Water Re-Use Employed To Reduce Plant Expansion Capital Cost

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A Southeastern US polymers plant planned to expand production along with new environmental rules on the horizon. The first stage process expansion economics were completed and it was time to evaluate the background economics. The usual questions arose. How can we expand, meet regulations and avoid unnecessary capital costs and are there hidden savings projects we can find and implement?

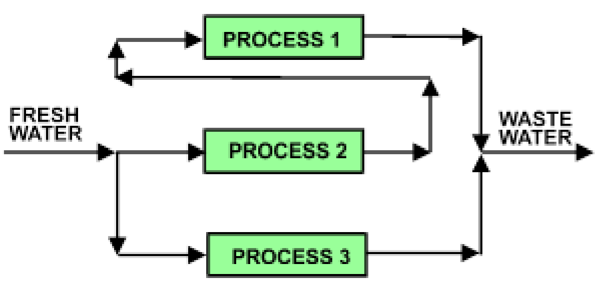
This case study will cover the techniques, mechanics, and thought processes employed to minimize the costs for a process plant expansion that on the surface would require a wastewater plant expansion.

This facility had several major process units all of which consumed some fresh water and generated wastewater. The wastewater treatment plant at this facility was at the limit of its hydraulic capacity. With tighter environmental restrictions on the horizon and a production expansion plan of 30% over the next five years, an expansion in the water treatment plant was almost certain to be required at an estimated cost of over $3MM. Long term agreements allowed the plant fresh water supply for this plant allowed it to be considered free and plentiful; a rare economic situation.

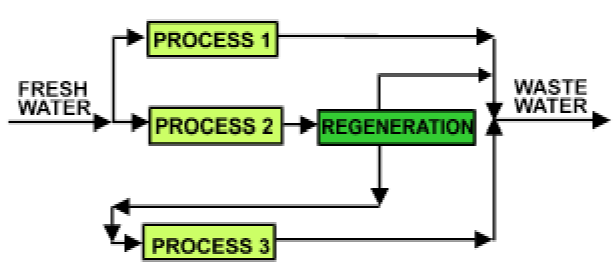
Management proposed a reduction in wastewater flow by 25%? This would permit the existing wastewater treatment facility to meet expected future loads and save $3MM in avoided capital cost. The processes were complex and there were no obvious solutions to cherry pick or visualize, let alone calculate. What process techniques could we employ to accomplish the task? Pinch Analysis was selected as the analytical technique with a goal of reducing wastewater flow through reuse and regeneration at a total cost not to exceed $1MM.

Water Minimization Techniques:

<u>Water re-use</u> : implies that we use the outlet water from one operation to satisfy the water requirement of another or same operation. In some cases the water may require partial treatment (regeneration) prior to re-use. Figure 1 illustrates two main options for re-use.



<u>Figure 1(a)</u>: Direct water reuse

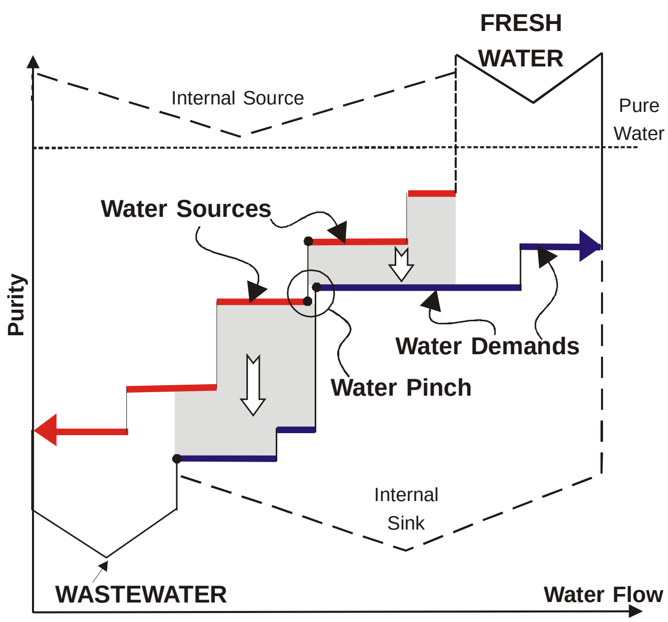


<u>Figure 1(b)</u>: Water reuse after regeneration

Direct re-use: The outlet water from one unit operation can be directly reused to satisfy the water demand of another operation as shown in figure 1(a). The outlet water is sufficiently clean for the next operation.

Regeneration re-use: The outlet water from a process unit is treated sufficiently to make it suitable for use in one or more of the water-consuming operations as shown in figure 1(b). Partial treatment, for the purpose of rendering the wastewater suitable for reuse, is called regeneration. There are many different types of regeneration. Regeneration could imply something as simple as pH adjustment or physical removal of unwanted impurities e.g. by filters, membrane separators, sour water strippers, ion exchange systems, etc.

Regeneration recycle: In some cases the regenerated water may be suitable for re-use within the same operation from whence it came. This is called recycling. Water recycle carries with it the risk of potential build-up of trace contaminants in the process which must be addressed before deciding to do so.

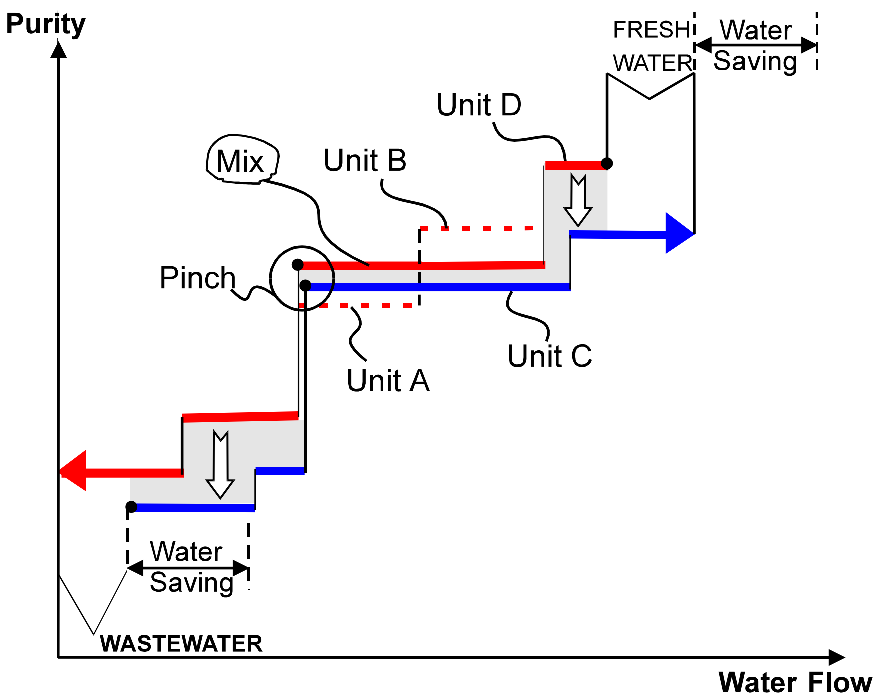


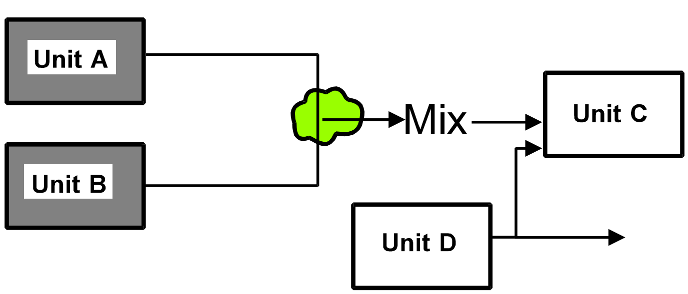
<u>Figure 2:</u> Water Pinch Approach: Basic Representation

Figure 2 shows the basic representation used in the Water Pinch approach, which is similar in concept to the composite curves used in energy pinch analysis. Water purity is plotted on the vertical axis and water flowrate on the horizontal axis. Each water-related process operation can be considered as having input and output water streams. There can be several input and output water streams at different purities for a single operation. The input water streams of all the water using operations are plotted in a "demand composite" form to define the water demand for the overall plant as shown in figure 3. Similarly the output water streams of all the operations are plotted to construct the "source composite" for the plant. The Water Pinch approach employs a stream focus.

The overlap between the source and the demand composite (shown by shaded area) indicates scope for water reuse. The available overlap is limited by the "pinch point" between the source and the demand composite. The representation in figure 3 also identifies minimum fresh water demand and minimum wastewater generation without water mixing (as we will see later).

The representation also guides the designer to identify specific design changes that will enable increased re-use of water. Figure 4 shows an example. By mixing water sources from units A and B we generate a mixture of intermediate purity (shown as "Mix"). This relieves the existing pinch point bottleneck, allowing greater overlap of the source and demand composites and increasing the overall water recovery in the process. The Water Pinch representation also simultaneously provides the design guidelines as shown in figure 4. For example, the representation indicates that the water mixture from outlets of units A and B needs to supply water to unit C. The remaining water demand for unit C can be satisfied by part of the water outlet from unit D. The Water Pinch approach therefore not only sets the targets, but also suggests appropriate network design changes which maximize the re-use of water.





Figures 3 & 4: Combined targeting and design using Water Pinch approach
(3) Composite Curves (4) Flowsheet representation

To illustrate the methodology, we confine our attention to just one of the process units on site, polymer manufacturing. Figure 5 shows a simplified process flowsheet.

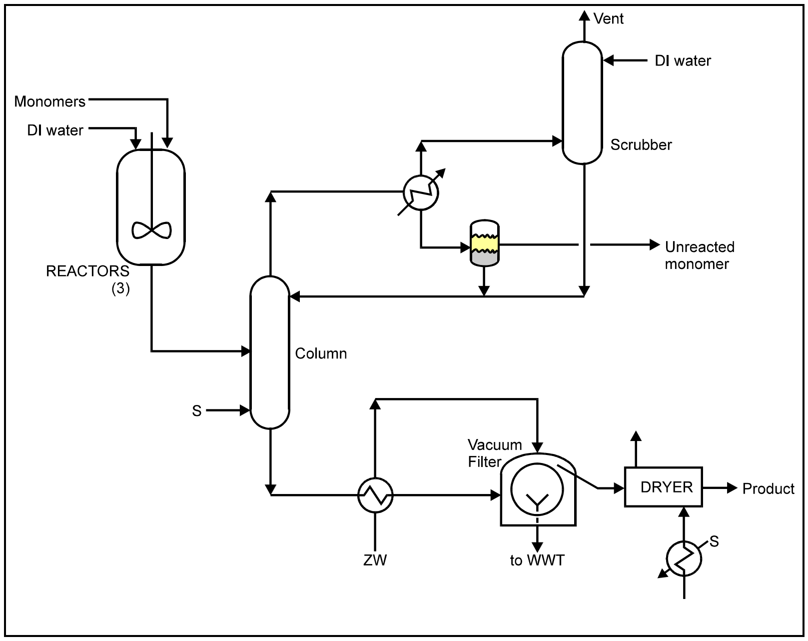


Figure 5: **Polymer Manufacturing Process**

The first step was to identify all the water sources (effluents) and sinks (users). For this process, there was only one source, the vacuum filter effluent and the sinks were the reactor, scrubber, stripping steam and vacuum filter cake wash. So our "data extraction" gave us:

Stream ID	Flow, gpm	Comments
Reactor dilution water	185	need DI
Scrubber wash water	6	using DI; switch to ZW ?
Vacuum filter cake wash	260	need ZW
Vacuum filter effluent	489	has SS, toxic organics

We now started looking for possibilities to reduce water use. Based on the foregoing fixed process requirements, there were no obvious opportunities for water reuse. One possibility for consideration could be multistage filter cake washing, but this would be very expensive. The vacuum filter effluent was unsuitable for reuse because of unreacted monomer which is toxic and suspended polymer particles could plug up downstream equipment. It looked like the process could not be improved, but appearances can be deceptive. The Pinch approach provided a systematic way to determine conservation potential.

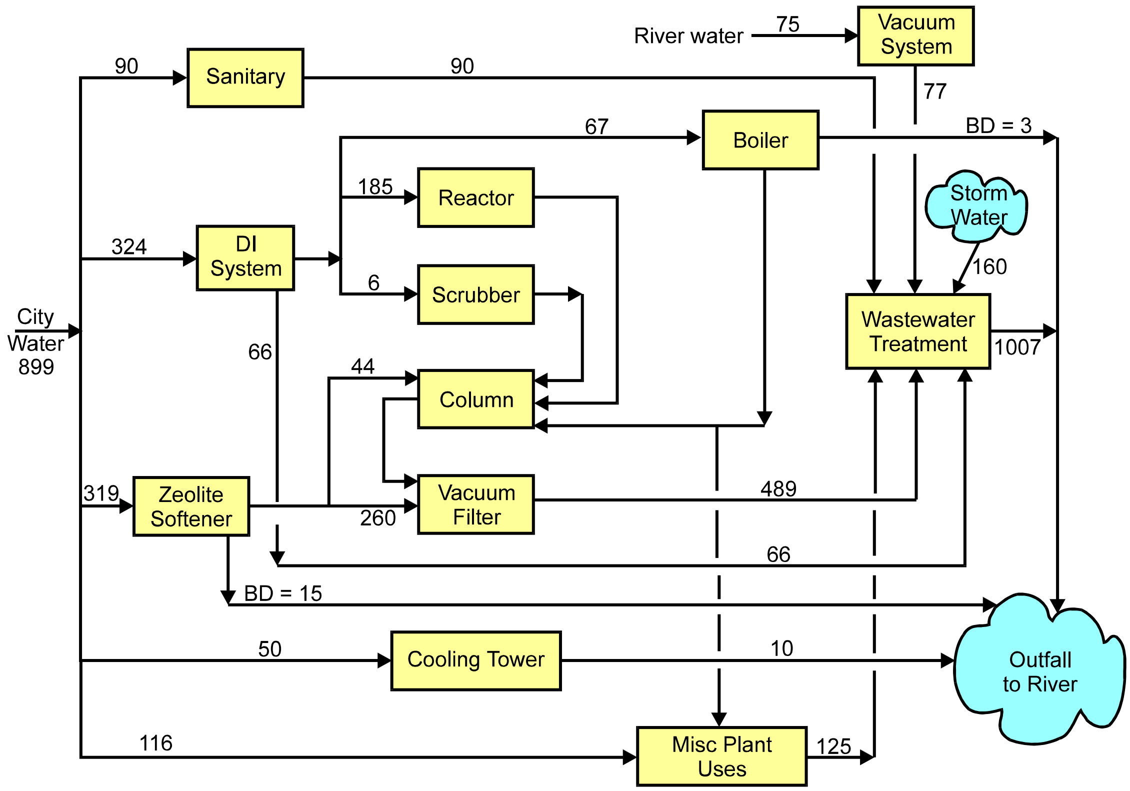
Step 1- Consider the Entire Water system, Not Just the Process

Draw out the complete water system flowsheet, as in Figure 6. All of the water that enters or leaves the plant must be identified. We employed a Pinch evaluation process which could be used to systematically evaluate hundreds of streams and contaminants at the same time.

Step 2-Develop a Total Plant Water Balance

We needed to make sure that the sum of individual water users agreed with the metered water intake. Similarly, the sum of the identified effluents had to be equal to the measured flow to the wastewater treatment plant. If the differences were less than 10%, then we accepted the balance. If the difference was greater than 10%, we had to look for non-obvious sources and sinks. It was not essential that city water in was equal to wastewater out because of water losses from cooling tower evaporation, reaction effects, vapor vents and water gains, e.g., storm water. The important accounting check was that the sum of the sinks equaled the metered inflow and the sum of the sources equaled the metered outflow.

After a number of trial balances the final plant water balance gave good agreement. See Table 1.



<u>Figure 6</u>: Schematic Flowsheet and Water Balance

Step 3-Data Extraction

The next step in the pinch analysis process was data extraction. Here we selected the streams and identified the key contaminants. The key contaminants were those which rendered the effluent water <u>unfit</u> for reuse. The "In" streams included those where we were prepared to use alternate sources of water. The "Out" streams were those which were currently going to wastewater treatment. The rationale for including or excluding streams in the pinch analysis is summarized in Table 2.

Now we had to choose the key contaminants. But how? We started simply with just three:

- Organics (BOD)
- Salts (Conductivity)
- Suspended solids.

Other potential contaminants could be added later such as COD, oil, dissolved solids, specific toxins, pH, and temperature. We now had our preliminary stream data for the existing process, per Table 3.

		Consumption, GPM				Production, GPM						
Process/Equipment	**Stream ID**	CW	ZW	DI	Other	ZW	DI	Other	WWT	Outfall		
Zeolite Softener	Feedwater	304										
	Rinse water	15										
	Spent backwash									15		
	Softened Water					304						
	Subtotal	319	0	0	0	304	0	0	0	15	Difference	0
Demin System	Feedwater	268										
	Acid rinse	16										
	Acid spent wash								16			
	Caustic rinse	40										
	Caustic spent wash								40			
	Test meter bypass			10					10			
	Product DI water						268					
	Subtotal	324	0	10	0	0	268	0	66	0	Difference	0
Process (direct)	Reactor dilution water			185								
	Column steam				50							
	Scrubber wash			6								
	Filter cake wash		260									
	Product							56				
	Vac Filter effluent								489			
	Subtotal	0	260	191	50	0	0	56	489	0	Difference	-44
Process (indirect)	Column tray flush		7									
	Column spray nozzles		12									
	Water to column feed		25									
	Vac jet steam				2							
	Vac jet barom				75				77			
	Pump seals	43							43			
	Pump hosedown	5							5			
	Dryer wash down	42							42			
	Dryer exhaust vapor				53			53				
	Safety shower trips	6							6			
	Unrecov'd stm				8				8			
	Floor washing	20							20			
	Subtotal	116	44	0	139	0	0	53	202	0	Difference	44
Boiler	Feedwater makeup			67								
	Condensate return				45							
	Steam							108				
	Blowdown									3		
	Subtotal	0	0	67	45	0	0	108	0	3	Difference	0
Cooling Tower	Makeup	50										
	Evap loss							40				
	Blowdown									10		
	Subtotal	50	0	0	0	0	0	40	0	10	Difference	0
Other	Storm water				160				160			
	Sanitary users	90										
	Sanitary sewer								90			
	Subtotal	90	0	0	160	0	0	0	250	0	Difference	0
SITEWIDE TOTALS		899	304	268	394	304	268	257	1007	28	Difference	0
METERED FLOWS		900	300	260					1000			
DIFFERENCE, %		0	-1	-3					-1			

Table 1: Plant Water Balance

Stream Description	**Comment**
1. Feedwater to zeolite system	No, because it is the supply for another utility.
2. Zeolite system backwash	Yes.
3. Spent Brine	No, because it does not go to WWT.
4. Softened Water	No, treat it as a utility source.
5. Demin system feedwater	No, because it is a supply for another utility.
6. Product DI water	No, treat it as a utility source.
7. Column Steam	Depends on process constraints: a) No, if reboiler is permitted. b) Yes, if vaporizer is required.
8. Pump Seals	Depends: Seal water consumption counts in all cases Seal water counts only if it is easily collectable; it does not count if it drains to sewer and ends

	up in the sump.
9. Dryer Exhaust Vapor	No, needs capital and there are no net water savings if the heat sink is the cooling tower.
10. Safety shower trips	Depends: a) Consumption included, but provide city water specs. b) Discharge included separately if collectable. c) Discharge included with sump if <u>not</u> collectable.
11. Unrecovered steam condensate	No, it's not easily collectable, included in sump flow.
12. Boiler FW makeup	Yes.
13. Boiler Blowdown	Depends: a) Yes for fresh water conservation objective. b) No for wastewater minimization objective because it does not go to WWT.
14. Cooling tower makeup	Yes.
15. Cooling tower blowdown	Depends: Same as boiler blowdown.

<u>Table 2</u>: Data Extraction Principles

		Flow, gpm		Actual Conc, ppm		
Process/Equipment	**Stream ID**	In	Out	Org	Salts	SS
Zeolite Softener	Backwash	15.2		1	150	5
Demin System	Acid rinse	16.1		1	150	5
	Acid spent wash		16.1	1	16405	300
	Caustic rinse	40.1		1	150	5
	Caustic spent wash		40.1	1	19058	300
	Test meter bypass	10	10	1	12	1
Process (direct)	Reactor dilution water	185		1	12	1
	Vaporizer feed	50		1	12	1
	Scrubber wash	6		1	12	1
	Filter cake wash	260		1	147	1
	Vac Filter effluent		489	26	1680	250
Process (indirect)	Column tray flush	7		1	147	1
	Column spray nozzles	12		1	147	1
	Water to column feed	25		1	147	1
	Vac jet barom condenser	75		50	150	100
	Vac jet hot well		77.3	60	150	100
	Pump seals in	43		1	150	5
	Pump seals out		43	20	150	5
	Pump hosedown	5		1	150	5
	Dryer wash down	42		1	150	5
	Satety shower trips	6		1	150	5
	Floor washing	20		1	150	5
	Area sump		73.3	50	1800	400
Boiler	Feedwater makeup	66.6		1	12	1
Cooling Tower	Makeup	50		1	150	5
Other	Storm water		160	50	100	300
	Sanitary users	90		1	150	5
	Sanitary sewer		90	60	400	1200
Utility Sources	Softened water		350	1	147	1
	Product DI water		350	1	12	1
	City Water		1000	1	150	5

Table 3: Initial Stream Data

Step 4-Run Water Pinch software to obtain initial water reuse strategy
The targets obtained by running the data in Table 3 were:

	gpm
City Water	325
Zeolite Water	304
DI Water	308
Wastewater	920

The reuse strategy given by the software was:

#	Source ID	Sink ID	Savings, gpm				
			DI	ZW	CW	RW	WW
1	Vac jet hot well	Vac jet barom cond	-	-	-	32	32
2	Pump seals	Vac jet barom cond	-	-	-	43	43
3	Test meter	BFW makeup	10	-	-	-	10
		Totals	10	0	0	75	85

While this strategy looked good on paper, a more detailed consideration showed several practical problems.

- Project 1 was not feasible because the hot well temperature was too high to use in the barometric condenser. Further, if it were cool enough, there would still be a problem with the buildup of contaminants. There was no way for the software to anticipate these details.
- Project 2 was not feasible because the pump seal water “out” was too hot to use in the barometric condenser.
- Project 3 looked good.

After rejecting projects 1 and 2, the savings potential was pitifully low. The reason for this was that we were forcing the software to use the same high quality of water as the current operation. We had to relax the design concentration specifications for the “In” and “Out” streams based upon judgment, as follows:

- C_{IN} = maximum allowable, and
- C_{OUT} = a) the desired target, or
  b) the expected value based on equilibrium or the heat and material balance

After running the Water Pinch several times and rejecting unrealistic projects we obtained a more realistic list:

#	Source ID	Sink ID	Savings, gpm				
			DI	ZW	CW	RW	WW
1	Vac filtrate	Column tray flush	-	7	-	-	7
2	Vac filtrate	Column feed	-	25	-	-	25
3	Vac filtrate	Vac jet barom cond	-	-	-	75	75
4	Vac filtrate	Pump seals in	-	-	28	-	28
5	Vac filtrate	Dryer washdown	-	-	42	-	42
6	Vac filtrate	Floor washing	-	-	20	-	20
7	Vac filtrate	Vaporizer feed	9	-	-	-	9
8	Pump seals out	Vaporizer feed	41	-	-	-	41
9	Test meter	BFW makeup	10	-	-	-	10
			60	32	90	75	257

Let's evaluate this revised project list critically:

- Projects 1 and 2 look good.
- Project 3: Temperature problem.
- Project 4: Vacuum filtrate is mixed with city water in a 2-to-1 ratio. It meets the concentration criteria, but what about temperature?
- Projects 5 and 6: Can't do. High temperature is good, but there is a problem with toxics.
- projects 7,8, and 9 look good.

Now we added temperature and toxics as new quality parameters. One way to include their effects was to add them as new "key contaminants". Alternately, we could have imposed constraints forbidding the use of known hot streams for vacuum jet barometric condenser use and the use of known toxic streams where human exposure is a possibility.

The savings potential was now better than before, but we still have a long way to go.

The adjusted stream data are shown in Table 4. and ran Water Pinch again, and obtain a more realistic projects list:

	Stream ID	Flow, gpm		Actual Conc, ppm			Design Conc, ppm		
Process/Equipment	**Stream ID**	In	Out	Org	Salts	SS	Org	Salts	SS
Zeolite Softener	Backwash	15.2		1	150	5	1	150	5
Demin System	Acid rinse	16.1		1	150	5	1	150	5
	Acid spent wash		16.1	1	16400	300	1	16400	300
	Caustic rinse	40.1		1	150	5	1	150	5
	Caustic spent wash		40.1	1	19060	300	1	19060	300
	Test meter in	10		1	12	1	1	12	1
	Test meter out		10	1	12	1	1	12	1
Process (direct)	Reactor dilution water	185		1	12	1	1	12	1
	Vaporizer Feed	50		1	12	1	100	3000	300
	Scrubber wash	6		1	12	1	1	150	10
	Filter cake wash	260		1	147	1	1	147	1
	Vac Filter effluent		489	26	1680	250	30	1800	300
Process (indirect)	Column tray flush	7		1	147	1	30	1800	300
	Column spray nozzles	12		1	147	1	1	147	1
	Water to column feed	25		1	147	1	30	1800	300
	Vac jet barom condenser	75		50	150	100	50	1800	300
	Vac jet hot well		77.3	60	150	100	200	3000	500
	Pump seals in	43		1	150	5	30	1800	200
	Pump seals out		43	20	150	5	50	1800	200
	Pump hosedown	5		1	150	5	50	1800	300
	Dryer wash down	42		1	150	5	50	1800	300
	Satety shower trips	6		1	150	5	1	150	5
	Floor washing	20		1	150	5	30	1800	300
	Area sump		73.3	50	1800	400	100	3500	700
Boiler	Feedwater makeup	66.6		1	12	1	1	12	1
Cooling Tower	Makeup	50		1	150	5	20	200	30
Other	Storm water		160	50	100	300	50	100	300
	Sanitary users	90		1	150	5	1	150	5
	Sanitary sewer		90	60	400	1200	200	1000	1500
Utility Sources	Softened water		350	1	147	1	1	147	1
	Product DI water		350	1	12	1	1	12	1
	City Water		1000	1	150	5	1	150	5

Table 4: Adjusted Stream Data

Step 5-Identify Pinches

Pinches are defined here as contaminant concentrations which if changed would permit greater water reuse. In general, we relieve the pinch by increasing the maximum allowable inlet concentration to sinks and decreasing the outlet concentration from sources. We might not have the freedom to arbitrarily specify lower values of C_{OUT}, however, as this was governed by process chemistry and the laws of physics.

Water Pinch software could identify the key pinch concentrations for us in the form of 3-D sensitivity charts per figures 4 & 5. Now the question was; could we really tolerate higher inlet concentrations for the pinch streams? Let's consider them one by one.

- Salts in reactor dilution water No
- SS in vacuum filter wash No
- Organics in sanitary water No
- Organics in pump seal water Maybe
- Etc.

Step 6-Identify Potential Beneficial Process Modifications

These were developed on the basis of questioning the purpose of every piece of equipment and process step, and asking if it could be accomplished in a different (not necessarily better) way. For example,

- Should scrubber bottoms be refluxed to top tray of column? No
- Column Vaporizer Yes
  Reduce vacuum filter operating temperature? (pro-need less wash water for cake)

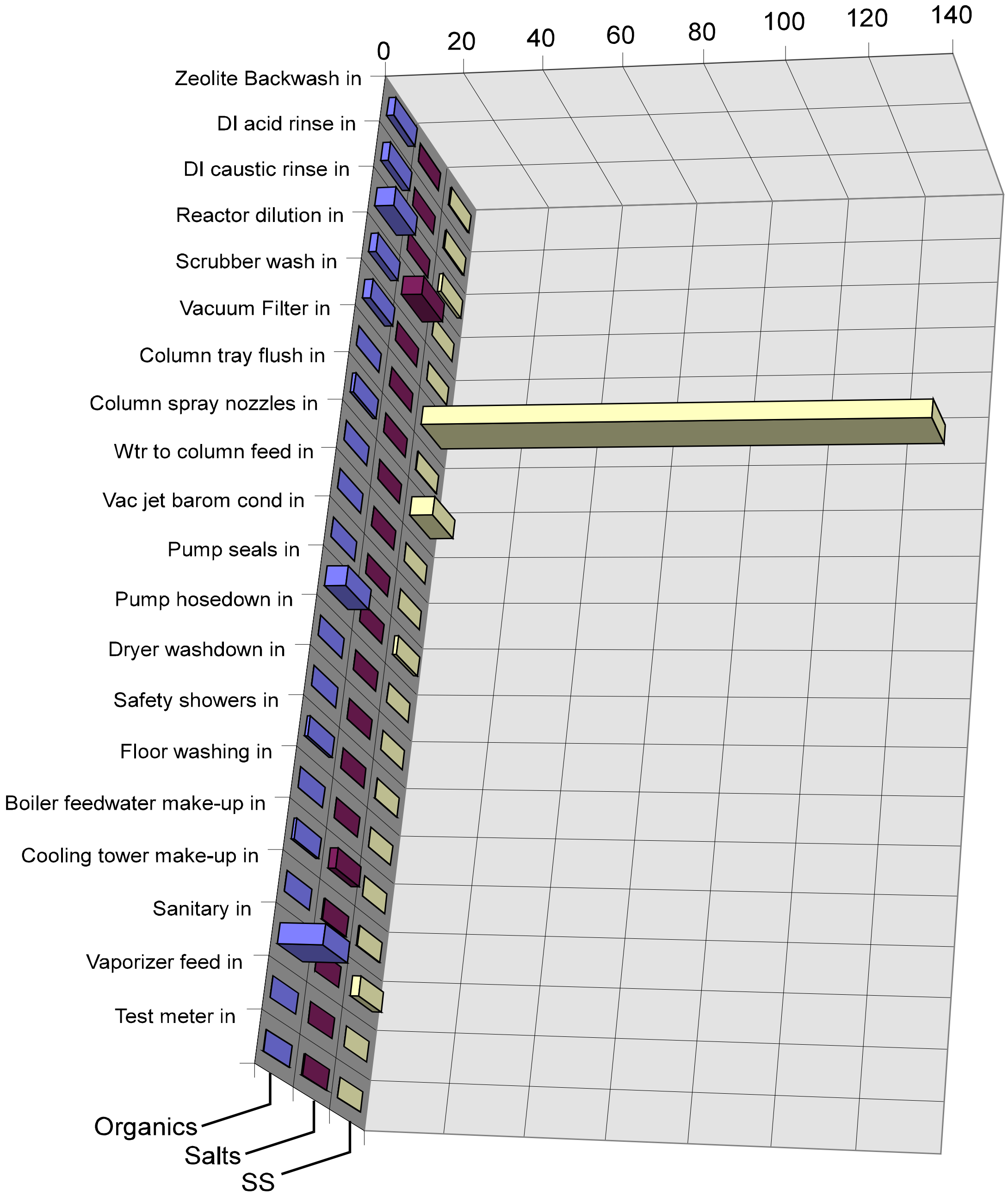
  (con-need more steam for drying)
- Could we place a thermocompressor on the dryer exhaust to recover heat (and water)?
- Could some of the streams that end up in the area sump be collected separately?

Step 7-Establish Design Basis

Once the preliminary ideas were developed, the final design basis was established. This was performed by the study team consisting of the pinch analyst(s) and process experts.

- Agree on permissible process modifications.
- Agree on final design values for pinch concentrations.

- Discuss and agree on regeneration options.



<u>Figure 4</u>: Sensitivity Chart for Inlet Concentrations

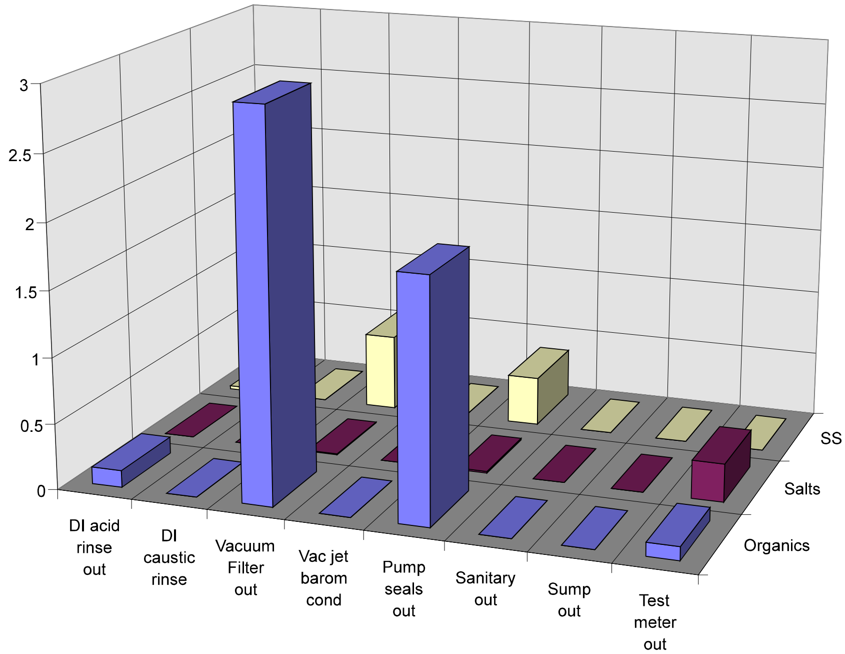


Figure 5: Sensitivity Chart for Outlet Concentrations

Step 8-Revised Pinch Analysis

The Water Pinch software was run again to obtain the revised water reuse strategy. The suggested project list was based upon experience and judgment to evolve the final design. In this case, the final project list was:

#	Source ID	Sink ID	Savings, gpm				
			DI	ZW	CW	RW	WW
1	Scrubber bottoms	Column tray nozzles	-	6	-	-	6
2	Vacuum filtrate	Column feed	-	25	-	-	25
3	Vacuum filtrate	Column tray flush	-	7	-	-	7
4	Vacuum filtrate	Vaporizer feed	50	-	-	-	50
5	Pump seals	Dryer washdown	-	-	42	-	42
6	DI spent wash	Vac jet barom cond	-	-	-	54	54
7	Area Sump	Vac jet barom cond	-	-	-	21	21
8	Test meter	BFW makeup	10	-	-	-	10
		Totals	60	38	42	75	215

Summary: The Overall Procedure for This project Was as Follows:

1. Develop A Process Flowsheet
2. Develop A Water Balance
3. Select Key Contaminants
4. Run Water Pinch Software (Initial)
   - stream selection
   - design concentrations
5. Identify Pinches
6. Develop Process Modifications
7. Revise Design Basis
8. Run Water Pinch Software(Revised)
9. Evolve a Practical Design

The final results of our project were:

- Operating Cost Savings = $100K/yr
- Capital Cost of Retrofit = $300K, including Engineering
- Fresh Water Intake Reduced 16%
- Flow to WWT Reduced 21%

The reduction in wastewater flow of 21% did not quite meet the target of 25% needed to avoid investment in new wastewater treatment capacity. We needed an additional 35 gpm of savings. Several options were considered.

a) Two-stage filtration/washing. This could potentially save 100 gpm, but the capital and operating costs were considered too high.

b) Reduce filtration/wash temperature. The polymer particles filtered out more easily at lower temperature, which meant that less wash water could be used. Potential savings were estimated by the R&D staff at 40 gpm. However, cooler filtration/washing meant higher steam consumption in the dryer which was already operating at its maximum condensing capacity.

c) Divert sanitary sewer to municipal waste treatment. Currently the sanitary sewer flow of 90 gpm was mixed in with process wastewater. It could potentially be collected separately and sent to the municipal sewer, thus offloading 90 gpm from onsite wastewater treatment flow. Sewer segregation and re-piping was estimated to cost $150K. Sewer charges were $50K/year.

It was decided that option (c) was the best one. Total savings in wastewater treatment flow now increased to 215 + 90 = 305 gpm, or 30% of the current load. This was more than needed to meet the project objectives.

Total capital cost for the Project were:

Reuse projects	300
Sewer segregation	150
	$450K

Net operating cost savings were:

Reuse projects	100
Sewer charges	-50
	$50K/yr.

Overall, the benefits were:

- Avoided $2.5MM in capital cost of expanding the wastewater treatment plant.

- Net operating cost savings of $50K/yr.

- Developed phased capital investment strategy for site infrastructure development.

Pinch analysis software can be leased from several venders and numerous training courses are available. One can also develop their own spreadsheet analysis program with knowledge of Pinch principles. Along with employing this technique to target and identify projects, good process engineering cannot be overlooked for successful cost reduction projects.

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