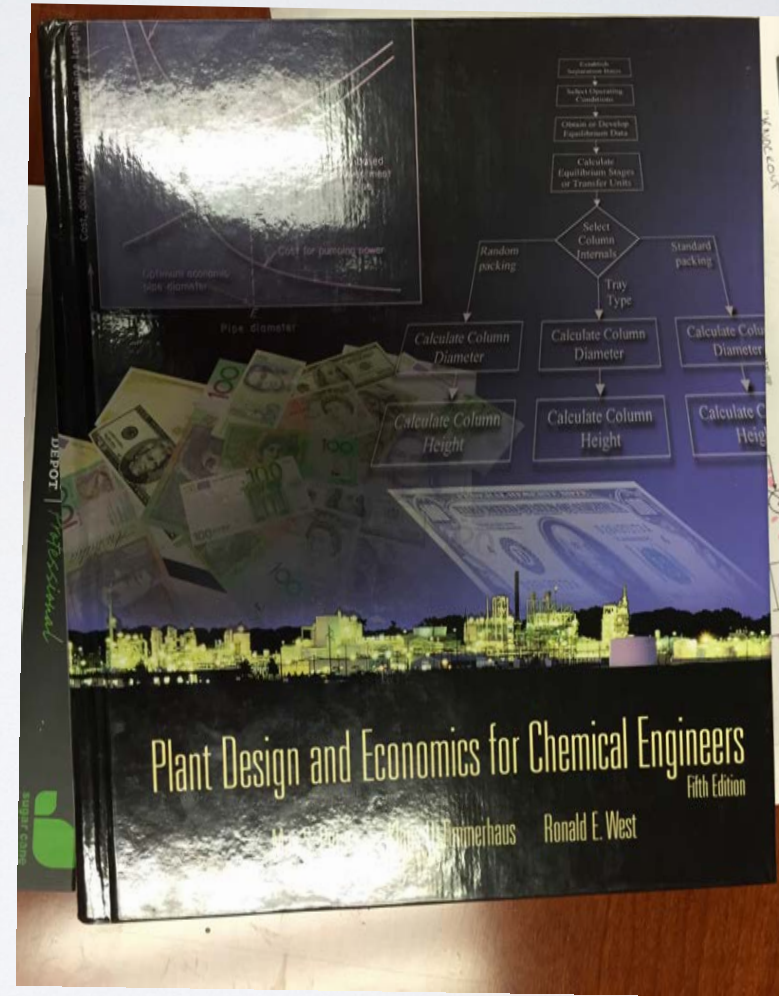
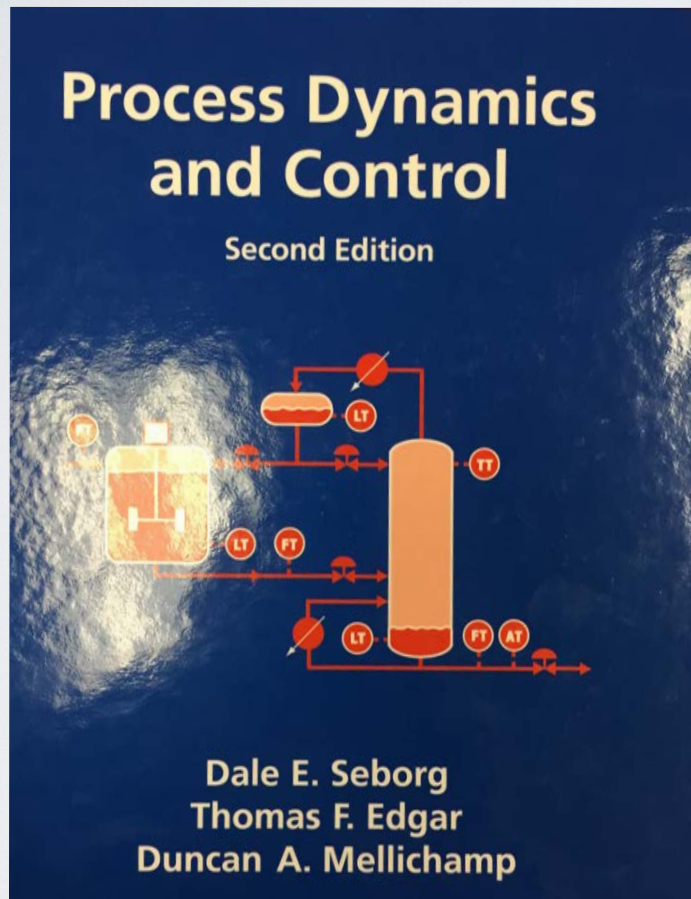


P&I DIAGRAMS PROCESS CONTROL

Mark J McCready
University of Notre Dame
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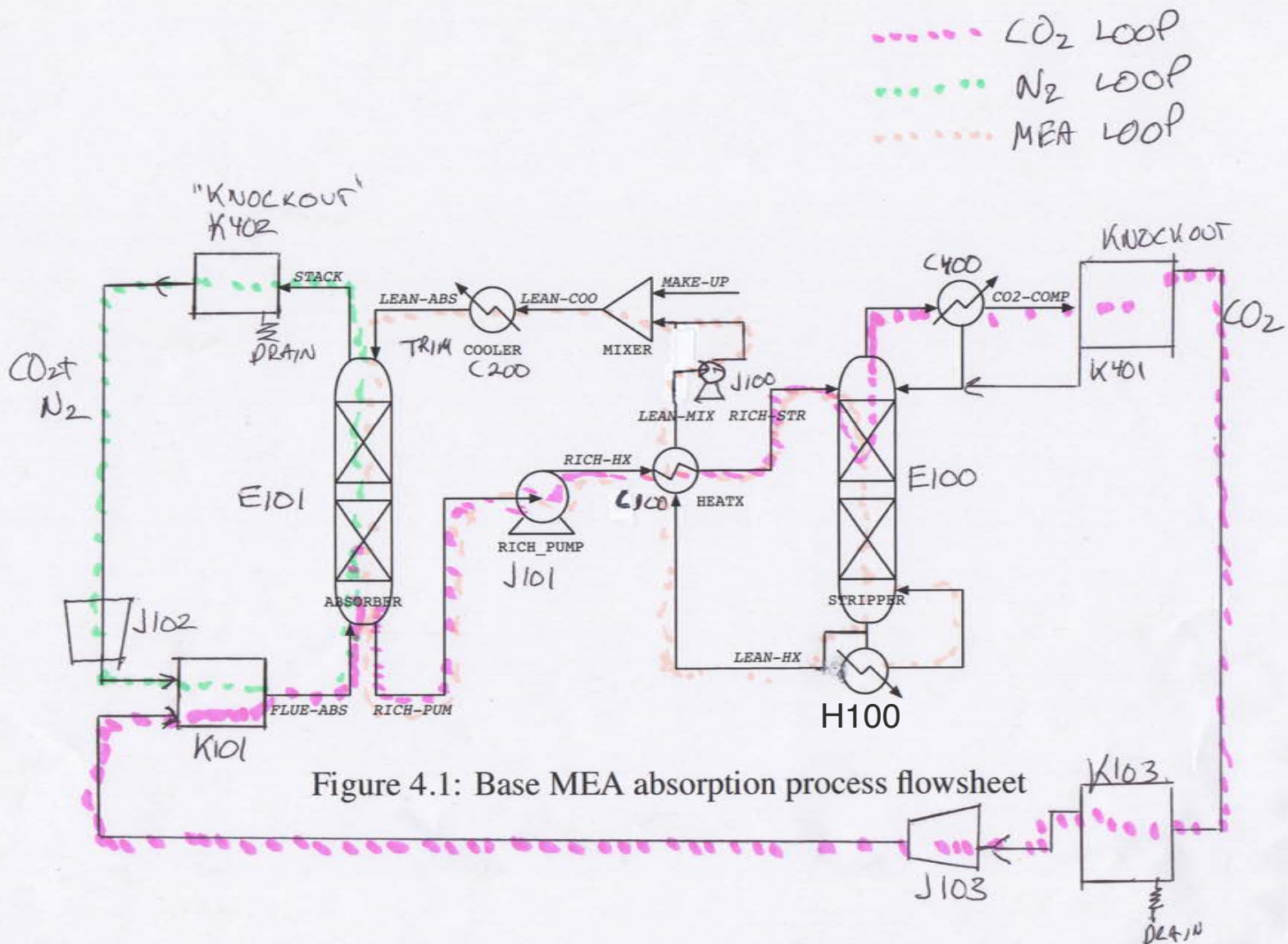
PARTIAL REFERENCES FOR TODAY



GAS ABSORPTION/STRIPPING

- Mass transfer is the main “business” of the process!
- The absorber is a column packed with a structured packing
 - Inlet gas mixture of N_2 and CO_2
 - Absorption liquid is monoethanolamine in water
 - reacts reversibly with CO_2 , to selectively remove CO_2 from N_2
- The stripping column is packed with a random, metal packing
 - Steam flow to reboiler, boils the mixture, reversing the reaction and the steam that is generated helps to carry the CO_2 out of the column

IMPERIAL FLOWSHEET



PIPING AND INSTRUMENTATION DIAGRAMS

- Intended to show the details of all pipes, valves, sensors/transducers of the process.
- If it were “your” process, you would want to know everything.
- There may be bypasses, multiple pumps, extra valves, heat exchangers in series, backup thermocouples, ...
 - that are not shown on the process flow diagram but might be important in an emergency or just for maintenance.
- The Imperial Instructors take this knowledge of the hardware very seriously so you will get a lot of time to trace every connection in the plant.

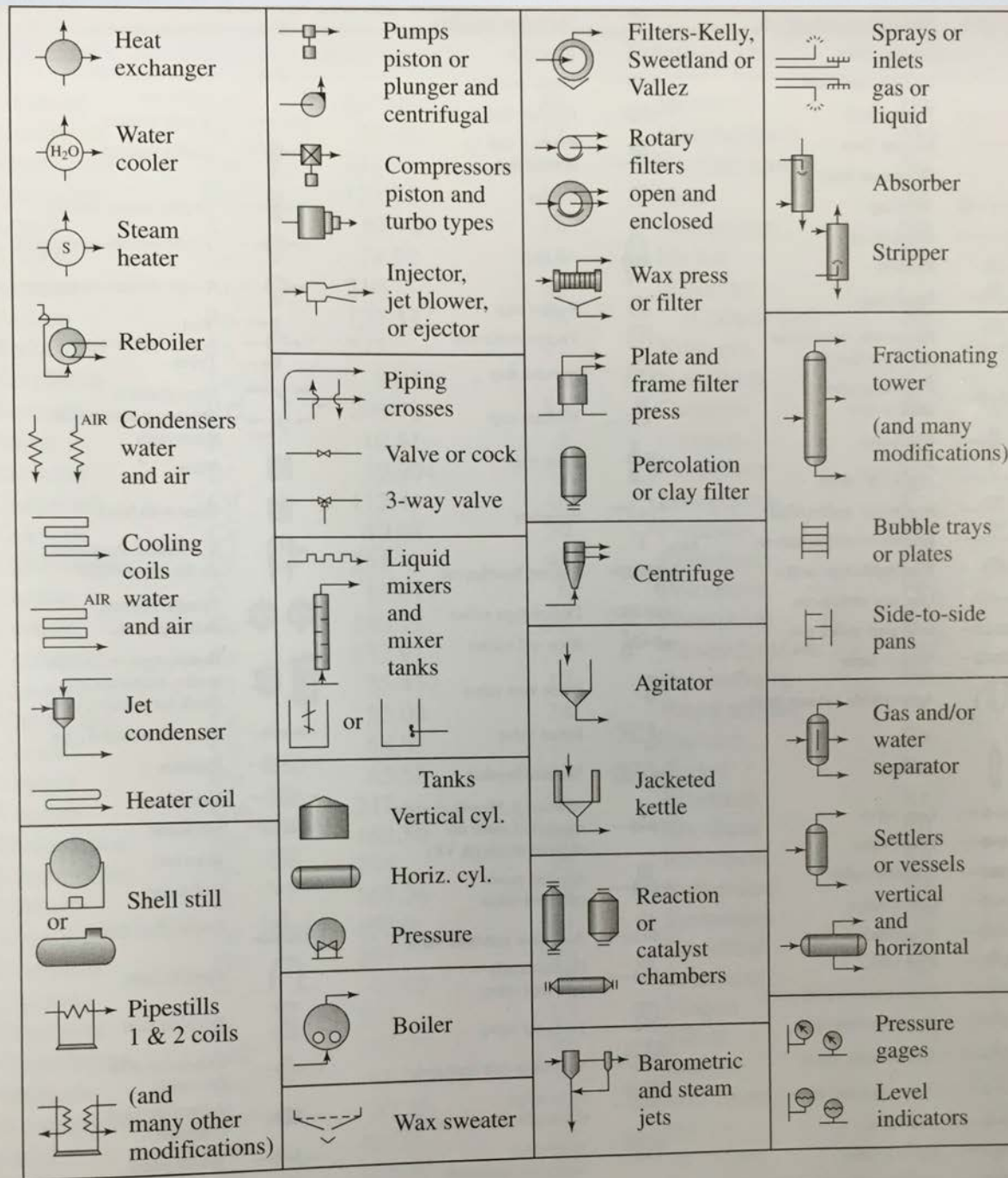


Figure D-5
Equipment symbols

Symbol	Description
	Lines crossing battery limit
	New lines or revamp job
	Existing lines
	Underground lines
	Battery limit
	Internal lines
	Instrument lines
	Weld cap
	Screwed cap
	Reducer
	Spool piece
	Removable spool piece and blind flanges
	Reversible elbow (serv. conn.)
	Line blind
	Figure "8" blind
	Restriction orifice (flgd)
	Restriction orifice (union)
	Removable type orifice
	Line size orifice run
	Increased orifice run
	Venturi meter
	Atmospheric exhaust head
	Silencer
	Gate valve
	Globe valve
	Lubrotite valve
	Check valve
	Stop check
	Plug valve
	Nonlubricated plug valve
	Quick opening valve
	Self-draining valve
	Chain operated valve
	Reel valve
	Quench valve
	Needle or V-port valve
	Angle nonreturn valve
	Angle valve
	Angle check valve
	4-way valve
	3-way valve
	Rotameter

Symbol	Description
	Flow quantity or displacement meter
	Sight flow indicator
	Pitot tube
	Flame arrestor
	Rupture disk in line
	Rupture disk to atmosphere
	Burner
	Air trap
	Bucket trap
	Thermostatic trap
	Impulse trap
	Vacuum trap
	Float trap
	Separator
	Ejector, booster, etc
	Durion-type mixer
	Blow-off valves
	Varec vent valve
	Relief valve
	Vacuum breaker
	Atwood & Morrill straight thru relief valve on exhaust steam (& VE)
	Electric motor operated valve
	Air motor operated valve
	Hydraulically operated valve
	Solenoid valve
	Side valve (air operated)
	Slide valve (hydraulically operated)
	Slide valve (manually operated)
	Butterfly valve
	3-way control valve
	Angle type control valve
	Control valve assembly Gate va. or globe va.
	Foot valve
	Tempering valve (TGeo Type "A")
	CSO = car seal open CSC = car seal closed

Symbol	Description
	Plugged valve
	Blind connection
	Hose connection
	Serv. conn. = service connection; S.O. = steam out
	Y-type strainer
	Basket strainer
	Duplex basket strainer
	T-type strainer (permanent)
	T-type strainer (temporary)
	Vent Slurry type strainer Drain
	Dual strainers Omit on underground water lines
	Filter
	Filter with hood
	R.P. Adams Poro-stone air filter type "TR"
	Tubular coolers, exchangers etc.
	Double type or fin type cooler, exchange, etc. Stack for multiple units
	Air-cooled finned pipe
	Radiator
	Unit heater
	Fin heater
	Blast coil
	Coil heater
	Cooler (box type)
	Flexible hose
	Rotation joint
	Expansion joint (external)
	Expansion joint (internal)
	Splash guard
	Drinking fountain
	Water bubbler
	Eye wash fountain
	Shower head
	Open drain
	Material furnished by others to be noted on drawing thus

Figure D-6

Flowsheet symbols, particularly for detailed equipment flowsheets. (Courtesy of the

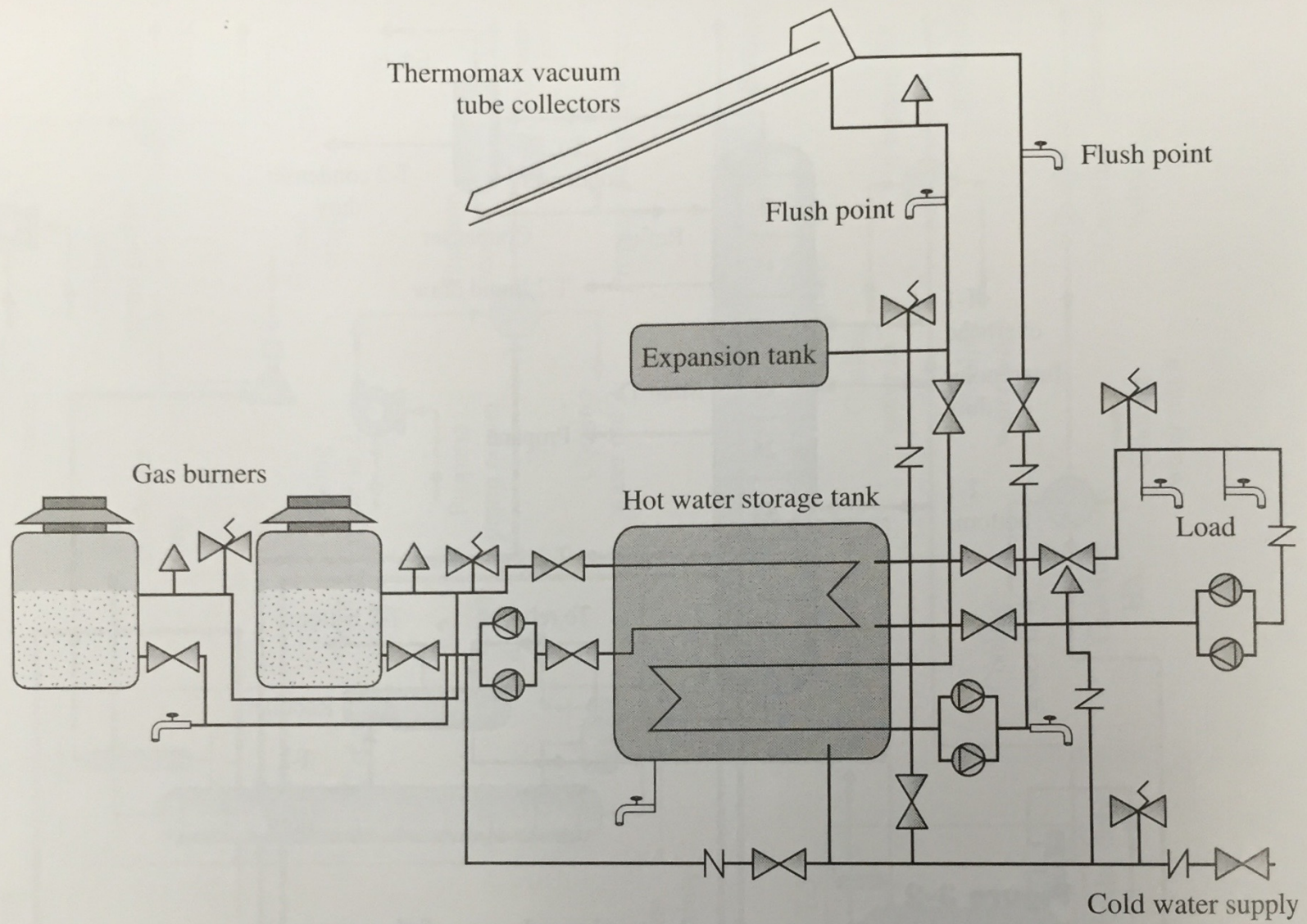
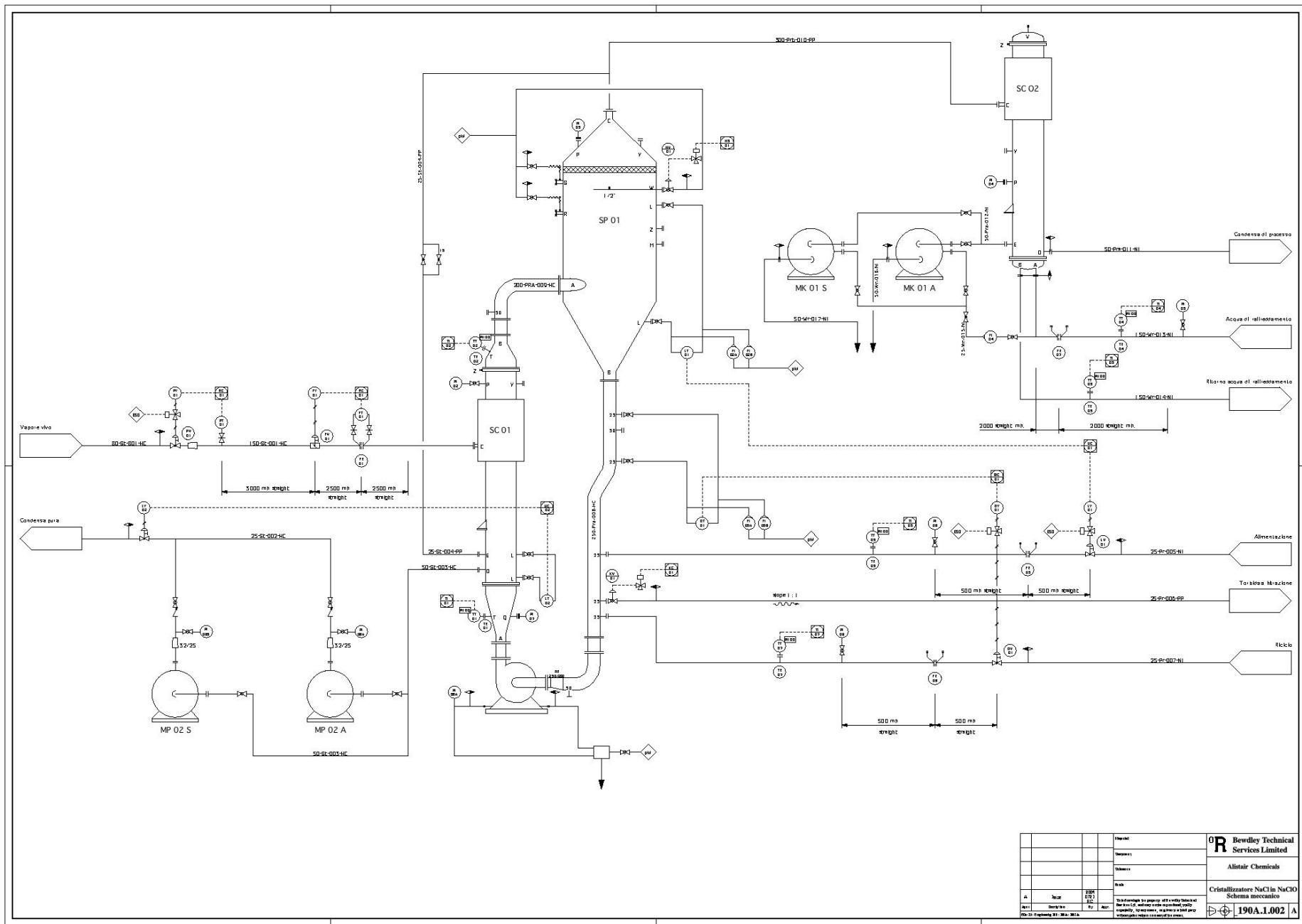


Figure 3-3
Piping and instrumentation diagram for a commercial integrated solar water heating system



Rev:	01	Issue:	1	Drawn:		Checked:		Approved:	
<p>OR Bewley Technical Services Limited</p> <p>Alstair Chemicals</p> <p>Cristallizzatore NaCl in NaClO</p> <p>Schema meccanico</p> <p>190A.1.002 A</p>									

IMPERIAL FLOWSHEET

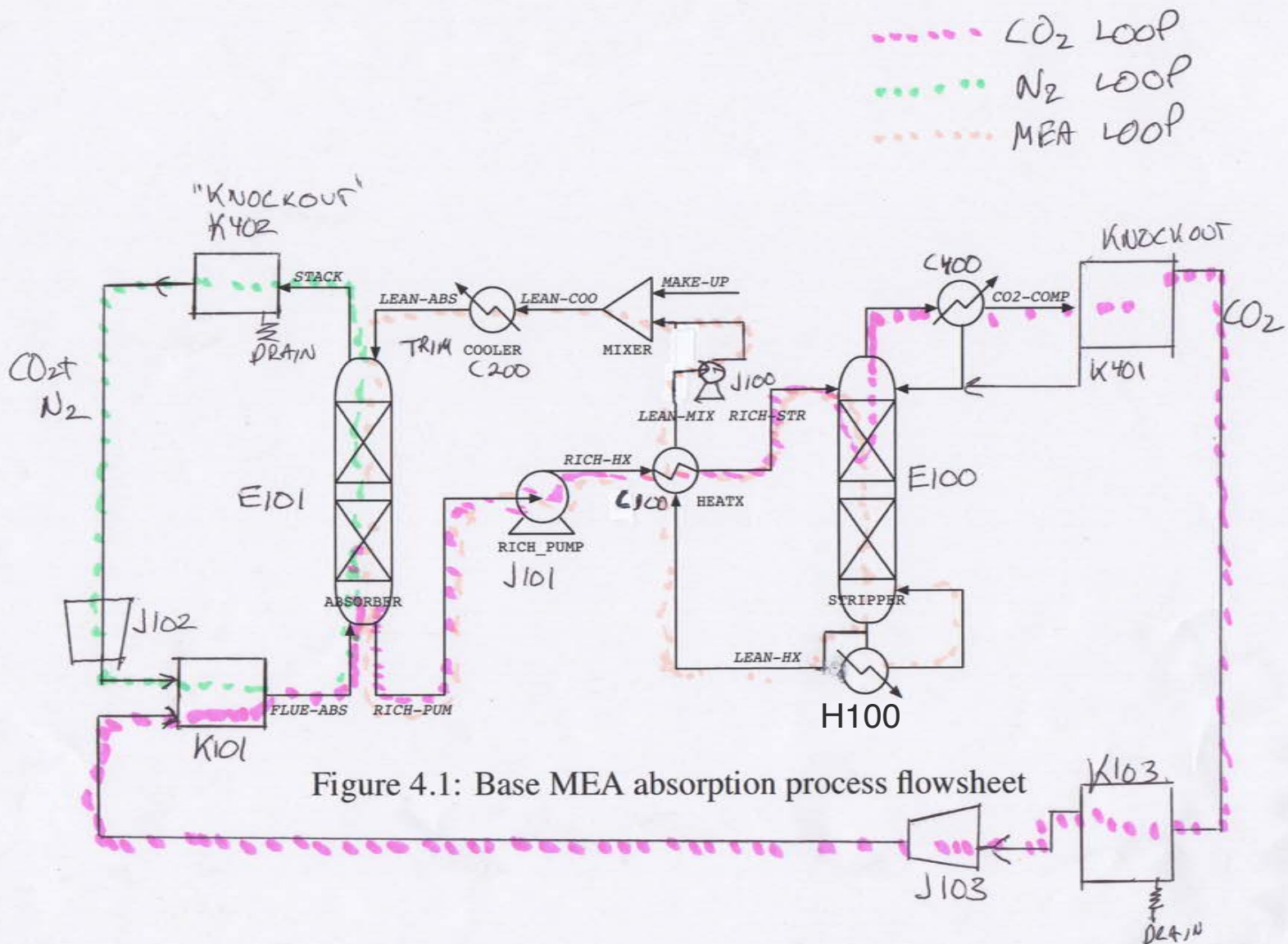
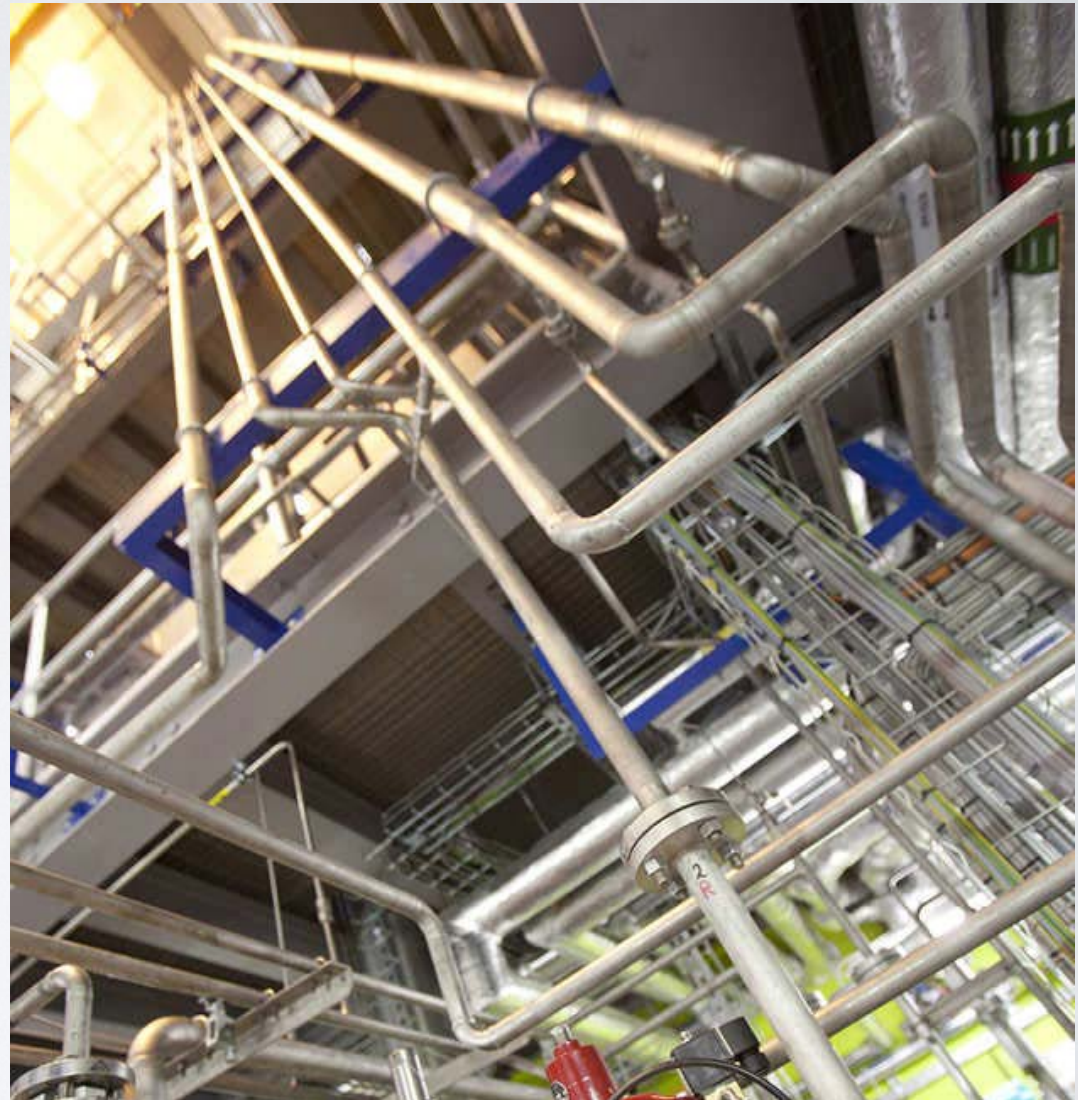
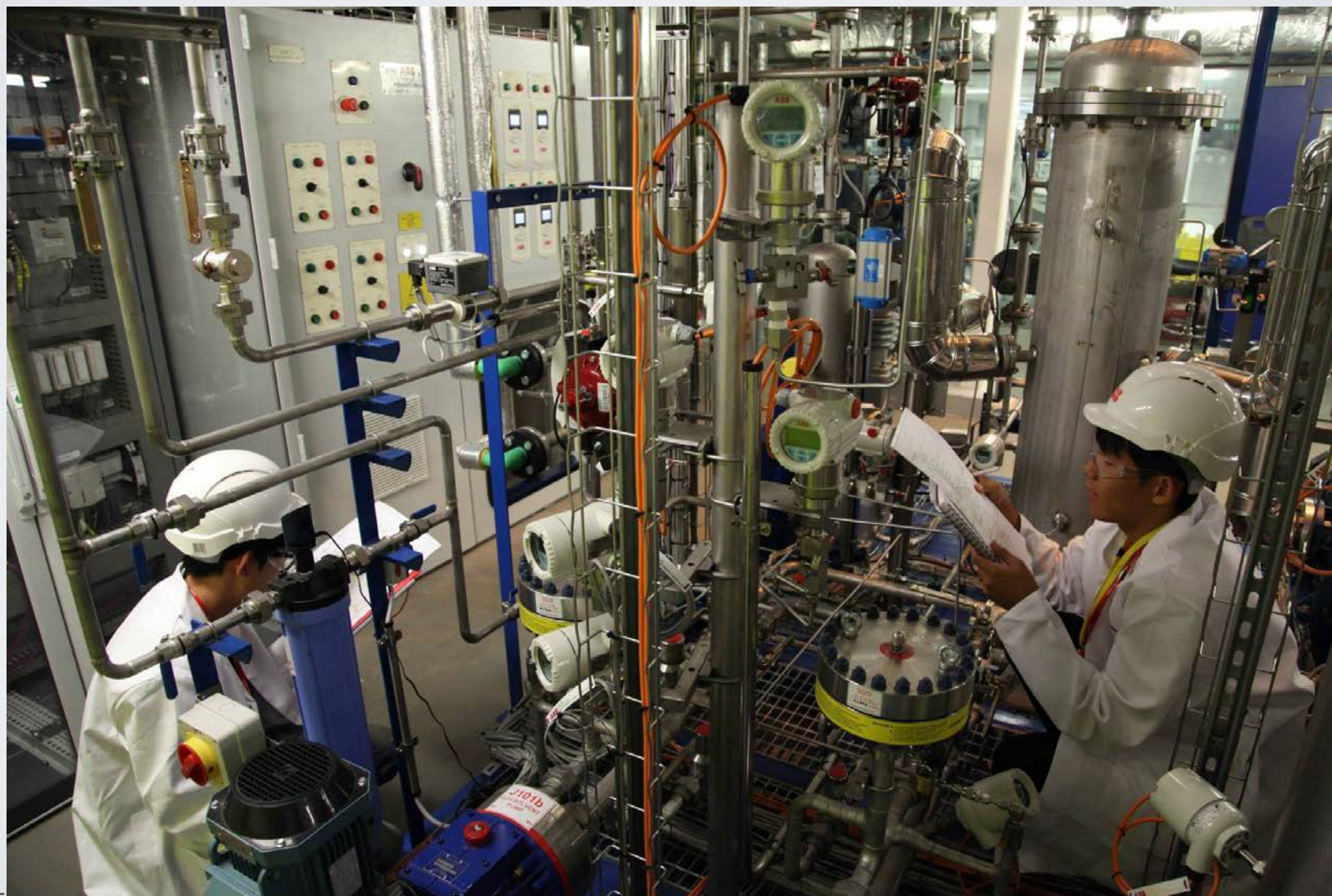


Figure 4.1: Base MEA absorption process flowsheet

PIPES!



CABLES, TRANSDUCERS, THERMOCOUPLES





INFRA-RED SPECTROSCOPY

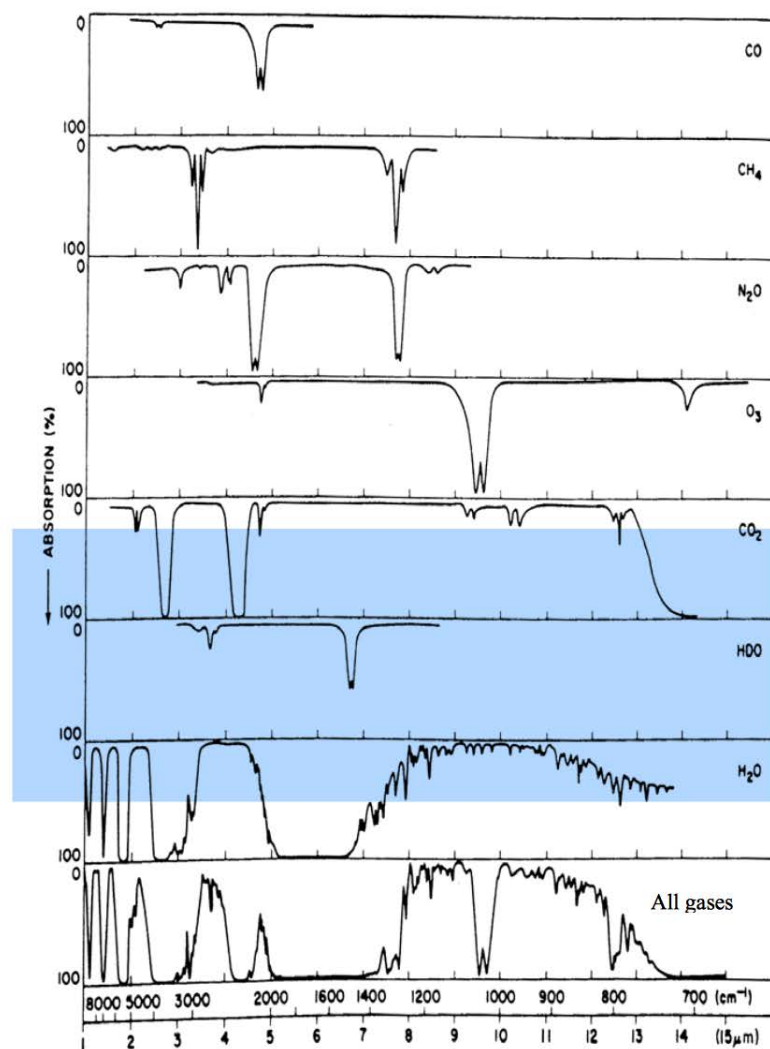


Figure 6.2 *Low-resolution* infrared absorption spectra of the major atmospheric gases.
(compare to Figure 6.3 that shows transmission with higher spectral resolution)

CONTROL: DRIVING A CAR

- If we just stick the basic situation...
 - You are driving a car on a “test track” with no other cars.
 - The goal is to drive a preferred “line” at constant speed.
 - How could this be accomplished?

DRIVING CAR

- Feedback control
 - You could be watching or listening to see/hear if you are “on” the track (or preferred “line”)
 - Yes: do nothing, No: turn wheel $1/12$ turn in correct direction (on/off)
 - Pretty crude and might not get you back *on* in time
 - You could have in mind a range of paths that are more or less desirable. As you get further away from a more desirable position, you correct harder
 - The second might work, but you could be *surprised* if the path changes

DRIVING CAR

- Feedforward Control
 - You look at the road ahead and turn the wheel according to a specified set of rules or equations that are presumed to be adequate to keep the car on track. In the simplest idealization you are not looking at where you are on the road, only what is coming up.
 - The ability to anticipate is certainly a benefit and if all goes well could get the car almost exactly on track
 - If something goes wrong, e.g., the road has bumps or some slope, then the specified turning won't work perfectly.

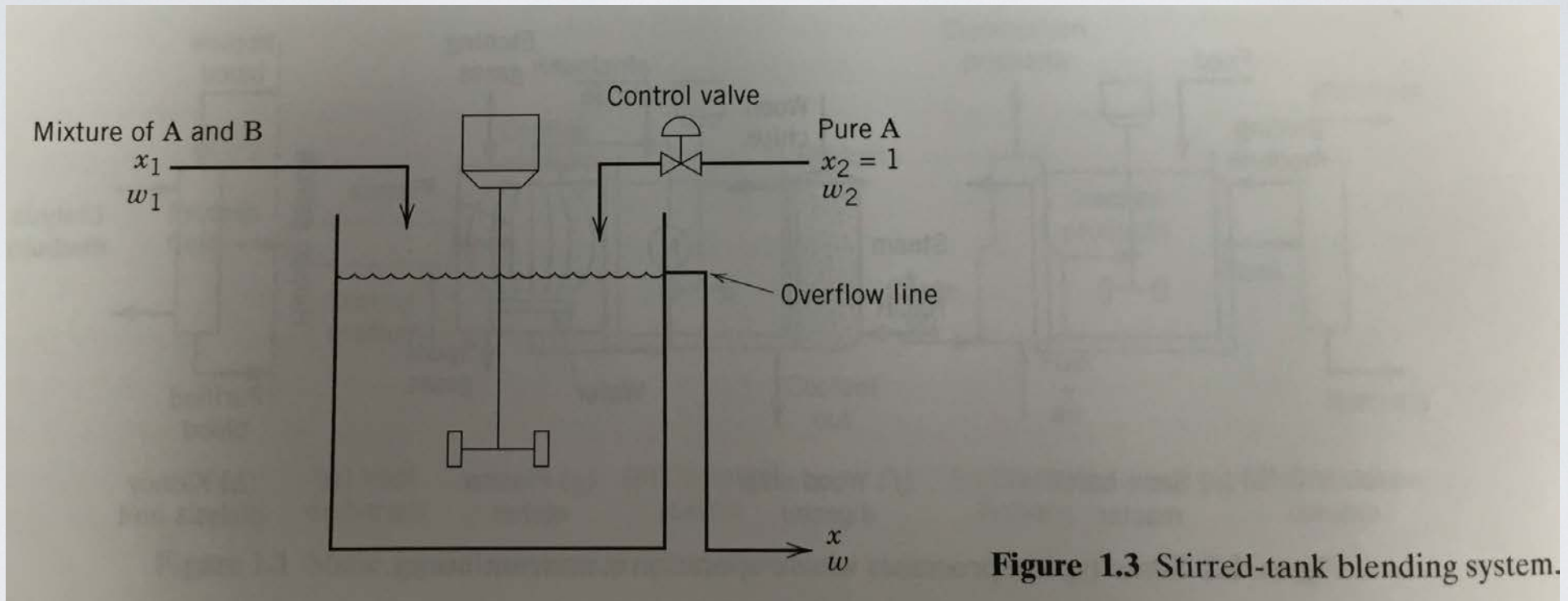
DRIVING A CAR

- We could also mention: Sensitivity/stability
 - Let's not..
 - or just say you will have to drive different vehicles differently!
- So what you really use is a combination of feedback and feedforward control
 - With feedback you use a complex algorithm that includes thinking of how fast the car is returning to the path.

PROCESS CONTROL

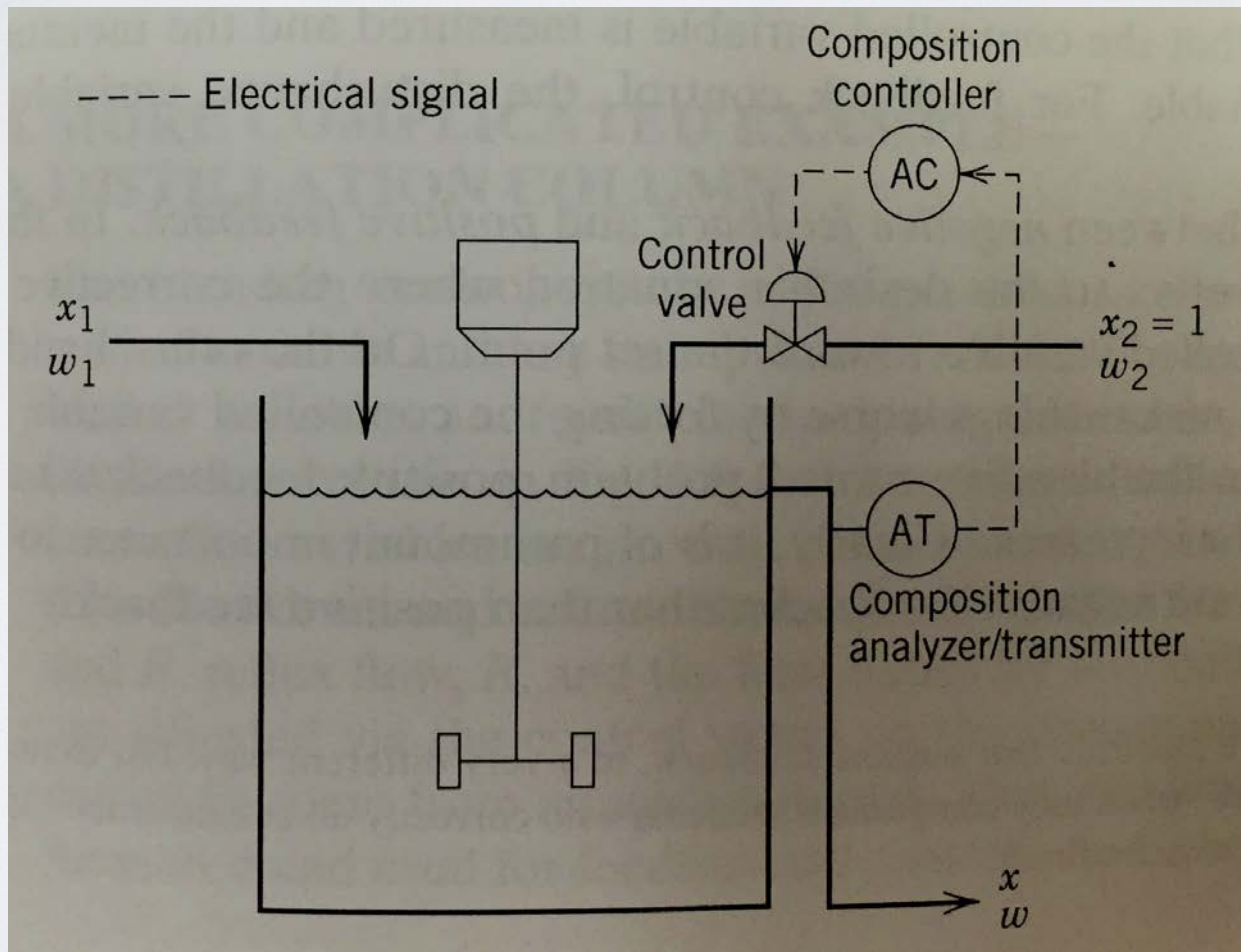
- These same principles apply to chemical processes.
 - Feedback to make sure you are on track
 - Feedforward to anticipate “upsets” — that could be caused by fluctuations in the feed concentration or temperature
- For either driving or a chemical process, you need specifications (e.g., concentration) from which you create “setpoints”.

SIMPLE PROCESS EXAMPLE

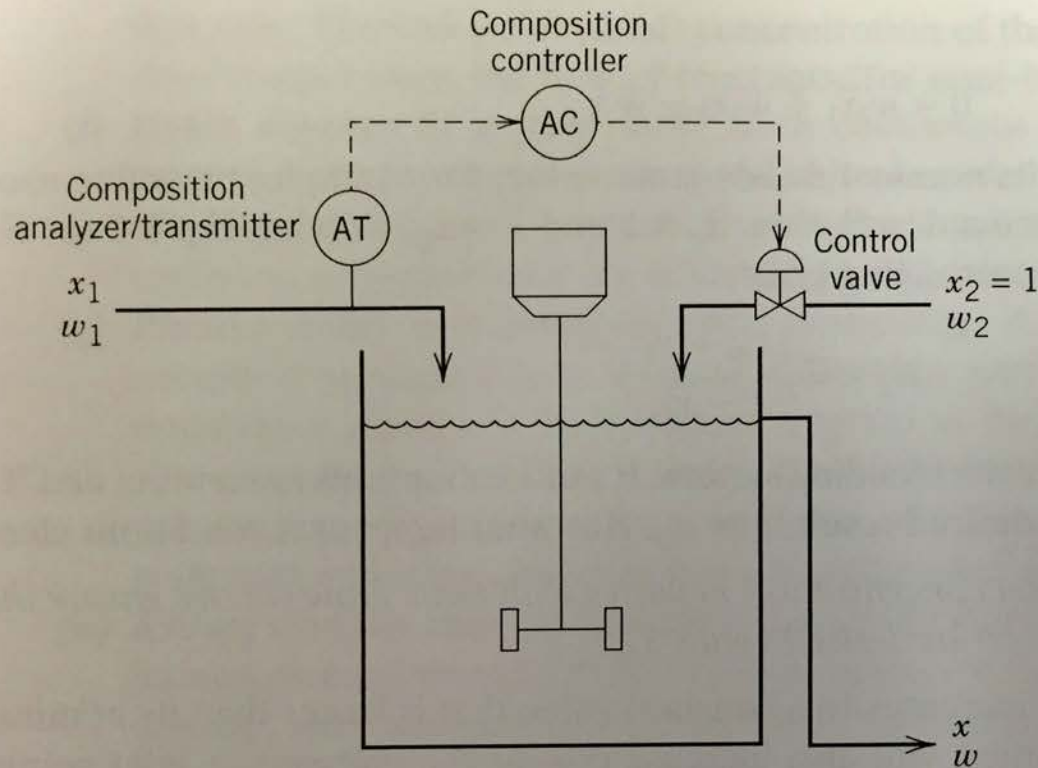


We are changing the relative concentration of A and B in a blending process

FEEDBACK: MEASURE OUTPUT, ADJUST “A” INPUT TO KEEP ON “SPEC”



FEEDFORWARD

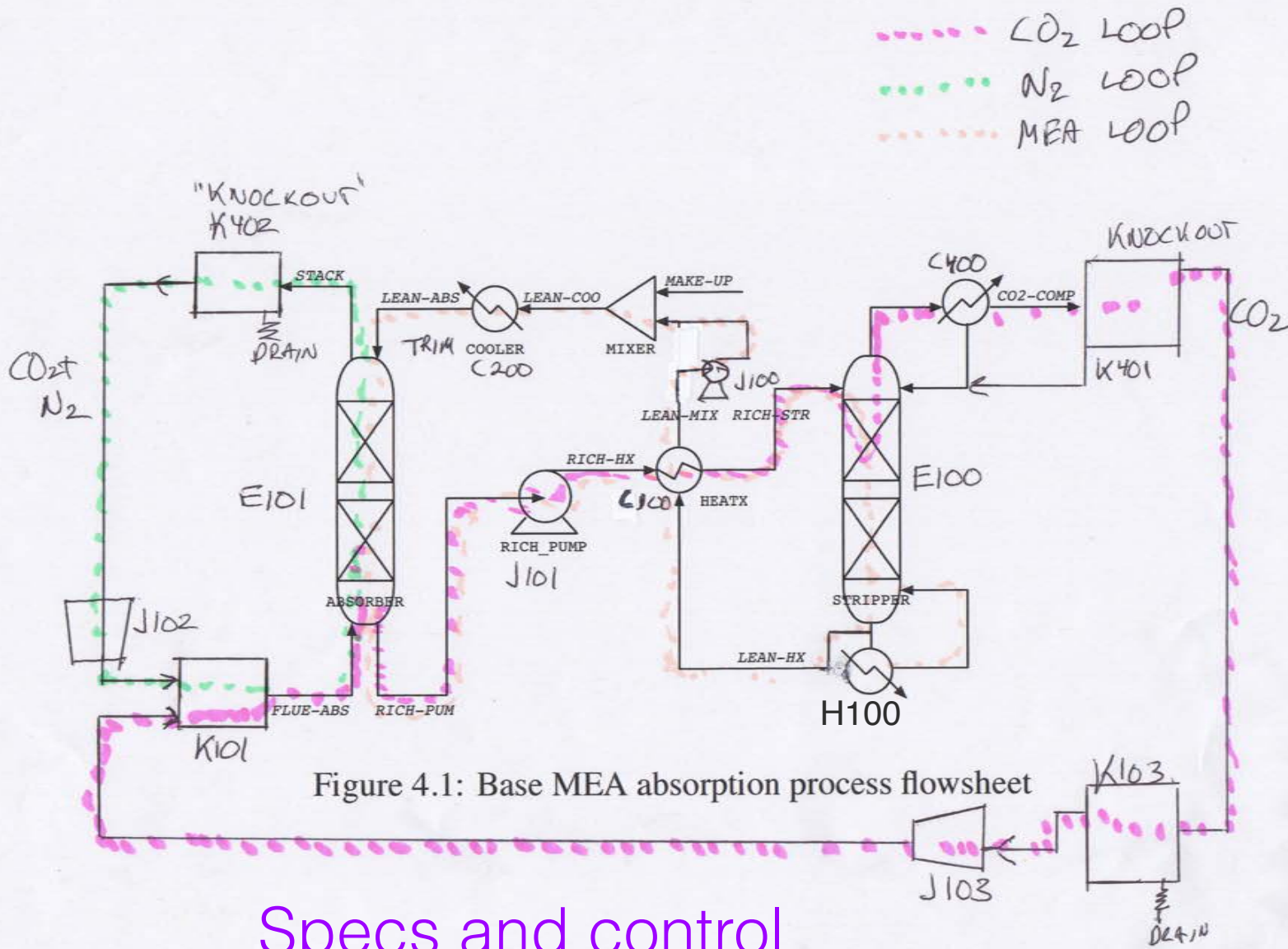


Measure input, adjust flow to match what is *apparently* needed to keep output on “spec”

Figure 1.5 Blending system and Control Method 2.

Method 2. Measure x_1 , adjust w_2 . As an alternative to Method 1, we could measure disturbance variable x_1 and adjust w_2 accordingly. Thus, if $x_1 > \bar{x}_1$, we would decrease w_2 so that $w_2 < \bar{w}_2$. If $x_1 < \bar{x}_1$, we would increase w_2 . A control law based on Method 2 can be derived from Eq. 1-3 by replacing \bar{x}_1 with $x_1(t)$ and \bar{w}_2 with $w_2(t)$:

OUR PROCESS



Specs and control

EXPECTED “SPECS”

- CO₂ concentration in Absorber exit is below ~1% or 5%
- Either because the other gas needs a specified purity or because you are required to remove a certain fraction of the CO₂
 - adjust temperature of input MEA stream (easy)
 - adjust flow rate of input MEA stream (easy, but propagates back through the process and changes concentration only in certain ranges)
 - remove more CO₂ from MEA in stripper

For dilute systems:

$$z = H_{OG}N_{OG} = H_{OG} \int_{y_2}^{y_1} \frac{dy}{y - y^*}$$

$$H_{OG} = \frac{V}{K'_y a S} = \frac{V}{K_y a (1 - y)_M S}$$

- V is the gas flow rate in moles/time
- K'_y is the appropriate mass transfer coefficient
- a is the area of gas-liquid contact per volume of packed bed
- S is the cross sectional area of the column
- y is the mole fraction of the component in the gas
- y^* is the equilibrium value of the transferring gas component in the liquid.

EXPECTED SPEC

- Nitrogen in exit CO₂ stream
 - Change temperature in absorber
- Water vapor in exit CO₂ stream
 - More/colder water in condenser

PROPAGATED EFFECT

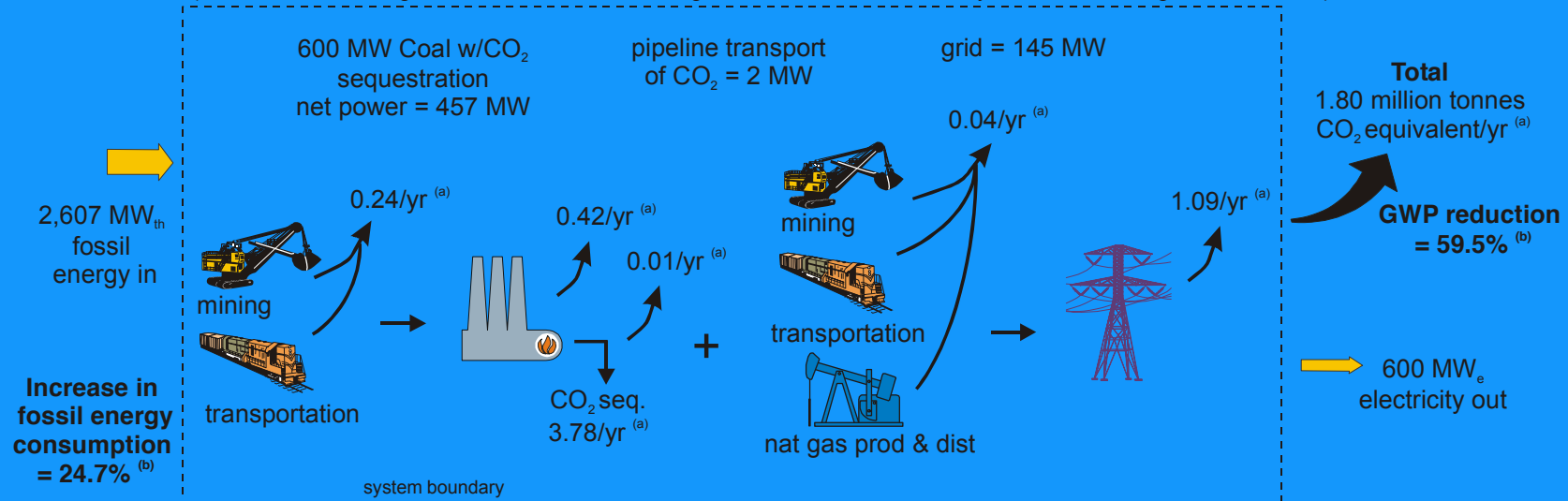
- If you change the MEA flowrate or want to change the concentration of CO_2 in the MEA feed, the reboiler steam rate will have to be adjusted

REVIEW

COAL/W SEQUESTRATION (+NG)

Figure 3: Coal-fired Power Plant with CO₂ Sequestration and 145 MW of Grid Capacity Added to Maintain 600 MW

(U.S. mid-continental grid mix is 64.7% coal, 5.1% lignite, 18.4% nuclear, 10.3% hydro, 1.4% natural gas, and 0.1% oil)



Notes: (a) GHGs (CO₂, CH₄, and N₂O) expressed in million tonnes CO₂-equivalents/yr at 100% capacity; (b) Change in GWP and change in fossil energy consumption compared to reference

PROCESS DIAGRAM

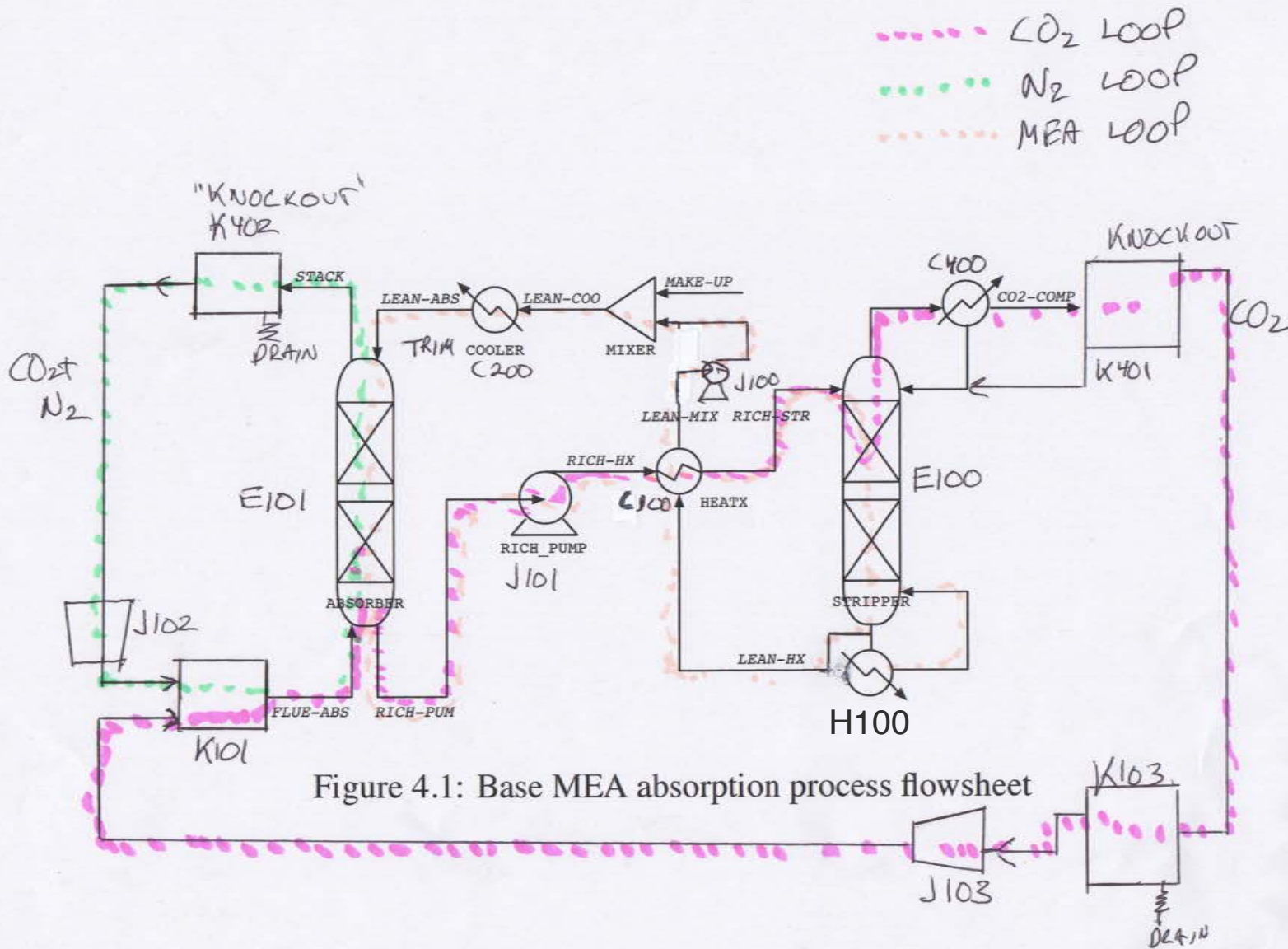


Figure 4.1: Base MEA absorption process flowsheet

CARBON DIOXIDE ABSORPTION FROM A GAS MIXTURE

- Why do: To get “pure” CO₂
- Reversible, cyclical process:
 - CO₂ (selectively) dissolves in (lean) MEA solution in the absorber
 - reversible chemical reaction greatly increases solvent capacity and selectivity
 - MEA solution is pumped to the “stripper” where heat (from steam) is used to reduce the CO₂ solubility (and reverse the reaction) so that CO₂ (now) without N₂ will come off.
- Usually need to hit a “spec” on CO₂ emitted.
- Need efficient contacting of gas and liquid
- CO₂ capacity per mass of solvent significantly influences the cost
- Energy to regenerate influences cost

ANALYSIS: TWO BASIC PRINCIPLES

- Conservation of mass
 - Keep track of chemical species in the two different flows
- Rate of interphase transfer equation
 - Analogous to Newton's Law of cooling
 - Driving force is a concentration difference:
 - Gas-liquid phase equilibria may include reaction

MECHANISMS OF MASS TRANSFER

- *Diffusion* (analogous to *Conduction* in heat transfer)
 - Transport by random molecular motion gases and liquids.
 - Fick's Law: $j = D \frac{\partial C}{\partial x}$ (same as Fourier's Law)
- *Convection* (essentially the same as *Convection* in heat transfer)
 - Transport by net motion of fluid. (molecular motion that is correlated, not random)
 - Describe using analog to Newton's law of cooling

$$N_A = k A (C_{gas} - C^*)$$

SUMMARY OF HEAT TRANSFER FUNDAMENTALS

- Three modes of heat transfer can occur:
 - Radiation (electromagnetic radiation) $q \sim \epsilon \sigma (T^4 - T_0^4)$
 - Conduction (random motion of molecules, atoms and electrons) $q \sim k_A \frac{\Delta T_A}{l}$
 - Convection (heat transfer that is aided by bulk fluid motion)

HEAT EXCHANGER SUMMARY

- Heat exchangers are first analyzed using an energy balance

$$\dot{m}_c d\hat{T}_c = \dot{m}_c c_p dT_c = dq_c$$

- The rate of transfer across the walls is modeled using Newton's Law of cooling $q' = hA(T_w - T_\infty)$

- We get individual h 's from correlations

$$Nu = 0.023 Re^{.8} Pr^{.4}$$

- We get a U 's from a sum of resistances

$$\frac{1}{U_i} = \frac{1}{h_i} + \frac{A_i}{k\Delta r} + \frac{A_i}{h_o A_o}$$

- Because the temperature difference between the two sides of the heat exchanger is changing along the pipe, we formulate the problem as a differential slice of pipe and integrate. This gives the temperature driving forces as a "Log-Mean delta T"

$$\frac{\Delta T_2 - \Delta T_1}{\ln\left(\frac{\Delta T_2}{\Delta T_1}\right)}$$

FLUID FLOW SUMMARY

- Pipe sizing and piping system design is done based on the pressure drop — flow rate behavior that occurs
- This is well known and for simple fluids is captured in the single plot of friction factor and Reynolds number
- To design an entire pipe system and to determine the power necessary for pumping, the Engineering Bernoulli Equation is used.

BERNOULLI EQUATION

- To include gravity, friction from all of the straight sections of pipe and the pressure change associated with all of the fittings, the typical equation that is most convenient is the “Engineering Bernoulli Equation”
- This can be derived from the first and second laws of thermodynamics and the equation can be applied between any 2 “continuous flow paths” in a process system.

$$\left(\frac{V_2^2}{2} - \frac{V_1^2}{2} \right) + g(h_2 - h_1) + \frac{P_2 - P_1}{\rho} = \delta W_s - l_v$$

THIS FORMULATION WORKS! DATA FOR LAMINAR AND TURBULENT PIPE FLOW

