See also Section 1.15.

Ten prioritized suggestions are listed.

1. Change control: change set points, tighten control variations of key variables.
2. Better inventory control and reduction of fugitive emissions.
3. Identify realistic needs for process units.
4. Optimize the reactor/separation system.
5. Optimize cycle time; improve control.
6. Debottleneck by relocation.
7. Debottleneck by redesign and/or equipment replacement.
8. Manage the recycle of heat and mass networks; use pinch technology.
9. Substitute reagents, catalysts, solvents, additives.
10. If waste byproducts are formed reversibly, recycle to extinction.

1.15**Rules of Thumb about the Thinking Process: Trouble Shooting**

From experience, the typical faults are given for first-time startup, for ongoing processes and for different types of equipment. Also listed are mistakes commonly made by operators.

1. For *first time startup*, the faults encountered are usually:
 - 75 % mechanical electrical failures such as leaks, broken agitators, plugged lines, frozen lines, air leaks in seals
 - 20 % faulty design or poor fabrication, such as unexpected corrosion, overloaded motors, excessive pressure drop, flooded towers
 - 5 % faulty or inadequate initial data
2. For *ongoing processes*, the faults encountered are usually:
 - 80 % fluid dynamical for ambient temperature operations
 - 70 % materials failure for high temperature operations
3. *Frequency of failures* based on type of equipment:
 - 17 % heat exchangers
 - 16 % rotating equipment: pumps, compressors, mixers
 - 14 % vessels
 - 12 % towers
 - 10 % piping
 - 8 % tanks
 - 8 % reactors
 - 7 % furnaces

4. *Mistakes operators* make are usually:
 - 90 % no action taken when some kind of action is needed.
 - 5 % took corrective action but moved in the wrong direction, for example, knew the temperature should be changed but increased it instead of decreased it.
 - 5 % took corrective action on the wrong variable, for example, changed the temperature when the composition should have been changed.
 The most likely operator error is misreading technical instructions.

1.16

Rules of Thumb about the Thinking Process: Environment, Waste Minimization, Safety

Eight suggestions are:

1. Consider issues of safety, waste minimization, environmental concerns and health hazards together. Consult <http://webbook.nist.gov> and <http://toxnet.nlm.nih.gov>. Use HAZOP.
2. Identify the target or goal.
3. Eliminate the source: eliminate, substitute, recycle.
Try to avoid adding agents.
4. Minimize the source: intensify, substitute, attenuate.
5. Minimize the impact.
6. Isolate the source.
7. Isolate the impact.
8. For safety, the calculated reaction temperature to form stable products (CART) is a better predictor of hazard than H_{react} . See also Section 6.1, reactors.

1.17

Rules of Thumb about the People Part of Engineering: Communication

About the Product

1. Audience, audience, audience.
2. If the message isn't communicated, it's the speaker's or writer's fault.
3. Include advance organizers.
4. Include transitions.
5. Always give a summary.
6. Five criteria are audience, content, organization, style and format.

About the Process

1. Use an audience-based and not writer-based approach. The content addresses questions the audience wants answered (instead of incorrectly dumping the information the writer knows on the subject with the length of the topic being proportional to the time spent researching the topic); the organization is hierarchical instead of incorrectly using chronological or historical.
2. Effective communication is linked with clear thinking and problem solving skills.
3. There is not a universally-applicable template that fits all communications; each communication must answer the questions of the audience.
4. Confusion is welcome because it forces the writer to check and rethink his/her thinking.
5. Let the ideas flow rather than trying to polish the first and only sentence created.
6. When revising, be willing to rethink and rework the whole structure if it doesn't meet the needs of the audience, instead of incorrectly working only on polishing the grammar and style.
7. Develop a coherent written plan.
8. Spend most of the time planning and revising.
9. Be willing to discard sections already written instead of incorrectly hoping to use anything written somewhere.

1.18**Rules of Thumb about the People Part of Engineering: Listening**

1. Focus attention on the talker.
2. Avoid distracting behavior.
3. Show respect and frequently acknowledge through appropriate body language and “ahums” and reflecting statements.
4. The process can be modeled as Sensing, Interpreting, Evaluating and Responding or SIER. That is, we sense the message, we internally interpret what is being communicated; we evaluate the message in the context of the situation, our feelings, needs and goals and we select how to respond.
5. Sensing the message is complex because about 55 % of the message is communicated by body language, 38 % by tone and 7 % by the words.
6. Listening is about four times slower than thinking.

7. About 80 % of our waking hours are spent in verbal communication; with about half of that spent listening.
8. Untrained listeners understand and retain between 25–50 % of a conversation.
9. Only about 5 % self-assess themselves as being highly skilled listeners.
10. Attend: posture is inclined forward and open, facing squarely approximately 1 m apart; no distracting behavior and eye contact is called “soft focus” (contrasted with looking away or staring).
11. Tracking/following: provides minimal encouragement (for example, “*Tell me more*”, “*sure..*” “*Oh..*”, “*Then..*”) and infrequent questions (for example, prefer “*What?*” questions to “*Why?*”) and attentive silence.
12. Reflecting is responding with a concise restatement of the content and feelings expressed in the listener’s own words. That is, include the content and feelings of what was said, express it in the listener’s own words without adding new ideas or leaving out ideas. Some example approaches include saying “*As I understand it..*” or “*Are you saying that..*” Reflecting is usually used when someone is very emotional, or when you see differences developing between you and the other person, when there is disagreement, when the talker seems to be confused or when the talker needs encouragement that his/her contribution is valuable.

1.19

Rules of Thumb about the People Part of Engineering: People Skills

Nine suggestions are given.

1. Become aware of your own uniqueness and personal style, and how this might differ from the style of others
2. Honor the seven fundamental rights of individuals, RIGHTS. **R**, to be Respected; **I**, Inform or to have an opinion and express it; **G**, have Goals and needs; **H**, have feelings and express them; **T**, trouble and make mistakes and be forgiven, **S**, select your response to the expectations of others and claim these rights and honor these in others.
3. Avoid the four behaviors that destroy relationships: Contempt, Criticism, Defensiveness and Withdrawal/stonewalling
4. Trust is the glue that holds relationships together.
5. Build trust by *keeping* commitments to yourself and others; *clarifying* expectations that you have of yourself and of others;

showing personal integrity, honesty and loyalty to others, especially when they are not present; *apologizing* promptly and sincerely when you know you are wrong; *honoring* the fundamental RIGHTS listed above and avoiding the destroyers (listed above in point 3); *listening and understanding* another's perspective; *being truthful*; and *accepting others* "warts and all".

6. Destroy trust by the reverse of the Builders of trust listed above, and by selectively listening, reading and using material out of context; not accepting experience of others as being valid; making changes that affect others without consultation; blind-siding by playing the broken record until you've eventually worn them out or subtly make changes in the context/issues/wording gradually so that they are unaware of what is happening until it is too late.
7. The 12: 1 rule applies to rebuilding relationships. 12 positive experiences are needed to overcome 1 negative experience.
8. To improve and grow we need feedback about performance. Give feedback to others to encourage and help them; not for you to get your kicks and put them down. Focus on five strengths for every two areas to improve on.
9. Be skilled at responding assertively. "*When you... I feel.. adjust by...*"

1.20

Rules of Thumb about the People Part of Engineering: Team and Group Skills

A team is more than a collection of individuals. In a collection of individuals each has a personal goal, trusts self, rarely exposes personal skills, decisions are usually not made and conflict is ignored. In a team, all unanimously accept the goals, each is clear about role, trust and involvement are high, personal unique skills are used effectively, decisions are made by unanimity and the team has methods for handling conflict. Our meetings and teamwork improve when we strive for the characteristics of teams. Some target behaviors of teams are:

1. Have a purpose for each team and each meeting. Set and follow agendas to get the task done.
2. No agenda; no meeting! If a meeting must be held without a circulated agenda, then spend the first five minutes creating the agenda.
3. The team must have the correct membership and resources to achieve the goal.
4. The team should be empowered and accountable to achieve the goal.

5. Both Task (getting the job done) and Morale (feeling good about the group work and about how you have interacted with the other group members) are important.
6. Have a chairperson whose role is to facilitate the team process: thinks through the tasks to be done, decides on the need for a team meeting, identifies the time and place for the meeting, sets and circulates an agenda, facilitates the meeting and start and stops the meeting on time.
7. Chairperson and leadership are different; different people may become leaders at different times.
8. Group evolution tends to follow a pattern described by such descriptors as *“forming, storming, norming and performing”*.
8. Establish group norms of behavior early. Agree on terminology and procedures for problem solving, for brainstorming, for decision-making, the role of the chair in decision-making, *for example, vote or no vote*; roles, minutes and records of decisions, *for example, format, details, who prepares them, are they circulated? use for subsequent meetings*; how to handle conflict and level of intervention; combating “group think”; how to handle emergencies and criteria and procedures for asking a member of the group to resign.
9. Each has a clear idea of roles and of group norms.
10. When groups are functioning effectively, about 70 % of the time is spent on the task; 15 % on morale building activities and 15 % of task process activities.
11. The products from groups or teams are improved when members have different “styles”.
12. The quality of decisions, product, task is improved if group members offer different perspectives, disagree and seem to introduce conflict into the process. The trick is to manage the apparent conflict well.
13. Use Sanderson’s 20 minute rule. After 20 minutes either make a decision or identify the key information that is missing and arrange to obtain that information for the next meeting.
14. Document decisions and record **Actions** with “what”, “who” and “when”. *Example*: “Decide to compare two optional control strategies” **Action**: JBM by March 30.
15. Systematically assess the quality of the teamwork and set goals for improvement. Table 1.4 is an example form for such an assessment.

Table 1.4 Assessment of group activity.

Purpose of meeting: _____	Date of meeting: _____
Chairperson: _____	Agenda circulated ahead of time, yes <input type="checkbox"/>
Meeting started on time, yes <input type="checkbox"/> .	Meeting ended on time, yes <input type="checkbox"/>
start delayed ____ min.	

- As a group, by consensus, agree on a rating for Task and Morale.

Task: Problem defined, many issues and hypotheses explored, criteria listed and the issues prioritized. Refrained from early closure. Task carried out and looked back at the result to assess it. Group agreement as to goals. Process was active with monitoring. Completed task on time. The accuracy in the group's answer matched the time available. Group avoided contributing excessive information.

None of these behaviors		Few of these behaviors but major omissions		Most features demonstrated		All of these behaviors
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
1	2	3	4	5	6	7

Morale: Group relaxed; enjoyed working together. They gave emotional support to each other and were able to express disagreement or disappointment directly. Seven fundamental rights preserved. Members are enthusiastic and involved.

None of these behaviors		Few of these behaviors but major omissions		Most features demonstrated		All of these behaviors
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
1	2	3	4	5	6	7

- Individual Contribution to Task and Morale: Each, in turn, takes 30 seconds to describe his/her contribution to the group. This is not for discussion.

- As a group, by consensus, list the five strengths and the two areas to work on.

Group Strengths	Group Areas to work on
_____	_____
_____	_____

from D.R. Woods (1995)

- *Trouble Shooting*

Trouble shooting teams

Use Table 1.4 after each meeting, set goals and celebrate achievement. Use the framework developed by Francis and Young (1979) for growth; consult Fisher et al. (1995) for more short-term ideas.

Trouble shooting team meetings

These are organized by symptom with possible corrective responses suggested for chair {C} and member {M}.

1. Problems with purpose and chairperson.

"No apparent purpose for the meeting": {C} don't have a meeting. {M} question the purpose of the meeting. See also Agenda and timing problems.

2. Agenda and timing problems:

"No agenda": {M}: phone {C} and ask for agenda. Invoke "no agenda, no attendance."/at meeting: "Perhaps the first thing we should do is to create an agenda."/After 5 minutes, "We seem to be lost. Could we draw up an agenda and follow that?"

"Meeting drags on and on": {C} should have circulated an agenda with times for each item and used the 20 minute rule/{M} "Perhaps we can follow the agenda."/{M} indicate to {C} ahead of time the amount of time you have available for the meeting and then leave at that time.

"Get off the track": {M} seek direction, purpose, summary of progress: "Now where are we?" "Would someone want to summarize what we have done so far?" "Let's check on the purpose of this meeting and see our progress."/see also Behavior problems: *"Subgroups interrupting and talking"*.

"Group gets bogged down": state problem/summarize/seek agenda clarification/invoke 20 min rule.

"Decisions made just at the end of the meeting": state frustration/suggest tabling/suggest future corrective way to handle. See also Agenda and chairperson problems.

3. Behavior and participation problems

"People come into a meeting cold": {C or M} suggest reconvene meeting when all are prepared.

"Late arrivals": {C} start meeting on time and continue with the agenda through the disruption of the retardee/{M} "I realize that not everyone is here but I suggest that we start. It looks like a long agenda to get through."

"Some people do all the talking and some remain silent": wrong membership/encourage quiet ones to contribute/ask each, in turn, to summarize his/her point of view/ask a "safe" question of the silent ones/private check with the silent ones and reevaluate whether they need to attend./ask open ended questions/use nominal group.

“Sub groups interrupting and talking”: identify problem/suggest discussing one issue at a time and add subgroup’s issues to agenda/be silent until the side conversation stops. “Thank you.”/Interrupt the side conversation.

“Indecisive members, continual question asker”: ask for their ideas early/redirect questions he/she asks back to him/her.

4. Conflict or apparent conflict

“Conflict because of differing views”: restate the importance and value of everyone’s opinions/attempt to bring conflict into the open/summarize different views/focus on different performance or opinions and not personalities/remind of fundamental RIGHTS.

“Conflict over facts”: stop the argument, identify problem as you see it and check that that is a problem/identify facts we need clarified and probable expert.

“Conflict over values, goals, criteria, process or norms”: stop discussion, identify problem as you see it and check that that is a problem/use problem solving.

“Resistance to new ideas, we tried that before, it won’t work, over my dead body, we don’t have the resources”: surface the resistance/honor the resistance/invoke consequence of no decision or of repeating what we’ve always done before/use consensus building techniques/reflect on the home turf of the objector and the impact the decision might have on them; explore if this might be brought to the group as an issue to address/root cause of most resistance is fear of change, apathy, vested interests, not invented here, negativism, overwhelmed by the enormity of proposal.

1.21

Rules of Thumb about the Context in Which We Function: Performance Review

Assessment is a judgment of the degree to which a goal has been achieved, using measurable criteria or metrics and based on agreed-upon forms of evidence.

1. Assessment is about performance not personal value or worth.
2. Assessment is based on evidence and not gut feelings.
3. Assessment is done in the context of published, observable and unambiguous goals.
4. Assessment is done in the context of published measurable criteria related to the goals.
5. Assessment is done based on agreed-upon forms of evidence.
6. Assessment should be a combination of continual and periodic and based on many different forms of evidence.

- *Trouble shooting*

“Failure to reach agreement”: gut feelings used instead of evidence/evidence inadequate and or poorly presented/assessor uses this as an opportunity to “get even” or to show power.

“Frustration and anger”: goals not published and or ambiguous/no published criteria/no agreed-upon forms/inconsistency between the goals and the forms of evidence/no attempt to help employee set personal goals for the next time period.

“Inadequate or inappropriate forms of evidence”: misunderstanding of principles of assessment/no forms of evidence agreed-upon for some of the goals or target behaviors.

1.22

Rules of Thumb about the Context in Which We Function: Leadership

1. Know yourself: discover your unique styles; build trust by meeting commitments and keeping your word; know your many roles; know your personal goals, vision and mission; know your style of networking; strike the balance between being part of the system while retaining a position of authority; know how to support subordinates empowered to do tasks.
2. Know the environment. don't just do things right; do the right things. Know the strengths to be preserved; the areas to work on to improve and the areas to avoid.
3. Challenge the process: search for opportunities by confronting and challenging the status quo; experiment and take risks; learn from mistakes and successes.
4. Inspire a shared vision: create a vision of the future, communicate that vision to others and attract others to common purposes. We tend to under-communicate by a factor of 10.
5. Enable others to act: foster teamwork; strengthen others and share power and information.
6. Publish the vision, the goals, the milestones and measures/yardsticks/criteria to measure achievement.
7. Model the way: set by example; walk the talk; build commitment to action and understand the grieving process that some will experience as change occurs.
8. Encourage the heart: recognize contributions, link rewards with performances and celebrate accomplishment.
9. Consolidate gains and anchor the new approaches in the culture.

A leader has internal motivation, is authentic and promotes trust, brings out the best in people, seeks and learns from feedback, is curious and is a good listener.

1.23**Rules of Thumb about the Context in Which We Function: Intrepreneurship**

(based on Valikangas, 2003 and Cooper, 1987)

Innovation within the corporation:

1. Create the motivation first: want to bring new products to the market. This is a high risk but vital activity.
2. Ensure management commitment: concrete, consistent and explicit.
3. Set concrete and achievable goals with resources to support.
4. Create the infrastructure: a process (and reward system) to identify winners, develop a plan and market the new product. A major cause of failure of new products is marketing: underestimating the competition, and overestimating the potential.
5. Build into the process elements to manage risk: if the uncertainty is high, keep the stakes low, reduce uncertainty by using an incremental decision process, buy information to reduce the uncertainty, don't be afraid to stop one project when it now looks unattractive.
6. Cultivate innovation routines and name your innovation ambassadors. Often select a person to lead who has a Kirton KAI inventory (Kirton, 1976) value of about 100 to 110, midway between the adaptors 85–100 and the innovators 110–130.
7. Evaluate progress effectively, purposefully and regularly.
8. Focus on quality first.

1.24**Rules of Thumb about the Context in Which We Function: Entrepreneurship**

Creating your own company:

1. Need technology, creativity, courage and business know-how.
2. Kondratieff wave of world-wide prosperity with highs 1860, 1920, 1960.
3. Major innovation cycles 6 years; next major high 2035.
4. Cost of invention, R&D 5–10 %.
Conception and product design 10–20 %.
Fabrication & process development 40–60 %.
Fine tuning and manufacturing 5–10 %.
Market launch 10–25 %.
5. Business plan, business plan, business plan.
6. Use the rules of thumb for intrapreneurship that are pertinent.

7. It takes 15 years between a company's inception and a viable product entering the market.
8. One in ten brilliant start-up ideas is successful financially; nine are not.
9. The startup idea should be patented.
10. The startup company should have an address, a board, a CEO, a business plan and a bank account.

For more see Doyle (1983) and Curran (1991).

1.25

Rules of Thumb about the Context in Which We Function: e-Business

e-Business uses the same business and marketing principles, combined with ideas related to change management and building consumer trust.

1. Start small.
2. Write out your goals and focus on the goals.
3. Develop consumer trust by knowing your product and customers, through careful design of the consumer-vendor interface.
4. Astutely select the informational content: create value, be credible, be transparent, show company values and the real people behind the company by providing names and photographs, describe the company's achievements, address security concerns up-front, provide reassurance in case of fraud, give a privacy policy and let consumers be in control of their data.
5. Continue to build trust after the purchase by giving different means of contact, by handling customer inquiries efficiently, and by giving feedback about the order. Provide great after sales service.
6. Take your best people on developing e-business and take care of them.
7. Spend at least 10 % of the advertising budget on on-line advertising.

1.26

Rules of Thumb about Mentoring and Self-management

Whether it is managing yourself or giving advice as a mentor to someone else, here are my personal suggestions.

1. Complete jobs as if you were a consultant. Do them well and on time. Indeed, add a few extras.

2. Learn to say No.
3. Keep a balance in your life among physical, emotional, spiritual and intellectual.
4. Honor yourself; feel good about yourself.
5. Keep a sense of humor.
6. Be positive.
7. Be trustworthy and build trust.
8. Do things right the first time.
9. Keep good records. For example, sign and date all calculations.
10. Keep good personal files. Become an active member in professional organizations, subscribe to professional journals and set time aside to read and keep up to date.
11. Learn the company's economics.
12. Use the above ideas to learn how to cope well with the current "instant response" expectations. The e-mail and the internet have fostered a new concept of time. Many now seem to leave things to the last minute; expect instant response and incorrectly select some action, even if they know it is not the best choice. We need to re-establish that it takes time to do jobs well; we need lead times for meetings. Be patient with yourself and with others.
13. Apply the main principle of networking: "give to your network five times for any single time you want to draw on your network." (Woods and Ormerod, 1993)

1.27

Summary

The major focus of this book is on the rules of thumb for selecting, rough sizing, costing, operating and trouble shooting many different types of equipment used in chemical processes. This is **what** the book is about. The introduction and details of the organization of these rules of thumb were given in Section 1.1. Details for each major type of equipment are given in Chapters 2 to 10.

However, in selecting equipment engineers need information about the properties of materials, corrosion, process control, batch versus continuous and economics. We refer to this as the context for the chemical process and provided rules of thumb for each in Sections 1.2 to 1.7, respectively.

Rules of thumb for the thinking process used, or **how** engineers design and practice their skills, were given in Sections 1.8 to 1.16. More specifically the emphasis was on problem solving, goal setting, decision making, thermal pinch, systems thinking, process design, process improvement, trouble shooting and health-safety-environment issues, respectively.

Sections 1.17 to 1.20 summarized the rules of thumb for the people part of engineering (communication, listening, interpersonal skills and team work).

Finally, the context in which engineers function (performance review, leadership, entrepreneurship, entrepreneurship, e-business and self management) were described in Sections 1.21 to 1.26.

References

- Cooper, R.G. (1987) "Winning with New Products" Gage Publishing, Agincourt, Ontario.
- Covey, S.R. (1989) "The Seven Habits of Highly Effective People", Simon and Schuster, New York.
- Curren, Alex (1991) "Making Ventures Succeed: Earning the Right to Succeed in Business," Curren Publishing, Oakville, Ontario.
- Doyle, D.J. (1983) "Making Technology Happen", Doyletech, Kanata, Ontario.
- Fisher, K. et al. (1995) "Tips for Teams", McGraw Hill, New York.
- Francis, D., Young, D. (1979) "Improving Work Groups: A Practical Manual for Team Building", University Associates, San Diego.
- Holmes, T.H., Rahe, R. H. (1967) "The Social Readjustment Rating Scale," J. Psychosomatic Res., Aug., 213–218.
- Kirton, M. (1976) "Adaptors and Innovators: a description and measure", J. Appl. Psychol., 61, no. 5, 622–629.
- Valikangas, Liisa (2003) "Manage Innovation as a Corporate Capability" Chem. Eng. Prog., Jan. pp. 64 –69.
- Woods, D.R., Ormerod, S. D. (1993) "Networking: How to Enrich Your Life and Get Things Done" Pfeiffer & Co., San Diego.