CHAPTER EIGHT : POLLUTION PREVENTION

8.1 The Problem

This chapter is different than the others. It is about ideas and not calculations. The goal is to demonstrate how knowing the material balance will stimulate ideas about pollution prevention and control. The ideas are illustrated with case studies that show the materials that move through the manufacturing and pollution control system. In all cases, mass in equals mass out, which is required by the law of conservation of mass. The examples are quantitative, but the methods of calculating the material balance are not discussed until Chapter 4. The case studies are food processing, metal fabrication, organic chemical manufacturing, and semiconductor manufacturing. A possible first reaction may be “I don’t know anything about those industries. I won’t be able to understand the case studies.” Don’t be intimidated. There will be unfamiliar names of processes, chemicals and equipment, but you need not worry too much about these details. Focus on what the case studies have in common – the material balance concept – and you will learn. Pollution prevention is done in the manufacturing process. Watch for the changes that reduce water use and waste quantities. Waste treatment is done on whatever materials are discharged as waste liquids, gas, or solids. Watch for how the characteristics of the wastes, in particular the presence of toxic chemicals, will influence decisions about waste management. These concepts, and the material balance, are useful in any kind of process. That is the message of this chapter. Some students may wish to come back to this chapter when they are more familiar with basic concepts and vocabulary. This is fine, and a second reading is recommended, but do not skip over it on the first reading. It will be helpful to use the examples to build the concept of processing systems and how they can be rearranged and improved, and how the material balance data guides the innovation. The goal in pollution prevention is to find low-cost or no-cost improvements to save money. The savings may come from higher yield, reclaimed material, lower utility costs, lower raw material cost, or lower waste disposal cost. During design these savings are made or lost at the drawing board. An existing industry must first find waste and then reduce it. Accounting for all the material flowing through the system is the ultimate material balance exercise. Acquiring the necessary data requires a good deal of care and effort. Many industries do not know the flow of water into or the flow of waste materials out of various processes. Sometimes the best estimate of a pollutant discharge comes from purchasing records. It may be known, for example, that mercury is being purchased and put into the process, but mercury is not detected in the discharges from the plant.

8.2 Pollution Audit – The First Steps

The first step for an existing industry is to walk through manufacturing areas, plant utilities, and waste treatment facilities and look for waste.

- Look in the waste bins.
- Identify the various waste streams produced on site.
- Look at packaging for both suppliers and customers. Packaging is paid for twice – once to buy it and once to dispose of it.
- Water use and disposal is critical because you pay for the clean water input and the wastewater output. Check meters and bills to be sure you pay only for what you are discharging. Turn off water to idle processes. Eliminate leaks and dripping faucets.
- Look for energy savings. Saving water almost always saves energy, and vice versa.
- Compressed air leaks are expensive, but easy to find and eliminate.

Information about the manufacturing and waste treatment processes must be organized.

1. *Draw a flow diagram of the manufacturing process.* The starting diagram might look like Figure 8.1. Many details remain to be filled in.
2. *Identify and quantify all raw material inputs, products and byproducts*. Help will be needed from the purchasing department. Many raw materials are sold under trade names so it may take some work to discover the chemical components. Material safety data sheets are useful here.
3. *Check all* permits, compliance test data, violations and complaints, past and potential spills, underground tank inventory, and accidental containment plans.

4. *Identify the source of all pollutants and waste discharges (solid wastes, drums, and gaseous emissions as well as wastewater).* Fugitive gaseous emissions represent a special challenge to locate and quantify. Maps of drainage and ventilation ducts must be checked. Existing plans may be wrong in the details of plumbing and drainage and some sewers and drains may not be shown at all. It may be necessary to use dye or smoke to trace some discharges. Flow meters and sampling devices may need to be installed.

5. *Quantify all discharges in terms of flow and contaminant levels.* Make the material balance on water and other contaminants. Getting an accurate accounting of material flow in a real system requires care and effort. If the material balance is based, wholly or in part, on field measurements, there will be discrepancies due to imperfections in the measurement process or failure to identify and measure all inputs and outputs. Similar problems exist with regard to getting representative samples of discharges and of measuring concentrations in the laboratory. All sampling must be coordinated with the laboratory to eliminate mistakes about sample preservation, sample size, and whether measurements will be made in the field (pH, temperature) or in the laboratory.

6. *Use the material balance to identify opportunities for improvement* by ranking pollution sources in terms of magnitude, toxicity, or treatment cost. Develop a list of ideas, screen and rank them, and work toward implementing the best.

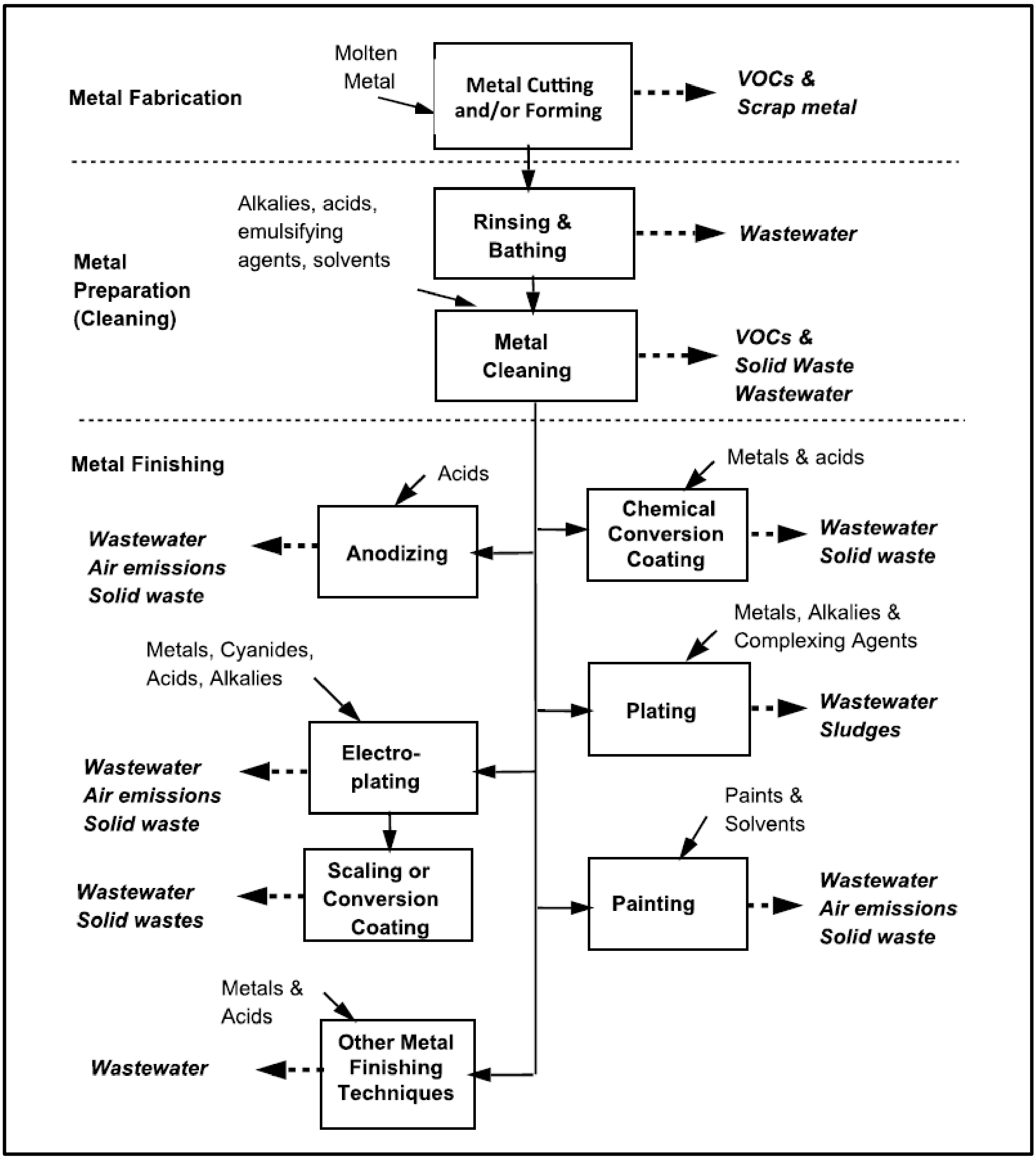

Figure 8.1: Preliminary process flow diagram for a pollution audit.

8.3 Case Study – Sweet Potato Canning

A sweet potato canning factory processes sweet potatoes coming directly from the fields. Operation is 10 h/day, 6 days a week, for a six-week season. Figure 8.2 shows the amount of water used and the pollutant load from each manufacturing step for an input of 1,000 kg/h. There is no way to compute these values from theory so they must be measured in the plant. This is laborious and expensive, but necessary to support intelligent redesign decisions. For every 1000 kg (1 T) of sweet potatoes that

comes from the field, 400 kg leaves as canned product, 520 kg is lost immediately as solid waste (dirt, plant material, and substandard vegetables), and 80 kg leaves in the wastewater. The total water use is 10,585 L/T. One-third of this is used for cleanup and cooling. Another one-third is used in the canning process. Preparation for canning (lye bath peel removal, snippers, abrasive and brush washer) accounts for another 25% of water use. The retorts (industrial pressure cookers) use the most water, but the wastewater is clean. Cleanup uses a lot of water and contributes six to eight percent of the pollutant load. The cooling water is a large volume but it never becomes polluted. Biochemical oxygen demand (BOD) and suspended solids (SS) are the only pollutants of interest in this industry. The pollutant concentrations of the combined wastewater are 2,940 mg/L BOD and 1,480 mg/L SS. The mass pollutant loads per ton of product are 31.1 kg BOD and 15.6 kg of SS. The lye bath/peel removal, snippers, and the abrasive peelers are the source of roughly 90% of the BOD and SS loads. Slightly more than half of the total BOD load comes from the lye bath peel removal step. Abrasive peeling contributes 25% of the BOD load. Peeling accounts for almost all of the suspended solids load. Peeling is the first target for process redesign. A search of the food processing literature and consultation with experts suggests dry caustic peeling as an option. The peel is removed as a pasty solid. This eliminates the abrasive scrubbing step and reduces the wastewater flow by 80% and BOD and SS loads by 90%. The estimated waste reductions are in Table 8.1
There are direct cost savings by reducing water use, chemicals, steam, fuel, and waste surcharges. In addition there will be slightly more product to sell because peel loss is reduced. The savings from wastewater and solids disposal and water purchased is $710 per day or $25,560 per canning season. Are there other improvements to consider? It may be possible to recycle some water from the retort to the first washing step. The lye can be cleaned of solids and reused. The high-solids water coming from washing, snipping, brush washers, and trimming could be screened to remove 60–80% of the solids. This simultaneously reduces the BOD and the wastewater disposal costs. Making the material balance was the key to setting priorities and selling the solution to management.

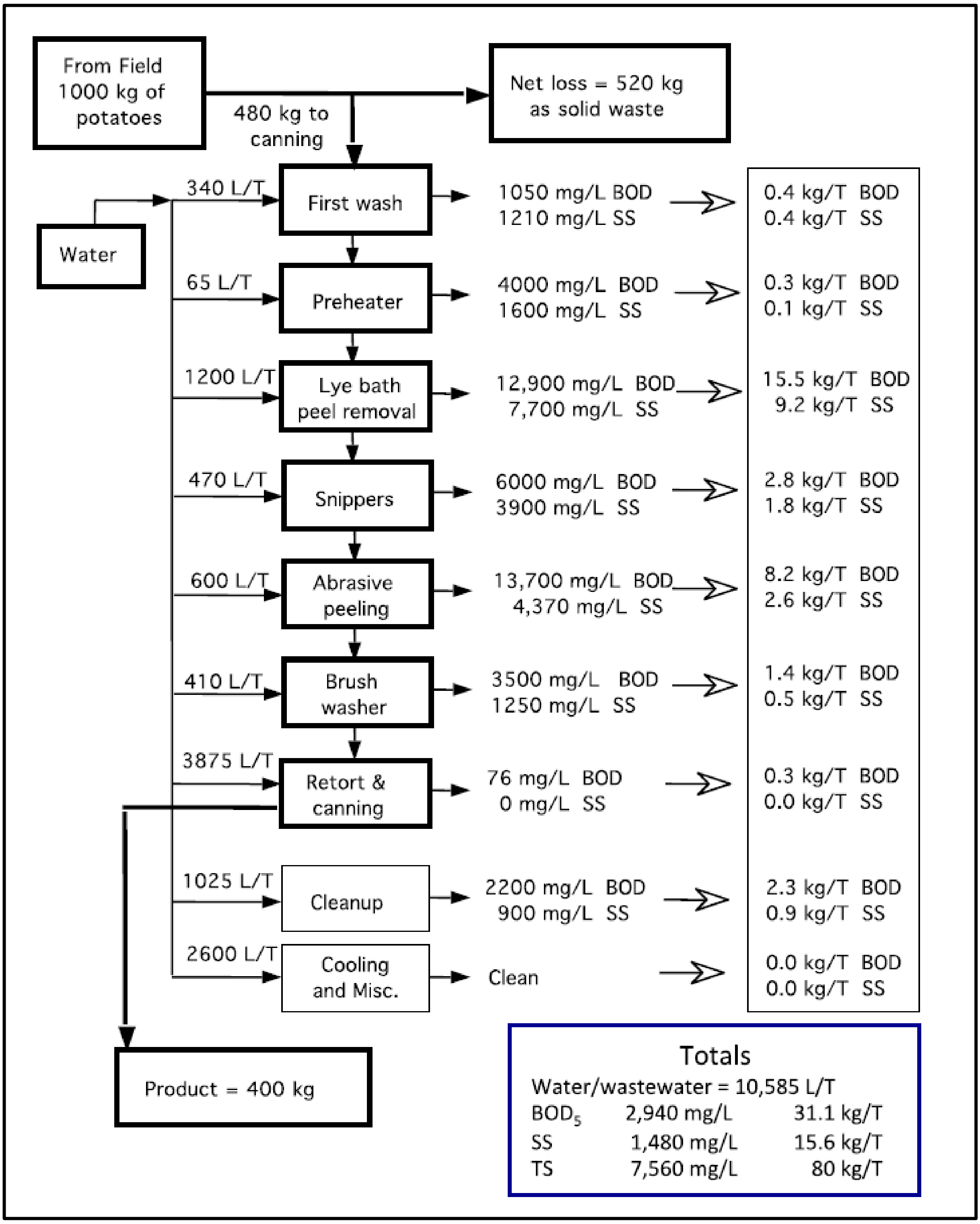

Figure 8.2: Material balance for water, BOD and suspended solids in a sweet potato canning plant.

Table 8.1 Waste loadings for the conventional process and the dry caustic process.

Item	Original Process	Dry Caustic Process
Process input	10 T/h	10 T/h
Peel loss	12% = 1.2 T/h	6% = 0.6 T/h
Canned output	8.8 T/h	9.4 T/h
Water/Wastewater	10,585 L/h	2,120 L/h
BOD	311 kg/h	31.1 kg/h
SS	156 kg/h	15.6 kg/h
Water and Wastewater Costs		
Water purchase @ $0.70 per m^3	$7.41/h	$1.48/h
Wastewater surcharge		
– BOD @ $0.15/kg	$46.65/h	$4.67/h
– SS @ $0.10/kg	$15.60/h	$1.56/h
Solid waste disposal @ $25/T	$30/h	$15/h
Total Costs ($/h)	$92.25	$21.23
Total cost ($/10-hour day)	$922.50	$212.30

8.4 Case Study – Water Reuse and Toxic Metals Management

An industry uses 12 L/m of city water to supply three manufacturing processes. The process water contains 200 ppm total dissolved solids (TDS), which is excellent for the manufacturing process. The objectives are to minimize the discharge to the city sewer, eliminate the toxic sludge, and minimize all waste outputs. Table 8.2 and Figure 8.3 summarize what is known. The three waste streams are combined for treatment. The tumbler water contains about 5,000 ppm of non-toxic suspended solids. The acid-etch water contains dissolved toxic metals. The alkaline rinse water contains 230 ppm TDS but is not toxic. Most of the solids, which are non-toxic, come from the tumbler water. The pollutants carried in the acid etch water and alkaline rinse water are dissolved; they are free of suspended solids. The alkaline rinse water is not important in terms of pollution, but it contributes 20 L/m, or 17%, of the total flow. Coagulants enhance the removal of suspended solids in a settling tank. This also causes the removal of some toxic metals so sludge from the settling tank is contaminated with toxic metals from the acid etch rinse. The sludge is thickened by gravity and dewatered in a filter press. Mixing the metals with the non-toxic tumbler solids creates a filter cake that must he handled as a hazardous waste. The effluent is neutralized by adding acid or base as needed. The effluent has a total dissolved solids concentration of 600 mg/L TDS, which is too high for water reuse. The salt that prevents the effluent from being recycled is proportional to the drag-out from the acid etch and alkaline rinses. The chemicals added for neutralization are also proportional to the drag-out and they increase the salinity.

Table 8.2: Characterization of water use and wastewater treatment. (TSS = total suspended solids; TDS = total dissolved solids)

Water Source	Flow (L/m)	TSS (mg/L)	TDS (mg/L)	Toxic	Direct Reuse
City water	120	nil	200	No	NA
Tumbler water	80	5,000 (0.4 kg/h)	< 200	No	Yes (low TSS)
Acid etch water	20	nil	< 400	Yes	No
Alkaline rinse water	20	nil	< 400	No	No
Effluent	180	< 10 mg/L	600 mg/L	No	No (high TDS)
Sludge filter cake	--	20–30 kg/d	--	Yes	No

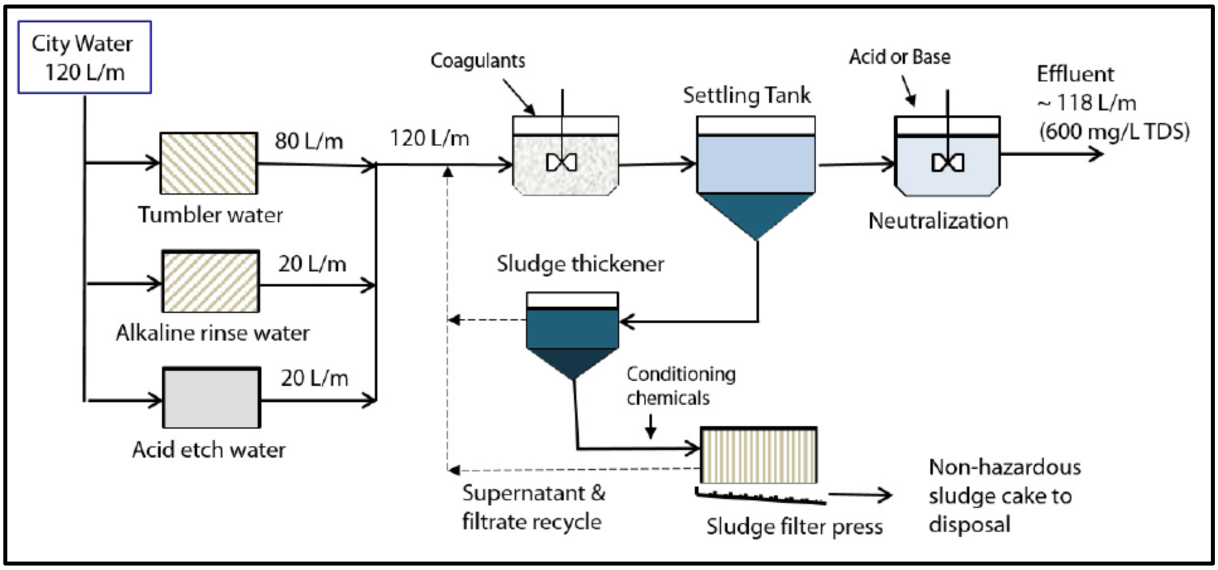

Figure 8.3: Wastewater Treatment Process Mass balance on water neglects water in sludge cake.

The engineers have some ideas after seeing the material balance information.

Engineer 1: We should treat the tumbler water separately with some sort of solid-liquid separation process. Removing the suspended solids should make the water suitable for reuse. The solids will be non-hazardous for purposes of disposal to a landfill.

Engineer 2: True, that would mean having two clarifiers, one for the tumbler water and one for the other combined wastes. There is no room to build a new unit for this waste stream.

Engineer 1: There are other ways to removed solids, like microfiltration. This is a membrane process that is widely used and extremely versatile. I would expect to find a membrane that would do the job.

Engineer 2: Let’s make a quick phone call to Membranes International.

Engineer 2: You are right. There is an ultrafiltration system that will deliver excellent water with 500–600 ppm TDS and a reject slurry with 35% solids. The volume of water in the slurry is 1 L/m or less, so let’s say we can recycle the 79 L/m of tumbler water. The operating pressure is reasonable. This slurry will be non-hazardous and therefore disposal is not a problem.

Engineer 1: The next step should be to reduce the drag-out from the acid etch and alkaline rinses. This will reduce the salt buildup and the metals in the sludge.

Engineer 2: There are low-cost ways to do that. Modify the drip tanks and put in air knives to blow dry the parts before rinsing. Put in automatic shut-off valves and counter-current rinsing. That will reduce each rinse by half and the salt content will be low. We could recycle 11 L/m water. We can’t recycle everything. Our effluent is like the blow-down on a cooling tower or a boiler. Some effluent is needed to control the salt build up.

Engineer 1: That gets us to the flow sheet shown in Figure 8.4. That is a nice improvement. The volume of sludge and the metals content are greatly reduced. The sludge may still be hazardous, depending on the metal concentration and its stability in the RCRA leaching test.

Engineer 2: We could treat the acid-etch water separately. This would reduce the sludge volume and it might make metal recovery possible.

Engineer 1: Right. And the volume is so small – the volume for one day is 10,800 L (10 L/m for 18 hours), the same as the flow for one hour when we used 180 L/m of city water. That means the existing settling tank has sufficient volume to treat one day's waste as a batch. Add chemicals directly to the settling tank, mix it, settle the precipitate, allow the sludge to thicken, and dewater it.

Engineer 2: What happens to the alkaline rinse? It's non-toxic. We might mix it with the tumbler water and use the ultrafiltration system to recover a few more liters of water.

Engineer 1: Figure 8.5 is a sketch of the proposed system. Details need to be checked to be sure it will work, but it is an excellent working plan. City water purchase is reduced from 120 L/m to 5 L/m. Most solids are in a non-toxic slurry. The metals are concentrated in a very small volume of sludge.

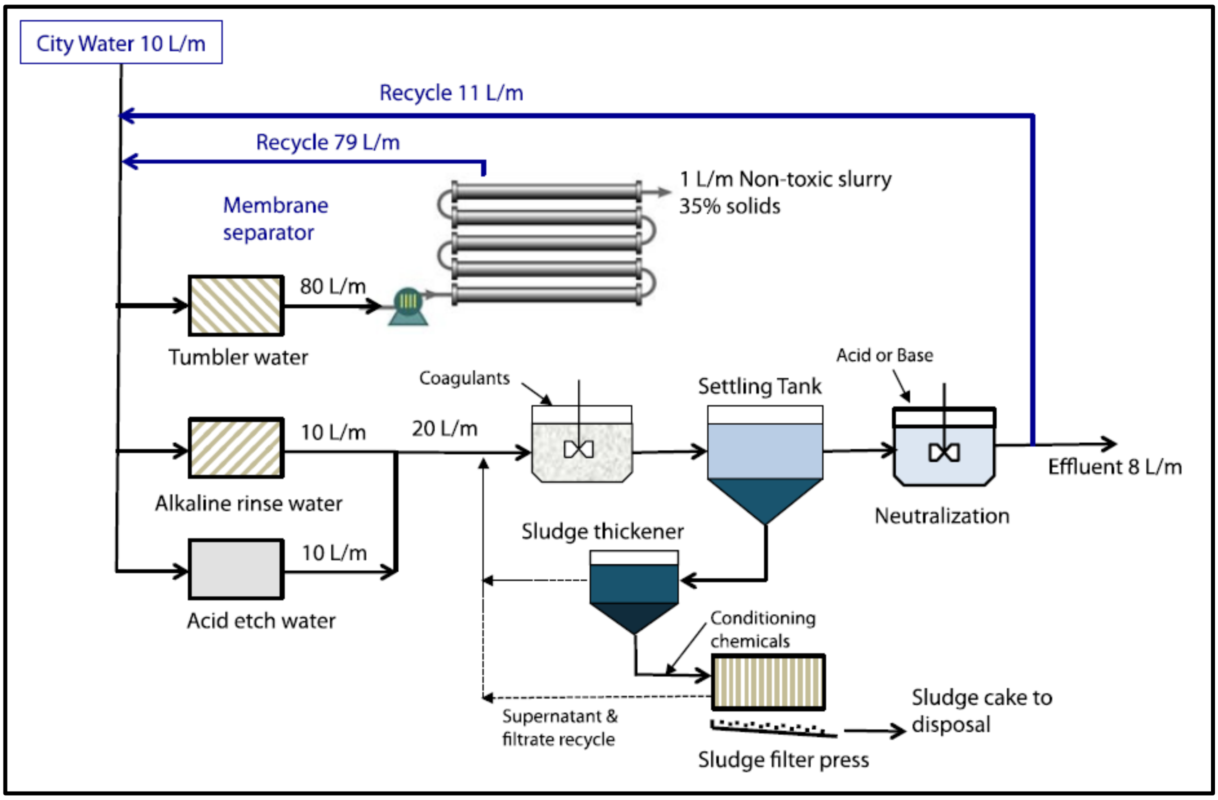

Figure 8.4: Redesigned process. Mass balance assumes 1 L/m water in sludge cake and 1 L/m in membrane process slurry.

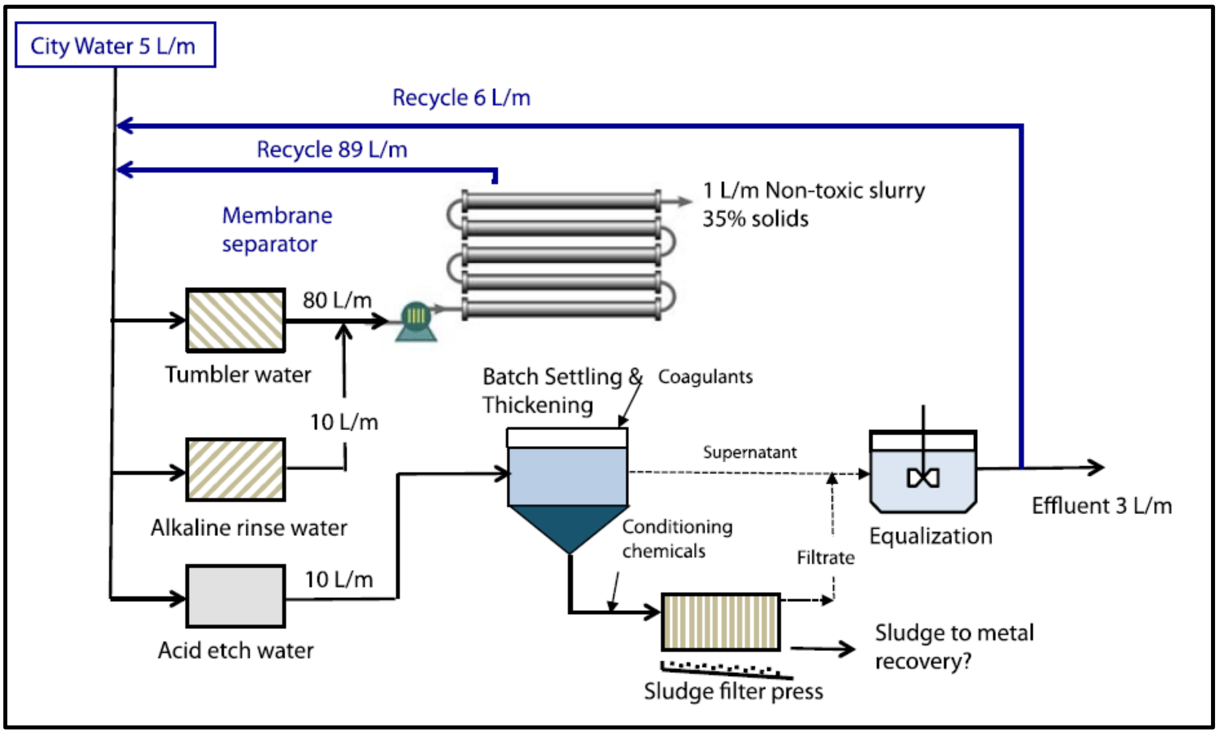

Figure 8.5: Flow diagram for the final proposal. Mass balance assumes 1 L/m water in sludge cake and 1 L/m in membrane process slurry.

8.5 Conclusion

The material balance is the most valuable tool for determining the magnitude of a pollution problem and stimulating ideas about pollution prevention. We use it to expand fragmentary information into a more complete picture that stimulates the synthesis-analysis iterative cycle. The methods for doing this are explained in the next chapter. Opportunities for pollution prevention in an existing plant may be discovered during a plant walk around and from discussions with operators and plant engineers. When the easy fruit has been harvested, sampling and analytical work may be needed to assemble the necessary flow and pollutant load data. We have skipped over the important details of how to design a sampling program, how to measure flows and collect representative samples, and the parameters that should be measured. Data are expensive, but information is valuable and short cuts will not be rewarded. The plant 'walk-around' during design is a creative exercise to imagine the kinds and sources of possible pollution and to use material balance calculations to estimate quantities. In particular, we hope to discover opportunities to minimize the creation of wastes and to recover and recycle material. Recognizing that zero emissions is almost never possible; the material balance also guides the designer in formulating treatment systems to deal with pollutant discharges that cannot be avoided.