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INDUSTRIAL WASTEWATER MANAGEMENT: THE WATER PINCH ANALYSIS APPROACH

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ABSTRACT

Water, a necessary and important resource for the process industry is growing in demand every year as the result of the booming world population. Wastewater generation in industrial operations and consequent harsh environmental disposal regulations calls for intensive '*in si-tu*' wastewater management. This paper describes how the water pinch analysis (WPA) technique, based on the pinch technique, wasadapted to establish the reduction of freshwater demand for a typical Nigerian brewery. TheWPA is a graphical methodology for freshwater and wastewater minimization. The results obtained showed that applying the reuse approach of the WPA to brewery operation could lead to a reduction in freshwater demand of 17.08% with a freshwater pinch of 1570.00 ppm and an outlet average concentration reduced from 9684.00 ppm to 8507.70 ppm. The WPA technique can rapidly yield accurate minimumwater targets, pinch-point locations and water allocation targets for a brewery water network which could be very useful in management decisions.

KEYWORDS: Freshwater Demand, Pinch Point, Wastewater Generation, Wastewater Management, Water Pinch Analysis

INTRODUCTION

In recent years, the rapid growth in population, industrialization and urbanization has resulted in an increase in the demand for water leading to serious environmental consequences [1,2,3], and stringent regulations for industrial effluents has led to a paradigm shift in thinking about water usage [4].

The amount of water used in manufacturing varies significantly from industry to industry as well as process to process. Alva-Argaez et al [5] reported rough estimate consumption in chemical manufacturing for total process and cooling water usage as between 4.5 – 45 litres per kg of product. After utilizing the water, these processes deliver wastewater, which contain various hazardous or toxic pollutants that need to be strictly controlled. Therefore a critical environmental concern of the chemical processing industries (CPI) lies in the generation of large quantities of organic and chemical bearing wastewater.

As water supply and treatment costs increase, there will be increasing pressure onCPI to reduce water consumption [6,7]. Also, the need for CPIs to cope with the dynamically changing environmental regulations and the need for reducing the wastewater discharges into the environment through wastewater reuse and recycling programs is becoming more significant in the process industries. Thus, water conservation and wastewater reuse and recycling programs are proven to be more economical in the recent past.

In most wastewater management scheme, wastewater is treated before discharge into the environment to remove contaminants to such limits that meets environmental regulations. Water treatment processes are expensive. Hence, the minimization of freshwater usage as well as wastewater generation in process systems is of great environmental and economic importance. Focussing on processes that generate wastewater in industries, ensuring proper process-to-process freshwater utilization, recycling, regeneration and reuse methodologies, have proven to minimize wastewater generation in various processing industries [8], thus achieving adequate wastewater management.

There are so many researches in water minimization to solve this problem in industries with different spatial approaches [9,10,11,12,13]. Water system integration, one of the important methodologies of wastewater minimization(otherwise known as water pinch analysis) considers how to allocate the water quantity and quality to each water using unit, so that water reuse is maximized within the system and simultaneously the wastewater generation is minimized. This method shows excellent effectiveness in saving freshwater and reducing wastewater [14]. Water reuse is gaining popularity throughout the world as an option for supplying a reliable alternative supply of water for applications that do not require high-quality water, freeing up limited potable water resources, while reducing effluent discharges into receiving waters [15,16].

The brewery, one industry that is of important economic value in the agro-food sector, utilizes large amount of water and generates considerably large amount of wastewater in its processes. About 67.76% of the fresh water utilized in beer production is generated as wastewater. Except for the quantities of water that beer holds in or its by-products, the rest of it is considered aswastewater. The brewery's wastewaters as a result of its materialcontentrequire a high level treatment, which are usually very expensive[17,18]. Xiao et al [19] reported that breweries are among CPI that consumes large amount of freshwater per ton of beer.

Generally about 10–40 t of freshwater is consumed, and at the same time, producing one ton of beer correspondingly generates 7–35 t wastewater. The wastewater consists of non-toxic organic components in higher concentration, such as protein, fattiness, fibre, carbohydrate, waste yeast and hop residue. Such wastewater, when discharged into the natural water result in serious environmental pollution. How to decrease effectively the environmental pollution from beer wastewater and reduce the cost of beer production, by means of saving freshwater and reducing wastewater discharge, has become an important issue for the breweries.

Water Pinch Analysis, a systematic technique for analyzing water networks and reducing water costs for processes has helped companies to systematically minimize freshwater and wastewater volumes. It uses advanced algorithms to identify and optimize the best water reuse, regeneration and effluent treatment opportunities. It has also helped to reduce losses of both feedstock and valuable products in effluent streams [20].

Hence the objective of this paper is to apply the reuse approach of the water pinch analysis to managing the volume of wastewater generated in a typical brewery in Nigeria with the sole aim of reducing freshwater utilization and minimizing wastewater generation.

WATER PINCH

Wang and Smith [21]introduced a graphical methodology for water and wastewater minimization. This method was established on the basis of developing a pinch technique for heat integration[22]. Each water-using operation is supposed as a mass exchange process. The curve related to each operation is drawn by specifying a maximum acceptable inlet and outlet concentration of that operation. This curve touches the water supply line (which starts from zero point) at one or more points. These points are *pinch points*.

It must be pointed out that this method is based on a contaminant concentration curve versus mass load. The minimum amount of fresh water and the water that can be reused can easily be determined by plotting the curve of total required water on the concentration/contaminant load diagram. This minimum required water is called minimum target and the limit of critical concentration of the process that prevents any drops in target is called the pinch point[23].

Water Cascade Table (WCT)

Tan *et al.* [14,24] proposed the use of Water Cascade Table (WCT) as a supplement to water surplus diagram introduced by Hallale[25]. WCT is tabular and numerical in nature, it eliminate the tedious trial-and-error graphical solution of the water surplus diagram during the determination of the minimum utility targets[26,27].

METHODOLOGY

The analysis of a typical Nigerian brewery was done using the water-pinch analysis method. The steps taken during the analysis are as follows.

- Identification of Water-Using and Wastewater Generation Units.

The process flow diagram of the entire process plant and water network was obtained. The water-using and wastewater generation units were identified.

- Data Extraction

From each of the water-using and wastewatergeneration units identified, the following concentration and flow rate data were obtained.

  - The contaminant concentrations of the inlet and outlet water of each water-using unit available.
  - The corresponding water flowrates of each available unit.
  - The quantity of freshwater consumed by the process plant, which for this typical brewery stands at 175.90 t/h.
  - The quantity of wastewater generated daily as a result of production
  - The mass load was also obtained from the expression as shown below;

    Mass load = Volumetric flow rate x Mass concentration

- Construction of Problem Table

Problem table for data that were obtained was carefully constructed and the data carefully tabulated as shown in Table 1.

- Concentration-Composite Curves

The concentration-composite curves for the selected water using processes were plotted using concentration and mass load values. These plots were used to determine the pinch point of the analysis.

RESULTS AND DISCUSSIONS

- Data Analysis

Water using operations along with contaminant loading for the operation are as shown inTable 1 and the average water demand by the brewery before the application of the water pinch analysis is 175.90t/h.

Table 1: Problem Table for the Water-Using Operation of a Typical Nigerian Brewery

Operation	Limiting Flowrate (t/h)	Limiting Inlet Concentration (ppm)	Limiting Outlet Concentration (ppm)	Mass Load (kg/hr)
Mashing	70.00	0.00	1570.00	109.90
Wort Boiling	75.92	442.00	1695.00	95.13
Mash Filtering	56.58	1596.00	8474.00	389.16
1^0 fermentation	71.54	1950.00	9010.00	505.07
2^0 fermentation	42.64	857.00	1464.00	25.88
Beer Filteration	13.46	900.00	9684.00	117.02

Table 1 shows the various water-using operations of the brewery amongst several other operations. Each of these water-using operations could be seen to generate significantlevel of polluted wastewater. If the generated wastewater is discharged without treatment through the effluent streams to the receiving water body, it will constitute a serious environmental challenge and this will definitely attract a stringent fine by the Environmental Protection Agency. However, the cost of treatment also could be significant, bearing in mind the nature of the contaminants in the wastewater generated.

From Table 1, operations 3,4 and 6 are high pollutant generating wastewater processes, whereas operations 1,2 and 5 generate relatively lower concentration wastewater. Processes with lower concentration wastewater production could therefore be considered for reuse in the other operations in order to minimize the total wastewater generated and reduce freshwater utilization for such units, thereby reducing the overall freshwater demand.

Applying the water pinch analysis with the reuse approach, the concentration-interval diagram (CID) as shown in Figure 1 was constructed matching each water-using operation flowrate with both the inlet and outlet concentration levels. This then enabled the determination of the mass load for each concentration interval and subsequently the cumulative mass load and freshwater flowrates demand for each corresponding concentration level.

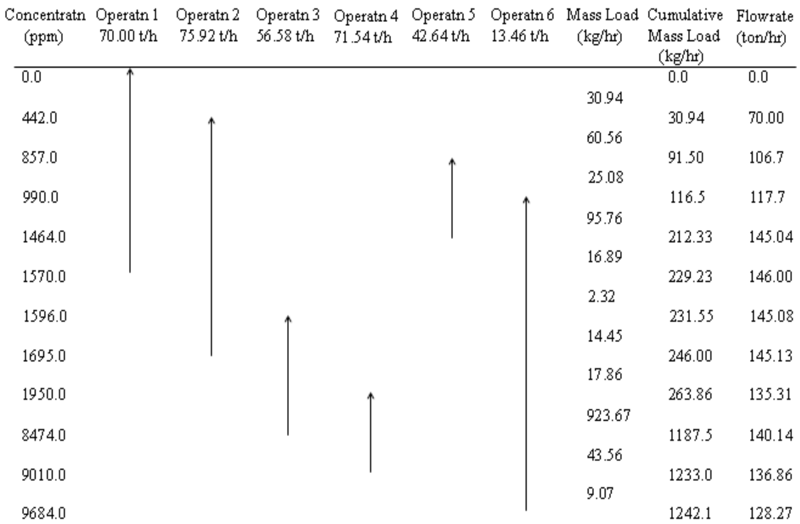

Figure 1: Concentration Interval Diagram for Reuse Approach

The concentration-composite curve (Figure 2) was then plotted from the value of the concentration level and the cumulative mass load of the processes. In Figure 1, it could also be seen that the cumulative mass load for the entire operation stands at 1242.16 kg/hr and the minimum freshwater flowrate needed for the entire operation would be 146.00 ton/hr.

By drawing the freshwater supply line from the origin to touch the concentration-composite curve just at a point (in Figure 2), help to determine the freshwater pinch point, which is the point of tangency.

Thus the freshwater pinched at 1570.00 ppm, which is the maximum allowable concentration level for freshwater supply. Above this concentration level reuse of such contaminated water may not be economical. Thus it could easily be observed in Table 1 that there are pinch violations in operation 3 and 4 in which the inlet concentrations of the streams are above the pinch points.

Also it could be observed from Figure 2 that the average outlet concentration of the effluent stream to be channeled for treatment would be 8507.70 ppm with a corresponding mass load of 1242.16 kg/hr. This is relatively lower compared to the highest 9684.00 ppm of the operation 6 in the existing design.

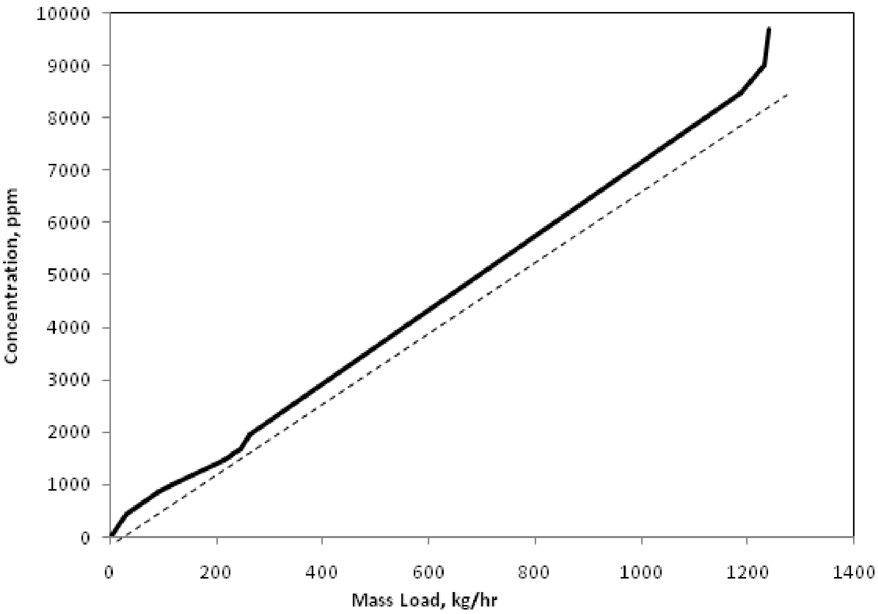

Figure 2: Concentration-Composite Curve for the Reuse Approach

Based on the analysis, the mass balance for the water-using network was then developed to enable proper retrofitting of the water network, Figure 3.

For the simplified water-using network, water supply into the process (reduced from 175.90 to 146 ton/hr) indicated by the thin line, the supply was made to operations 1,2,5 and 6; since their limiting inlet concentrations are lower than the pinch concentration being 1570ppm, thus making them to require freshwater supply.

The exit stream from operation 1 and 5 indicated by the dashed lines, instead of being disposed can be used elsewhere in the process as their concentrations are below the pinch concentration. Thick lines indicate the various water-using operations where wastewater generated have to be disposed.

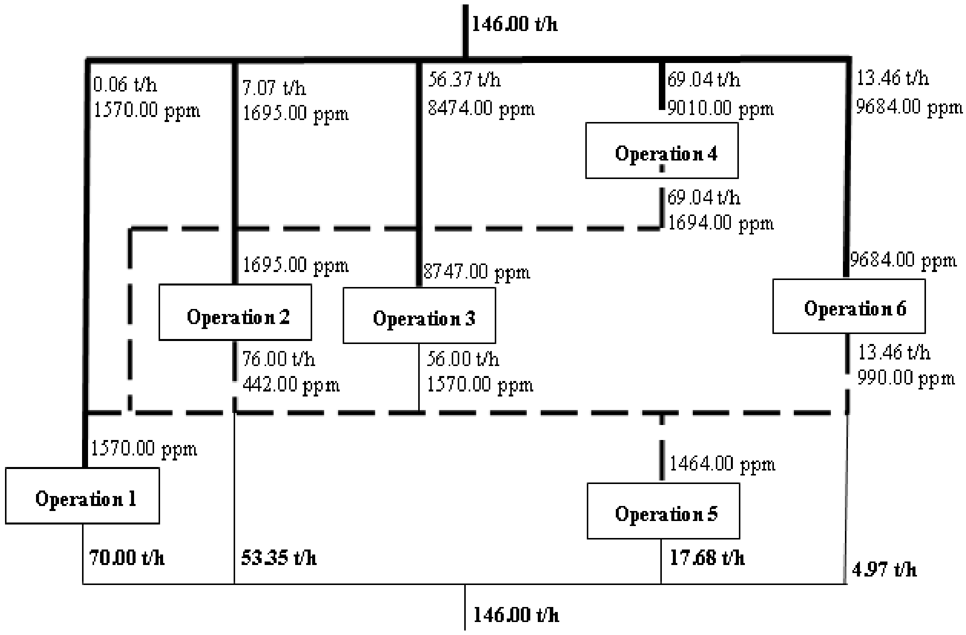

Figure 3: Mass Balance for the Simplified Water-Using Network – Reuse Approach after WPA

CONCLUSIONS

The application of the water pinch analysis was demonstrated on a typical Brewery in Nigeria using the reuse methodology approach. Developing a systematic water network design using the reuse application thus optimized the freshwater utilization of the water-using operations and reduced the water demand by 17.08%, freshwater pinch obtained was 1570ppm with an average outlet concentration of disposed wastewater of 8507.70ppm. This reduction could therefore be translated to potential financial saving annually in terms of both freshwater reduction and minimal wastewater disposed for treatment per batch process of production.

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