Following is a diagram of the shirt-cleaning process used by the Floods of Suds One-Day Laundry Services, Inc. The shirts are soaked in an agitated tub containing Whizzo, the Wonder Detergent, and are then wrung out and sent to a rinse stage. The dirty Whizzo is sent to a filter in which most of the dirt is removed, and the cleaned detergent is recycled back to join a stream of pure Whizzo, with the combined stream serving as the feed to the washtub.
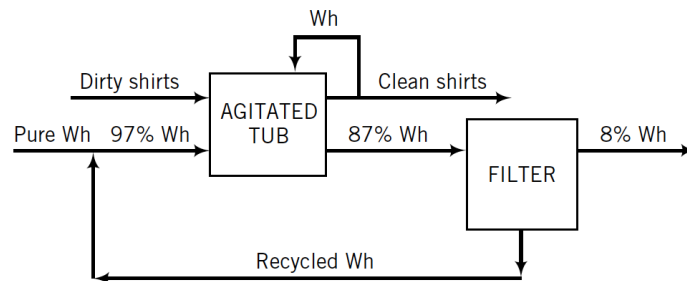
Data:

1. Each 100 lb_m of dirty shirts contains 2.0 lb_m of dirt.
2. The washing removes 95% of the dirt in the dirty shirts.
3. For each 100 lb_m of dirty shirts, 25 lb_m of Whizzo leaves with the clean shirts, of which 22 lb_m is wrung back into the tub.
4. The detergent that enters the tub contains 97% Whizzo, and that which enters the filter contains 87%. The wet dirt that leaves the filter contains 8.0% Whizzo.

(a) How much pure Whizzo must be supplied per 100 lb_m of dirty shirts?
(b) What is the composition of the recycled stream?

3.17 lb_m Whizzo

96% Whizzo, 4% dirt

A drug (D) is produced in a three-stage extraction from the leaves of a tropical plant. About 1000 kg of leaf is required to produce 1 kg of the drug. The extraction solvent (S) is a mixture containing 16.5 wt% ethanol (E) and the balance water (W). The following process is carried out to extract the drug and recover the solvent.

1. A mixing tank is charged with 3300 kg of S and 620 kg of leaf. The mixer contents are stirred for several hours, during which a portion of the drug contained in the leaf goes into solution. The contents of the mixer are then discharged through a filter. The liquid filtrate, which carries over roughly 1% of the leaf fed to the mixer, is pumped to a holding tank, and the solid cake (spent leaf and entrained liquid) is sent to a second mixer. The entrained liquid has the same composition as the filtrate and a mass equal to 15% of the mass of liquid charged to the mixer. The extracted drug has a negligible effect on the total mass and volume of the spent leaf and the filtrate.

2. The second mixer is charged with the spent leaf from the first mixer and with the filtrate from the previous batch in the third mixer. The leaf is extracted for several more hours, and the contents of the mixer are then discharged to a second filter. The filtrate, which contains 1% of the leaf fed to the second mixer, is pumped to the same holding tank that received the filtrate from the first mixer, and the solid cake—spent leaf and entrained liquid—is sent to the third mixer. The entrained liquid mass is 15% of the mass of liquid charged to the second mixer.

3. The third mixer is charged with the spent leaf from the second mixer and with 2720 kg of solvent S. The mixer contents are filtered; the filtrate, which contains 1% of the leaf fed to the third mixer, is recycled to the second mixer; and the solid cake is discarded. As before, the mass of the entrained liquid in the solid cake is 15% of the mass of liquid charged to the mixer.

4. The contents of the filtrate holding tank are filtered to remove the carried-over spent leaf, and the wet cake is pressed to recover entrained liquid, which is combined with the filtrate. A negligible amount of liquid remains in the wet cake. The filtrate, which contains D, E, and W, is pumped to an extraction unit (another mixer).

5. In the extraction unit, the alcohol–water–drug solution is contacted with another solvent (F), which is almost but not completely immiscible with ethanol and water. Essentially all of the drug (D) is extracted into the second solvent, from which it is eventually separated by a process of no concern in this problem. Some ethanol but no water is also contained in the extract. The solution from which the drug has been extracted (the **raffinate**) contains 13.0 wt% E, 1.5% F, and 85.5% W. It is fed to a stripping column for recovery of the ethanol.

6. The feeds to the stripping column are the solution just described and steam. The two streams are fed in a ratio such that the overhead product stream from the column contains 20.0 wt% E and 2.6% F, and the bottom product stream contains 1.3 wt% E and the balance W.

Draw and label a flowchart of the process, taking as a basis one batch of leaf processed. Then calculate

(a) the masses of the components of the filtrate holding tank.
(b) the masses of the components D and E in the extract stream leaving the extraction unit.
(c) the mass of steam fed to the stripping column, and the masses of the column overhead and bottoms products.

5540 kg solvent

211 kg (ethanol in extract)

3121 kg (mass of stripper overhead product)

6085 kg (mass of stripper bottom product)

3796 kg steam fed to stripper

In an **absorption tower** (or **absorber**), a gas is contacted with a liquid under conditions such that one or more species in the gas dissolve in the liquid. A **stripping tower** (or **stripper**) also involves a gas contacting a liquid, but under conditions such that one or more components of the feed liquid come out of solution and exit in the gas leaving the tower.

A process consisting of an absorption tower and a stripping tower is used to separate the components of a gas containing 30.0 mole% carbon dioxide and the balance methane. A stream of this gas is fed to the bottom of the absorber. A liquid containing 0.500 mole% dissolved CO_2 and the balance methanol is recycled from the bottom of the stripper and fed to the top of the absorber. The product gas leaving the top of the absorber contains 1.00 mole% CO_2 and essentially all of the methane fed to the unit. The CO_2-rich liquid solvent leaving the bottom of the absorber is fed to the top of the stripper and a stream of nitrogen gas is fed to the bottom. Ninety percent of the CO_2 in the liquid feed to the stripper comes out of solution in the column, and the nitrogen/CO_2 stream leaving the column passes out to the atmosphere through a stack. The liquid stream leaving the stripping tower is the 0.500% CO_2 solution recycled to the absorber.

The absorber operates at temperature T_a and pressure P_a and the stripper operates at T_s and P_s. Methanol may be assumed to be nonvolatile—that is, none enters the vapor phase in either column—and N_2 may be assumed insoluble in methanol.

(a) In your own words, explain the overall objective of this two-unit process and the functions of the absorber and stripper in the process.

(b) The streams fed to the tops of each tower have something in common, as do the streams fed to the bottoms of each tower. What are these commonalities and what is the probable reason for them?

(c) Taking a basis of 100 mol/h of gas fed to the absorber, draw and label a flowchart of the process. For the stripper outlet gas, label the component molar flow rates rather than the total flow rate and mole fractions. Do the degree-of-freedom analysis and write in order the equations you would solve to determine all unknown stream variables *except the nitrogen flow rate entering and leaving the stripper*. Circle the variable(s) for which you would solve each equation (or set of simultaneous equations), but don't do any of the calculations yet.

(d) Calculate the fractional CO_2 removal in the absorber (moles absorbed/mole in gas feed) and the molar flow rate and composition of the liquid feed to the stripping tower.

(e) Calculate the molar feed rate of gas to the absorber required to produce an absorber product gas flow rate of 1000 kg/h.

$0.976 \, \text{mol} \, CO_2 \, \text{absorbed} \, / \, \text{mol fed}$

$0.0478 \, \text{mol} \, CO_2 \, / \, \text{mol}$

$8.69 \times 10^4 \, \text{mol} \, / \, \text{h}$

The *indicator dilution method* is a technique used to determine flow rates of fluids in channels for which devices like rotameters and orifice meters cannot be used (e.g., rivers, blood vessels, and large-diameter pipelines). A stream of an easily measured substance (the *tracer*) is injected into the channel at a known rate and the tracer concentration is measured at a point far enough downstream of the injection point for the tracer to be completely mixed with the flowing fluid. The larger the flow rate of the fluid, the lower the tracer concentration at the measurement point.

A gas stream that contains 1.50 mole% CO_2 flows through a pipeline. Twenty (20.0) kilograms of CO_2 per minute is injected into the line. A sample of the gas is drawn from a point in the line 150 meters downstream of the injection point and found to contain 2.3 mole% CO_2.

(a) Estimate the gas flow rate (kmol/min) upstream of the injection point.

(b) Eighteen seconds elapses from the instant the additional CO_2 is first injected to the time the CO_2 concentration at the measurement point begins to rise. Assuming that the tracer travels at the average velocity of the gas in the pipeline (i.e., neglecting diffusion of CO_2), estimate the average velocity (m/s). If the molar gas density is 0.123 kmol/m^3, what is the pipe diameter?

55.6 kmol / min

1.08 m