Exploring Zero Discharge Potentials for the Sustainability of a Bottle Washing Plant

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ABSTRACT

The beverage industry which requires large amounts of good quality water in their processes is a major contributor to the problem of excessive pumping from existing aquifers in Thailand. In view of a government restriction on groundwater withdrawal, an overall water management plan was drawn for the sustainability of a softdrink plant in Bangkok which depends solely on deepwell source for its water needs. Technologies that can recover water for reuse, minimize raw water input and consequently lead to zero discharge were identified.

The overall water balance drawn for this plant revealed that 76% of the raw water consumed daily ends up in the biological wastewater treatment plant (WWTP). A large portion (40%) of this wastewater is generated from the bottle-washing units. By employing microfiltration for polishing of the WWTP effluent, the plant can recover process water for reuse such that, groundwater input is reduced by 40% and liquid discharged to the receiving water by 56%.

There are two proposed strategies for recovering rinse water from the bottle-washing units. A microfiltration-reverse osmosis system will purify the rinse water for reuse in the bottle washing process, thereby reducing raw water consumption further to 58% and the liquid discharge by 81.5%. On the other hand, a dual filter media-ion exchange system can reduce raw water input to 57% and the liquid discharge by 80.5%.

KEYWORDS

Zero discharge; softdrink plant; water recovery and reuse strategies; sustainability

INTRODUCTION

In the rapidly expanding area of Pathumthani in Metropolitan Bangkok, excessive pumping of water from existing acquifers has been experienced, and has resulted in contractions at the clay beds and ground subsistence of up to 150 mm per annum (DMR, 1991). Statistics show that water withdrawal rate in the Bangkok Metropolis and adjacent provinces is 1.4 million cubic meters per day. Currently, there is a government restriction on digging more wells around the Bangkok area.

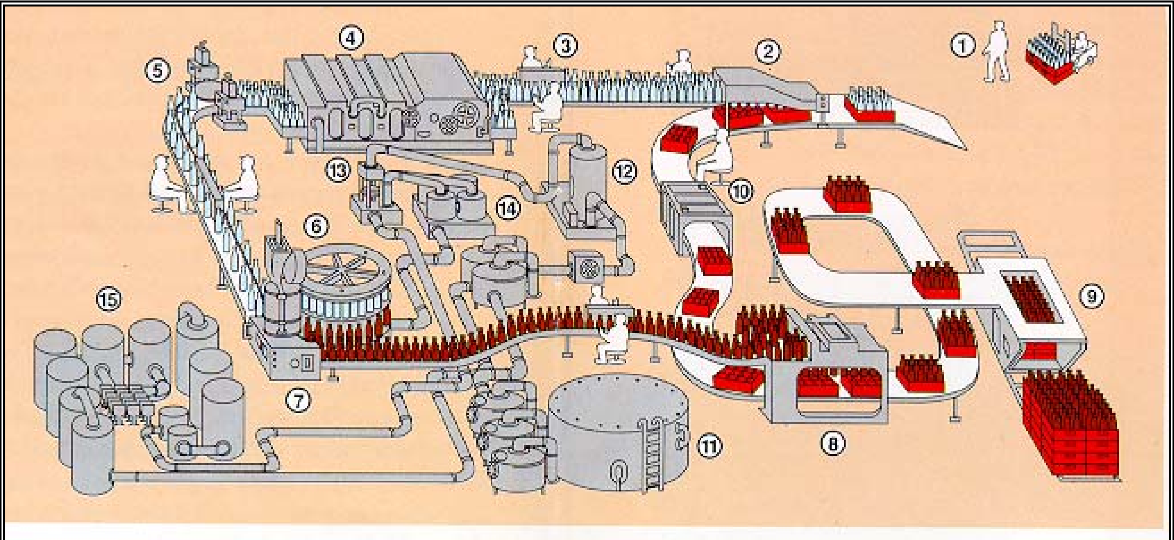
A setting like this has serious implications to industries that depend on groundwater sources for their water supply. The softdrink plant in this particular study which uses a large amount of water would be limited in its future expansion plans. Therefore, it was imperative that alternative ways of finding water sources or conserving water be developed for the sustainability of this company. Thus, zero discharge potentials in this bottle-washing plant were explored.

A facility called zero discharge is one systematic approach to water reuse. It means that no wastewater gets discharged to a receiving surface water. This is the aim set by manufacturing plants which consider that treatment and reuse of total plant effluent is more cost-effective than to treat it for discharge. Zero discharge will then eliminate the reliance of a manufacturing plant on raw water.

BACKGROUND INFORMATION ON THE SOFTDRINK PLANT

Process Description

The general production process (Figure 1) may be described as follows: Simple syrup is produced by dissolving refined sugar in treated water. Then, it is pasteurized at 85°C, filtered, cooled and sterilized using ultraviolet light. The final syrup is prepared by mixing the simple syrup with softdrink concentrate at definite proportions. Sufficient water is then added to dilute the final syrup before it is refrigerated, carbonated and transferred to clean bottles at definite volumes. Finally, the containers are capped or sealed and then packaged for distribution.



Legend:
1 - delivery of returnable bottles
2 - automatic uncasing
3 - visual inspection of dirty bottles
4 - bottle washing
5 - empty bottle inspection
6 - bottle filling
7 - bottle crowning
8 - case packing
9 - pallet loading
10 - case inspction
11 - water treatment
12 - refrigeration
13 - proportionation
14 - carbonation
15 - syrup

Figure 1. Process flow diagram of softdrinks production

Types of Process Water Used

The sole source of water for all plant operations is groundwater drawn from four deepwell facilities inside the plant. This plant does not have any city water supplement for their needs. Groundwater is not directly used for any purpose inside the factory, instead it is treated in several ways to produce *pre-treated*, *soft* and *treated* waters. Consumption values indicate that one liter of beverage produced requires 5.08 liters of raw water. The pre-treated type of water is used for operations which are not directly connected to softdrink production such as cleaning of vehicles and floors, domestic use, backwashing of softeners, etc. Soft water is used for rinsing in the bottle washing units, boilers, and dissolving lubricants in the production line. Overall, the average ratio of soft water consumption to beverage production is 2.05. Treated water is mostly used for the production of softdrink. For every liter of beverage produced, 1.11 liters of treated water is required.

Wastewater Treatment System

The plant runs a biological wastewater treatment plant (WWTP) that handles the wastewater generated from the production lines and the backwash sludge water generated from the water treatment plants. Wastewater is first pumped into an anaerobic pond for primary stabilization. The stabilized effluent is then pumped into aerated ponds. After aeration, the wastewater is sent to a settling pond, then to a maturation pond before it is finally discharged to Chao Phraya river. The biological WWTP performs satisfactorily and meets effluent standards.

METHODOLOGY

Daily monitoring of water consumption and wastewater generation is conducted by the factory. Data for the period of January 1995 to April 1996 was collected from the factory. From these facts, the average daily rates of water consumption and wastewater generation were determined to aid subsequent planning for water recovery strategies in the plant.

With the aim to reduce raw water consumption and the liquid discharged from the factory, other feasible technologies for water purification and recovery in the plant were taken into consideration. The impact of each alternative was evaluated by drawing an overall water balance for the whole factory and conducting a financial analysis for each.

RESULTS AND DISCUSSION

Demand for Water in the Plant

For the purpose of monitoring the demand for water, the plant has installed water meters along each major stream around the plant. These meters are read daily and records are compiled on a monthly basis so that they can serve as indicator of possible water losses or irregularities in the processing lines. Considering the fluctuations in the production rate of the plant over the year and the consequent variation in the amount of water consumed, the daily consumption rate was taken as the average values over a one-year period. In Figure 2, the overall water balance is shown . Assumptions were made regarding the losses of water incurred in each water treatment system. Therefore, out of the total raw water drawn from the deepwells, 31.3% is consumed as pre-treated process water, 21.9% as treated water and 40.3% as soft water. The rest is assumed lost in the treatment processes.

Rate of Wastewater Generation

There are two influent pipes with installed flowmeters that measure the flowrate of the influent as it is pumped from a water sump to the anaerobic pond. A flowmeter attached to

a computer records the flowrate every hour. According to flowmeter readings, the average amount of influent handled by the wastewater treatment plant is 4,298 m^3/d.

The average daily amount of wastewater generated by the plant was also deduced from the amount of input water to various unit processes. Table 1 shows that the total wastewater accounted for is 4,243 m^3/d, which is 98.7% of the average daily flowrate of influent measured at the WWTP sump.

Table 1 Average water consumption and wastewater generation rates of the plant

WATER QUALITY	*TYPE OF USAGE*	*CONSUMPTION RATE (m^3/d)*	*WASTEWATER GENERATED (m^3/d)*
Pre-treated	line D cleaning	49	49
	cleaning of trucks	123	123
	scrubbers	10	10
	training center	22	11
	canteen	21	11
	backwashing of softener tanks	338	338
	manual washing of stocks	117	117
	cleaning of toilets, machines, etc	1,071	854
	Sub-total	1,751	1,513
Soft	lubrication of line D	40	40
	post-mix line	96	96
	PET line	35	35
	boilers	68	55
	cooling water (refrigeration)	307	307
	bottle washers	1,708	1,708
	Sub-total	2,254	2,241
Treated	product	1,101	0
	cleaning of pipelines/drinking	125	122
	Sub-total	1,226	122
Treatment Losses (filter backwash, etc.)		367	367
GRAND TOTAL		5,598	4,243

<u>Water Reuse Strategies in the plant</u>

A. Microfiltration of Wastewater Treatment Plant Effluent

Data has shown that 20% of the raw water input is converted into softdrink while 76% ends up in the WWTP. The amount of wastewater that goes to the WWTP daily is 4,243 m^3. Considering the amount of wastewater lost from the 49,000 m^2 ponds due to evaporation and soil seepage, the final effluent discharged to the river is 3,994 m^3/d. If this amount of water undergoes further treatment, then this can be recycled back to the plant and the total amount of water withdrawn from the wells can be reduced. Hence, employment of a technology that will polish the wastewater treatment plant effluent before it gets discharged to the receiving water will help conserve precious water reserves.

Microfiltration (MF) of WWTP effluent can give good quality permeate that can be recycled for various uses within the plant. Microfiltered water which is free of suspended materials, bacteria and colloidal matter is ideal for reuse in processes which do not require high quality water such as those that consume pre-treated water. It can also be softened for distribution to soft-water-requiring streams outside the main production line. This zero discharge option has actually been adopted by the plant. A polishing unit equipped with 0.2μ hollow fiber, polypropylene MF membrane modules has been installed at their WWTP.

The reuse of microfiltered effluent results to a reduction in raw water consumption. Fourty one percent of the WWTP effluent can be directly reused for some of the plant's water needs while 10% more can be softened prior to utilization. This creates two positive impacts to the environment: first, the amount of water that is discharged to the river is significantly reduced by 56%; and second, raw water drawn from the wells is conserved considerably by 40%.

The proposed reuse strategy was limited by the fact that reuse can only be done for purposes such as cleaning of production floors and surrounding areas, delivery vehicles, and the like. Soft water produced from microfiltered effluent is also useful as process water for boilers and cooling water for the refrigeration plant. In the main production area, it can also be used for lubricating conveyor belts. This proposed water reuse strategy ensures that no recycled water will be used for processes that have direct contact with the product.

B. Purification and Reuse of Bottle Washer (BW) Rinse Water

The water balance clearly shows that the bottle washing units have the highest demand for water. These units also generate the largest amount of wastewater compared to other unit processes in the plant. Therefore, it is seen that a great potential for water conservation lies in purifying and reusing the relatively good quality final rinse effluent from the bottle washing units instead of draining it to the WWTP.

The plant has four bottle washing units, each supplied with an average rate of 427 m^3/d of soft water for rinsing. A part of the final rinse is reclaimed for the pre-rinse section where it gets discharged as a highly organic wastewater while the rest of it is drained to the WWTP. The final rinse effluent is discharged to the underdrain at the rate of 276 m^3/d per BW unit. Table 2 shows the characteristics of this waste stream.

Table 2. Final rinse bottle washer wastewater characteristics

PARAMETER	*Final Rinse Effluent*
Temperature (°C)	40-50
pH	10-11
Color (Hazen units)	5-10
Turbidity (NTU)	5.2
TDS (mg/L)	1,832
Conductivity (μS/cm)	1,628
Suspended solids (mg/L)	32
COD (mg/L)	393
Caustic concentration (mg/L)	720

There are two possible ways of doing this. First is by membrane filtration. This can recover pure water and concentrate the caustic content of the rinse water at the same time. Second is by ion-exchange, whereby caustic is removed from the rinse water and pure water is recovered for reuse. The intention in this research was mainly to generate a conceptual design for the plant under study.

B1. Membrane Filtration of Bottle Washer Rinse Water

A research by Tay and Jeyaseelan (1996) revealed that bottle washing wastewater can be treated by membrane filtration for reuse. The study further showed that it was economically feasible because the treatment systems did not only reduce the consumption of input water but energy was conserved as hot water was recovered in the process. Conceptually, the RO system will produce an effluent that is better than potable water, thus it will be acceptable for reuse in the bottle washing units.

It is proposed that a MF unit be installed as a pre-treatment unit for such a system. If the MF/RO system were employed for the recovery of the wastewater from the last BW compartment and the final rinse effluent that is directly discharged to the WWTP, then, 285 m^3/d of rinse water is potentially recoverable from each of the four bottle washers in the plant. At the same time, the caustic drained from the system can be recovered as a concentrate in the RO system. Assuming an overall yield of 83% for the MF/RO system, then a total of 237 m^3/d of soft water and 5 m^3 of 3% (w/w) of caustic solution (containing 170 kg of NaOH) can be recycled back to the bottle washers (Figure 3) daily. This reduces the amount of input rinse water by 56% and the input caustic soda by 60%. The impact of this recovery system on the overall water balance in the plant is illustrated in Figure 4.

Considering that the microfiltered effluent is utilized as suggested earlier, then, purification and reuse of rinse water will further reduce raw water consumption by 58%. This reuse strategy will have a corresponding effect on the wastewater generation of the plant and will lead towards zero discharge by reducing the water discharged to the river from the original 3,994 m^3/d to 740 m^3/d, achieving 81.5% reduction.

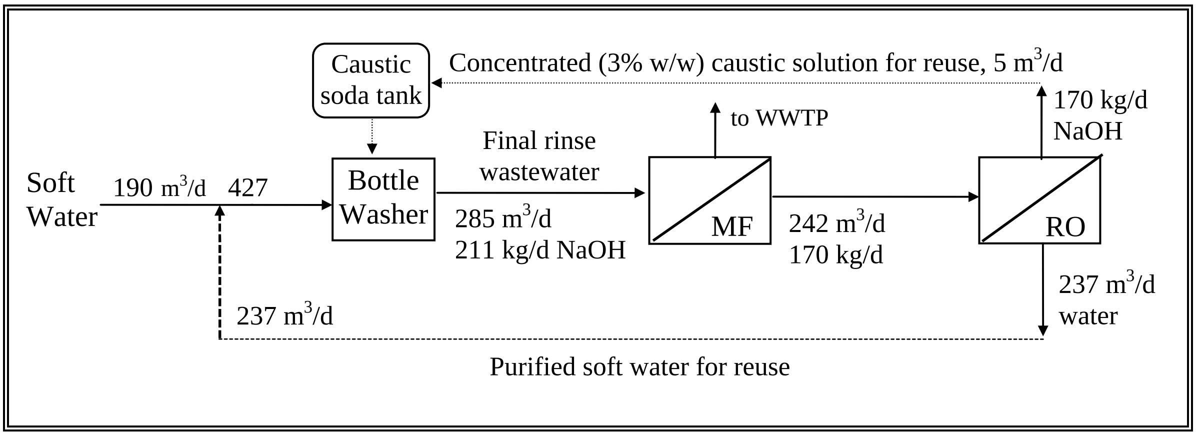


Figure 3 Schematic of the proposed MF/RO system for caustic and water recovery

In water softening, ion exchange (IE) is extensively used to remove calcium and magnesium ions in water by replacing them at a solids interface with another non-hardness cation, usually sodium. For the purpose of purifying the final rinse water contaminated with NaOH, a weak acid cation exchange column can be employed. As the alkaline water is contacted with the resin, the following generalized reaction occurs:

$$R\text{-}COOH + NaOH \longrightarrow R\text{-}COONa + H_2O$$

As long as exchange sites are available in the medium, reaction will be virtually instantaneous and complete. However, when all exchange sites are utilized, regeneration of the resin should be carried out by contacting it with 35% HCl solution. The strength of the regenerant solution overrides the selectivity of the adsorption sites (Peavy et al., 1985) and sodium is replaced by hydrogen as shown in the following reaction:

$$R\text{-}COONa + HCl \longrightarrow R\text{-}COOH + NaCl$$

To avoid plugging the resin with particulates, it is recommended that the rinse wastewater be pre-treated by dual-media filtration (DF) before it passes through the IE column. For a continuous process to be possible, there must be two units each of the prefilter and the IE column installed for each bottle washer to accommodate the regeneration cycle of the resin (Figure 5). At a designed recovery rate of 80%, the DF/IE system will recover 228 m^3/d of water that can be reused back to the bottle washer.

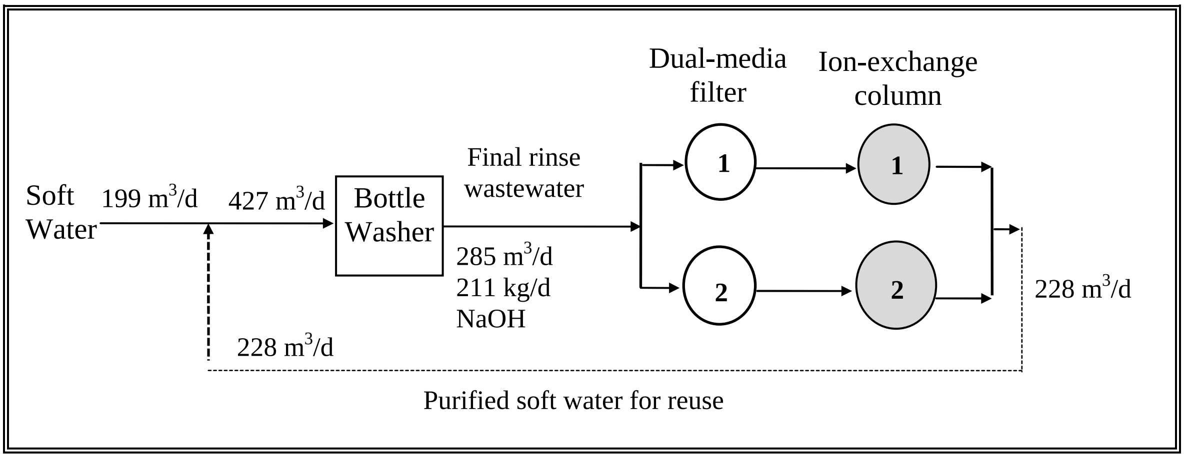


Figure 5 Design schematic of the DF/IE system for final rinse recovery

The overall impact of this alternative on the water balance of the plant will be similar to that of the MF/RO system. Raw water input will be reduced to 57% and the make-up rinse water for the bottle washers will be reduced by 53%. While liquid discharge will be reduced by 80.5% using this water recovery strategy , there will be additional wastewater produced loaded with NaCl due to the introduction of 35% HCl solution for resin regeneration.

Designing a scheme for reduced water consumption and wastewater generation for a specific plant often requires a compromise among water quality needs, wastewater constituents, operating costs and capital equpment costs. A comparison of the two proposed rinse water recovery systems is presented in Table 3. Each alternative has its own pros and cons - choosing an optimum system is simply a matter of corporate decision among the company executives.

Table 3. Comparison of proposed rinse water recovery systems

PARAMETER	*MF/RO System*	*DF/IE System*
1. Raw water consumption (m^3/d)	2,350	2,388
2. Water discharged to river (m^3/d)	740	779
3. Soft water recovered (m^3/d)	948	912
4. Caustic soda recovered (kg/d)	170	0
5. Installation cost (Baht/ BW unit)	4,200,000	1,780,000
6. Net annual savings (Baht/ BW unit)	1,322,000	525,184
7 Net Present Value (Baht/BW unit)	5,500,000	2,200,000
8. Payback period (years/ BW unit)	3.2	3.4
9. Internal rate of return (%/ BW unit)	31.3	30.5

CONCLUSIONS

Water consumption profile of a softdrink plant in Bangkok revealed that raw water is drawn from deepwells at an average rate of 5,598 m^3/d. Out of this volume, 31.3% (1,751 m^3/d) is consumed as pre-treated process water, 21.9% (1,226 m^3/d) as treated water and 40.3% (2,254 m^3/d) as soft water. The amount of wastewater treated in the biological WWTP averages 4,243 m^3/d, of which 40% comes from the bottle washing units.

Given the water consumption and wastewater generation profiles, the zero discharge potentials of the bottle washing plant were explored. This enabled the plant to confront the problem of limited expansion plans with the imposition of a government restriction on digging more wells around Metropolitan Bangkok. Water recovery and reuse strategies drawn that would lead to zero discharge include polishing of the WWTP effluent by MF and purification of the final rinse effluent from the bottle washing units using two types of systems.

Microfiltration of WWTP effluent and recycling of the permeate in unit processes which are not directly in contact with the product leads to cosiderable reductions in raw water input by 40% and liquid discharged to the river by 56%. There are two proposed alternatives for purification of final rinse effluent for reuse in bottle washing units. These are by MF/RO system and DF/IE system. The MF/RO system recovers pure water and caustic solution in the process. This membrane application can reduce groundwater input by 58% and liquid discharged to the receiving water by 81.5%. On the other hand, treatment of rinse water by DF/IE recovers only water. The employment of such a technology will reduce water input to 57% and the liquid discharge by 80.5%.

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