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Industrial wastewater minimization using water pinch analysis: a case study on an old textile plant

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Abstract Industrial wastewater minimization can be conducted using four main strategies: (i) reuse; (ii) regeneration-reuse; (iii) regeneration-recycling; and (iv) process changes. This study is concerned with (i) and (ii) to investigate the most suitable approach to wastewater minimization for an old textile industry plant. A systematic water networks design using water pinch analysis (WPA) was developed to minimize the water usage and wastewater generation for the textile plant. COD was chosen as the main parameter. An integrated design method has been applied, which brings the engineering insight using WPA that can determine the minimum flowrate of the water usage and then minimize the water consumption and wastewater generation as well. The overall result of this study shows that WPA has been effectively applied using both reuse and regeneration-reuse strategies for the old textile industry plant, and reduced the operating cost by 16% and 50% respectively.

Keywords COD; textile industry; wastewater minimization; water pinch analysis; water usage minimization

Introduction

Malaysia is striving towards becoming an industrialized nation by the year 2020. Despite the regional economic turmoil in the late 1990s, the rapid progress in urbanization and industrialization has brought forth an increase in infrastructures and industrial development. In addition, pollution control has been implemented to combat the degradation of the environment in Malaysia particularly that caused by industry activities. The Government of Malaysia estimates the following breakdown of industrial polluters: food processing (40 percent), rubber and palm oil industries (35 percent), industrial chemicals and electronics (12 percent), and textiles (9 percent) (USAEP-Malaysia, 1996). It is estimated that water pollution will continue to worsen in the future due to the increased volume and pollution load of wastewater that is discharged into the receiving water. Therefore, to encounter the problem large amount of investment has been and will be spent in treating the wastewater generated in order to meet the Environmental Quality Act (Sewage and Industrial Effluent, 1979). This is generally a burden for the small and medium scale industries (SMIs) in which most of the textile companies are classified in Malaysia.

Industrial wastewater is generated by processes as by-products of reaction and when water comes into contact with process materials in mass transfer and washing operations, direct contact heat transfer and steam ejectors (Wang & Smith, 1995). Once the wastewater generated has been minimized, it would directly affect both wastewater treatment and freshwater costs. There are four general strategies or approaches to water and wastewater minimization (Smith, 1995).

1. Reuse: Wastewater can be reused directly in other operations provided the level of previous contaminants does not interfere with the process. Reuse might require wastewater to be mixed with wastewater from other operations and/or freshwater.
2. Regeneration-reuse: Wastewater can be regenerated for purification by partial treatment to remove the contaminants, and then reuse in other operations. Again, reuse after

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regeneration might require mixing with wastewater from other operations and/or freshwater. When wastewater is reused after regeneration, it does not re-enter processes in which it has previously been used.

3. Regeneration-recycling: Wastewater can be regenerated to remove contaminants which have built up and then recycled. In this case, regenerated wastewater can re-enter processes in which it has previously been used.
4. Process changes: Process changes can reduce their inherent demand for water. For example, wet-cooling towers can be changed to air coolers, or washing operations can have the number of stages increased, etc.

It is important to distinguish between the first three approaches. In some cases recycling operations might be allowed. In other cases, it might not be allowed due to the built-up of contaminants not removed in the regeneration process (Wang and Smith, 1994).

A study has been conducted on the textile plant (Wong *et al.*, 2000) This paper will illustrate methods to target and design for minimum wastewater for the above first two approaches, i.e. reuse and regeneration-reuse. Although the focus is on an old textile plant, the methodology of this study could still be applied to any type of process industry, which consumes large amounts of water, and generates high volume and concentration of wastewater.

Water pinch analysis (WPA) for wastewater minimization

Water and wastewater minimization are generic issues in integrated process design (Linnhoff, 1993). Most wastewater design systems consist of a number of steps, which relate to different parts of the process, and are linked by water. Water may be supplied as freshwater or may originate from the process itself. In the case of integrated wastewater system design, wastewater can be reused and/or regenerated in all manner of possible configurations. As a result of reuse and regeneration, the overall water flowrate through the system is minimized. However, there will be various operational and design constraints in practical applications (Linnhoff, 1993).

WPA evolved from the concept of process integration in the domain of chemical engineering. It is also known as water pinch technology, which is a type of mass exchange integration involving water-using operations (Mann and Liu, 1999).

WPA is used for the minimization of wastewater in the process industries. It considers individual process constraints relating to mass transfer driving force, fouling, corrosion limitations, etc. (Linnhoff and Smith, 1994). WPA addresses single and multiple contaminants and includes opportunities for wastewater reuse, regeneration-reuse and regeneration-recycle approaches. It involves various methods that can set targets for the minimum overall use of water and identify designs that can achieve these targets. Therefore, WPA basically can be defined as a systematic technique for analyzing water networks and reducing costs for consumption. An industrial wastewater minimization project, in general, is a systematic effort to increase the regeneration, reuse and recycling of wastewater on a plant-wide scale, and such a project has been industrially implemented for a number of years using conventional methods. WPA does not replace the conventional principles. Instead, it provides a better means to identify an appropriate goal for wastewater reuse, regeneration-reuse and regeneration recycle, then pinpoints the available options using water networks design to an achievable approach the minimum flowrate targets as closely as possible.

Case study

A textile plant is chosen as a case study, and WPA was applied to minimize wastewater generation as well as water consumption. Prior to that, a general idea and methodology of the

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project has been formulated. Figure 1 shows the procedure for wastewater minimization applied in this study.

The plant owned by Company X, was incorporated and installed in 1957. The plant was the first textile factory established in Malaysia. Today, the company has three textile plants at different locations, that can produce 20 million metres per annum, with an annual turnover of RM 60 million (approximately US$ 16 million). At this study location, the plant has 200 employees with an average of 1,000 te of daily freshwater consumption.

In order to understand the textile plant, it is required to identify the major departments that consume large quantity of freshwater in the plant, i.e.:

1. Bleaching (singeing, mercerizing and bleaching) is to remove natural colorants, waterborne stains and oil-borne soils. In this paper, only the bleaching department is considered.
2. Finishing is to improve the appearance.
3. Dyeing is a process where the dyes are added.
4. Printing is the application of additional dyes to the surface of the cloth.

Methodology

In this study, three parameters have been identified and regularly evaluated, i.e.:

1. Water consumption (overall and in each process)
2. Chemicals consumption
3. Effluents quality

However, at present the company has only two sub-main water meters recording volumetric consumption in units of m^3, which are located at the bleaching and finishing departments, respectively for daily routine monitoring purposes. It is actually an inadequate way to monitor the freshwater usage. This explains why the present study is only focused on the bleaching department.

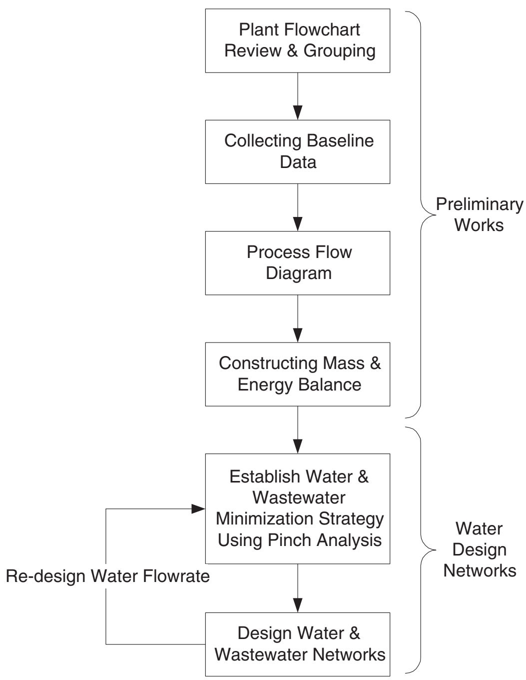

Figure 1 General steps in wastewater

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Freshwater is also used for factory cleaning that also contributes to wastewater generation. Workers generally depend on their own experience, rather than following a procedure in handling or adding the chemicals into the processes. This not only causes wastage of chemicals due to over-dosing, but it can also increase the degree of the pollution load in wastewater.

The company uses a conventional biological wastewater treatment system, i.e. activated sludge coupled with coagulation before discharging the wastewater into a reservoir and then to a river nearby. Sometimes, the treatment system fails to operate due to shortage of retention time or occasionally overloading.

It is technically known that when the wastewater is produced in higher than the designed quantity and quality, the biological treatment process is not able to operate effectively. Most of the colors and auxiliary chemicals from the processing textiles persist through the treatment plant and enter the receiving water.

In order to plan and execute WPA in the four major departments, a sequence of project tasks as shown in Figure 2 have been implemented. In this paper, only WPA to the bleaching department, which consists of three units, i.e. singeing, mercerizing and bleaching will be presented.

Wastewater parameters that are annually monitored in the plant are COD, BOD, SS and pH. These parameters are important to control the treated wastewater before discharging into the receiving water. In order to collect the wastewater data for this study, we have to identify the locations where the wastewater comes from within the system. Thus, eleven main holes have been identified for wastewater sampling and analysis. It is not only to identify the contaminant concentration but also for the purpose of developing a mass balance diagram.

The measurement of the most significant wastewater parameters, such as the concentrations of BOD, COD, SS etc. is very important to illustrate the concentration of the contaminant. In this case study, COD has been chosen, as a measure of the single contamination, and is considered to be the most appropriate parameter due to the high organic loading used in the textile processes. Water Design® software has been applied to solve the modeling equations and develop the water networks design for this case study.

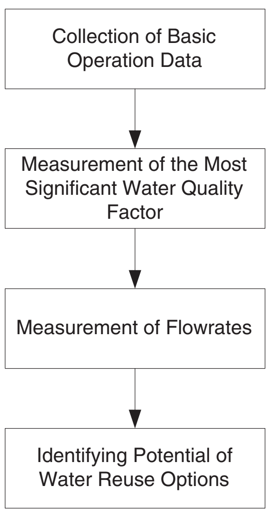

Figure 2 Flow diagram showing the sequence of the project task in order to redesign the water and wastewater networks in textile plant

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Results and discussion

Table 1 gives the measurements of the flowrates and concentrations of COD of the three water-using operations in the textile plant. COD for freshwater is assumed to be 0 ppm in the textile plant.

The total minimum freshwater flowrate for the entire single contaminant problem without water reuse or recycling is simply the sum of the minimum freshwater flowrates required by each operation, as follows:

$$f_i^{\lim}(te/hr) = \frac{\Delta m_{i,\mathrm{tot}}(\mathrm{kg/hr})}{[C_{i,\mathrm{out}}^{\lim} - C_{i,\mathrm{in}}^{\lim}](\mathrm{ppm})} \times 10^3 \quad (1)$$

where $C_{i,\mathrm{in}}^{\lim}$ is contaminant level in the inlet stream, $C_{i,\mathrm{out}}^{\lim}$ is contaminant level in the outlet stream, $\Delta m_{i,\mathrm{tot}}$ is the total mass load of contaminant to be transferred and $f_i^{\lim}$ is the minimum freshwater flowrate.

To determine the overall outlet concentration of the contaminant in the water stream for the whole system at the bleaching department, we calculate the flowrate-weighted average of the combined streams, as follows:

$$C_{out}^{w} = \frac{\sum_i f_{i,\min}(\mathrm{te/hr})C_{i,out}(\mathrm{ppm})}{f_{\min}(\mathrm{te/hr})} \quad (2)$$

where C_{out}^{w} is the overall outlet concentration contaminant and $C_{\mathrm{i,out}}$ is outlet concentration of the water-leaving operation.

Using the calculated values, the mass balance diagram for the bleaching department as shown in Figure 3 is drawn. Table 2 shows the highest possible inlet and outlet concentrations that still allow mass transfer from the contaminant-rich process streams to the water stream to occur, $C_{i,\mathrm{in}}^{\lim}$ and $C_{i,\mathrm{out}}^{\lim}$, respectively, that has replaced the original inlet and outlet concentrations of COD for various water sources, $C_{\mathrm{i,in}}$ and $C_{\mathrm{i,out}}$, respectively. Thus, Table 2 represents the limiting process data for the bleaching department.

Table 3 is the concentration-interval diagram (CID) for the bleaching department. The freshwater pinch concentration is 476 ppm and the minimum freshwater flowrate is 35.84 te/hr. Based on Figure 4, the graph shows that the outlet concentration of the study is 1,869 ppm. Compared to the water usage before applying WPA as shown in Figure 3, an obvious reduction in freshwater consumption from 43.16 te/hr to 35.84 te/hr can be seen. This saves approximately 17% of freshwater consumption for the whole textile plant.

Table 1 Original water using operation data for textile plant in the bleaching department

Operation	$f_{\mathrm{i,in}}$ (te/hr)	$C_{\mathrm{i,in}}$ (ppm)	$C_{\mathrm{i,out}}$ (ppm)	$\Delta m_{\mathrm{i,tot}}$ (kg/hr)
Singeing	2.67	0	47	0.13
Mercerizing	22.77	0	401	9.13
Bleaching	18.17	0	3171	57.62

Table 2 Limiting process data for textile plant in the bleaching department

Operation	$f_{\mathrm{i,in}}$ (te/hr)	$f_{\mathrm{i,out}}$ (te/hr)	$C_{\mathrm{i,in}}$ (ppm)	$C_{\mathrm{i,out}}$ (ppm)	$\Delta m_{\mathrm{i,tot}}$ (kg/hr)
Singeing	2.67	2.67	0	47	0.13
Mercerizing	22.77	22.77	75	476	9.13
Bleaching	18.17	18.17	47	3218	57.62

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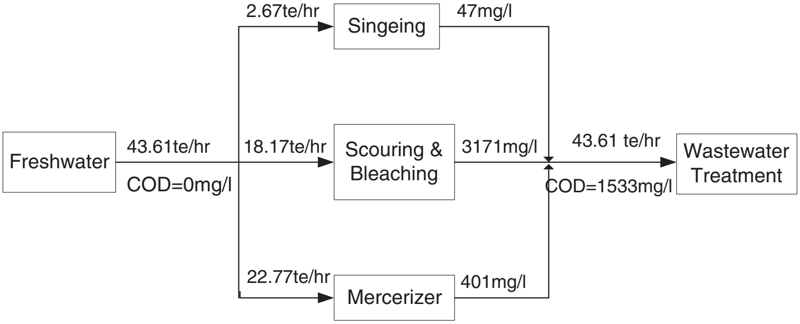

Figure 3 Mass balance in the bleaching department before applying WPA

Table 3 Concentration interval diagram (CID) for textile plant in the bleaching department for reuse approach

Concentration (ppm)	Singeing (2.67te/hr)	Mercerizing (22.77 te/hr)	Bleaching (18.17 te/hr)	Mass load (kg/hr)	Cumulative mass load (kg/hr)	Flowrate (te/hr)
0					0.00	0.00
	↑			0.13		
47					0.13	2.77
			↑	0.51		
75					0.64	8.53
		↑	↑	16.42		
476					17.06	35.84
			↑	49.82		
3218					66.88	20.78

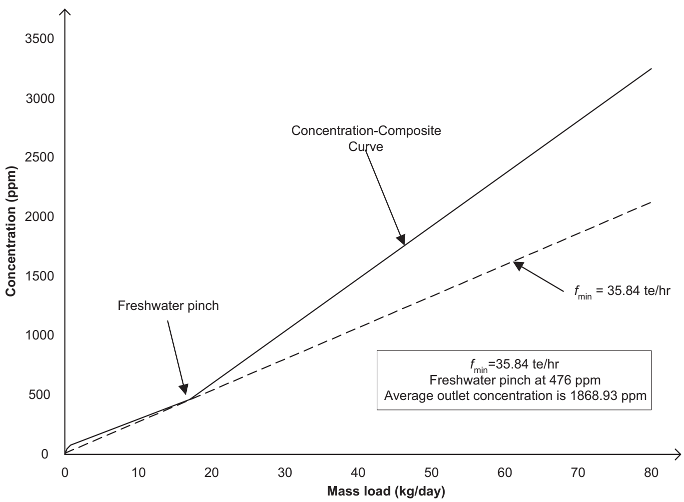

Figure 4 Concentration-composite curve optimum water supply line for bleaching department

Figure 5 shows the mass balance for the water-using network after applying WPA. It is designed to meet the minimum freshwater and wastewater flowrates using wastewater reuse scheme. Prior to designing the water-using network for the entire textile plant, there are three technologies that should be followed, i.e.:

1. Reuse wastewater from the same processes
2. Reuse wastewater from other processes
3. Use freshwater

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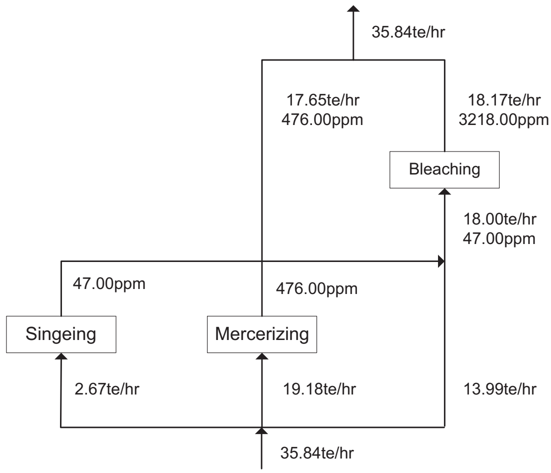

Figure 5 Mass balance for the simplified water-using network after applying WPA for bleaching department

Meanwhile, with partial regeneration technique, the regeneration-outlet concentration, C_o is assumed to be 125 ppm. In this case, the freshwater consumption and wastewater generation can be reduced. Table 4 shows the minimum flowrate is 21.45 te/hr and the regenerated flowrate is 19.52 te/hr.

The cost-saving analysis after using WPA is demonstrated in Table 5. However, capital cost is not included. It shows that with WPA, cost-saving can be in the range of RM92,600 and RM267,250 per year for freshwater in reuse and regeneration-reuse approach, respectively. In addition, RM8,684,200 and RM25,541,900 of cost-saving for sludge treatment

Table 4 Concentration interval diagram for partial regeneration-reuse approach for bleaching department

Concentration (ppm)	Singeing (2.67te/hr)	Mercerizing (18.17te/hr)	Bleaching (22.77te.hr)	Mass load (kg/hr)	Cumulative mass load (kg.hr)	Flowrate (te/hr)	Partial regeneration flowrate (te/hr)
0					0	0	
				0.13			
47					0.13	2.67	
				0.51			
75					0.64	8.53	
				2.05			
125					2.69	21.45	
				14.37			
476					17.06	35.82	19.52
				49.82			
3218					66.88	20.78	

Table 5 The cost-saving before and after using WPA

Cost	RM/m³ per year before WPA	RM/m³ per year after WPA (reuse)	RM/m³ per year after WPA (regen-reuse)	Reuse saving RM/year	Regen-reuse saving RM/year
Freshwater	544,500*	451,900*	277,250*	92,600	267,250
Wastewater	51,083,800**#	42,399,600**#	25,541,900**#	8,684,200	25,541,900

* Cost of freshwater = RM1.60/m^3
** Assume: cost of industrial sludge = RM500/te, i.e. the minimum charge of hazardous waste treatment and disposal provided by Kualiti Alam (M) Sdn. Bhd.
# Assume: consider the calculation is based on sludge, i.e. 30% of the volume of wastewater

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and disposal using WPA in reuse and regeneration-reuse approach, respectively, can be achieved.

Conclusion

Industrial wastewater minimization using WPA on an old textile plant has been conducted using two main strategies: (i) reuse; and (ii) regeneration-reuse. A systematic water network design using WPA has been developed to minimize the water usage and wastewater generation for the textile plant. An integrated design method was applied to determine the minimum flowrate of the water usage and then to minimize the water consumption and wastewater generation. This study has shown that with the regeneration-reuse approach, we can effectively minimize the freshwater consumption and maximize the wastewater reused by approximately 50% compared to the reuse approach, which can potentially result in only 16% of saving in freshwater consumption. Both approaches can ultimately result in the reduction of costs for the textile plant.

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