Water Conservation Initiatives and Performance Evaluation of Wastewater Treatment Facility in a Local Beverage Industry in Lahore

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Abstract

Study was conducted to evaluate the potential for water conservation in a local carbonated soft drink beverage manufacturing plant. In order to explore water conservation opportunities, water balance was carried out with the help of flow meters. Average daily water consumption was 3,015m^3 in the said plant. Results of water balance revealed that of the total water consumed in the plant, 46.8% was converted to beverage; while53.2% was used in bottle rinsing, other plant operations and miscellaneous uses. By employing various measures, water saving of 375 m^3/day (12.5%) was achieved; thus reducing the daily water consumption to 2640m^3.In addition, an annual saving of Rs 0.2 million was achieved in energy bill of tube wells. Performance evaluation of wastewater treatment plant revealed that 51.2% of average water used per day originated as wastewater from different plant sections. The mean values of pH, TSS, BOD and COD of treated wastewater were7.7, 39 mg/L,24 mg/L and 52 mg/L, respectively and in compliance with the enforced NEQS. Average removals of TSS, BOD and COD were found to be 59%, 78% and 92%, respectively. The study suggests various in-plant controls for water conservation which may also be implemented in other beverages plants in Pakistan.

Key Words: Water Conservation, Wastewater Treatment; Beverage Industry, BOD; COD

1. Introduction

Per capita water availability in Pakistan has decreased from 5,000 cubic meters in 1951 to 1038 cubic meter per annum in 2010. This is slightly above the internationally recognized scarcity level of 1000 cubic meter [1]. The projection for 2015 is 900 cubic meter per annum [2] [3]. The increasing gap between water supply and demand has led to severe water shortage in almost all sectors. Industrial sector utilizes almost 1973 million m^3 of water per year [4] and in turn generates large volumes of liquid wastes polluting water bodies intended for various beneficial uses.

Considering the scarcity of fresh water and the cost of treatment of wastewater produced, it is logical to investigate methods for conserving water in the industrial sector in Pakistan. Various strategies that can be adopted to reduce the use of fresh water include: changing the industrial processes and operations, installing equipment that uses less water, adopting clean production programs and recycling wastewaters to reduce the need of fresh supplies [1].

In Pakistan the current per capita consumption per annum for the beverage is 20 Liters, whereas in USA it is 340 Liters [5]. It shows that there is great potential of growth in beverage industry in Pakistan in the coming years. Since water is the major ingredient used, therefore, an expansion in this industry may place a burden on already squeezing water resources. There is thus a need to adopt water conservation strategies in beverage industries [6].

Figure 1 shows the water distribution breakdown in one of the beverage industry of

Australia. The figure shows that 60% of total inlet water is consumed in production of beverages whereas 25 % is used in plant cleaning activities. Other consumption areas of water are cooling towers, process operations and auxiliary uses.

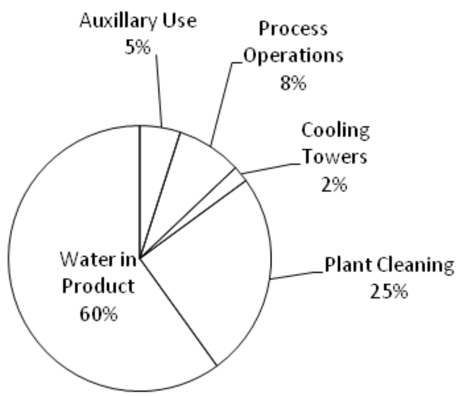

Fig. 1 Water use breakdown -Beverage industry in Australia [7]

Manufacturing process of beverage is briefly explained in Fig. 2.The water is first treated; it is then mixed with other ingredients like sugar and flavors to form syrup. The syrup is then diluted and carbonated with CO_2 to prepare the final form of soft drink. Afterwards, filling is done in washed bottles and packed for delivery [8].

Various renowned beverage brands have taken initiatives to reduce water usage in beverage production [9]. Water usage is usually defined in terms of water usage ratio (WUR). It is the ratio of water used to the volume of beverage produced; lesser is the WUR lesser is the freshwater used per unit production of beverage. Figure 3, shows WUR in Coca-Cola International from year 2004 to 2008. The WUR was reduced from 2.68 to 2.43 through various interventions thereby reducing the consumption of fresh water [10] [11].

In 2009 PepsiCo saved 12 billion liters of water through efficiency improvement in their system. PepsiCo, India manufacturing team has saved 3 billion liters of water during 2005 to 2010, by taking water conservation interventions. Moreover, Pepsico and Pepsico foundation have pledged USD15 Million in taking water conservation measures in developing countries [12].

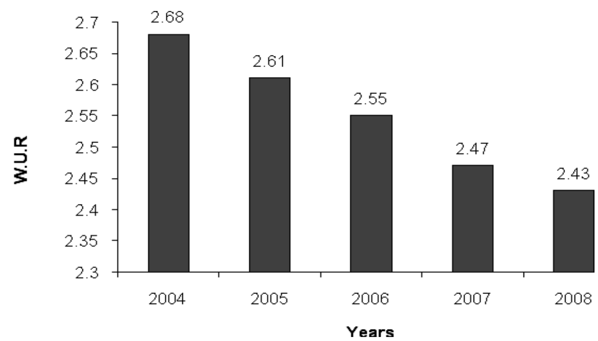

Fig. 3 Water usage ratio of Coca Cola International System [11]

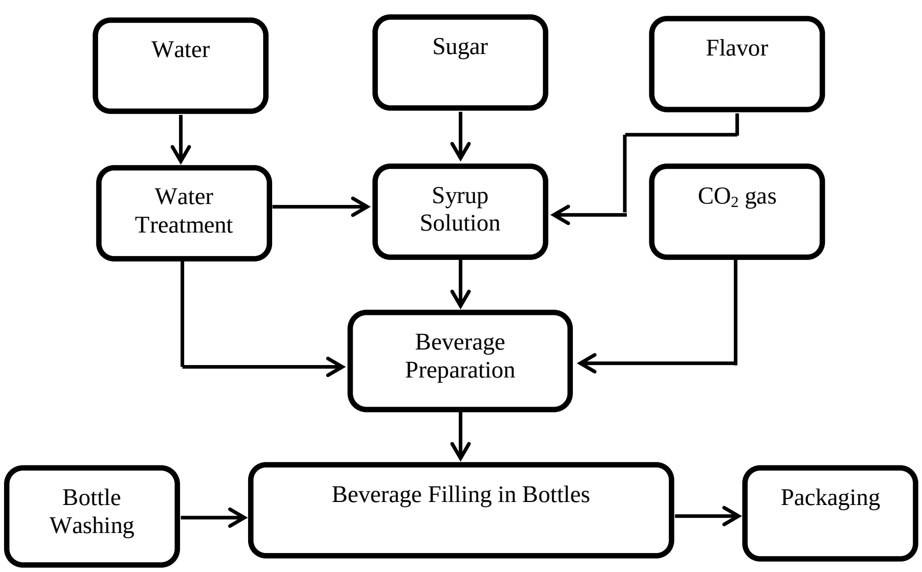

Fig. 2: Concept diagram of processes in beverage manufacturing industry

India has a big market for soft drink beverages.Few cases are observed in India, where beverage plants are shutdown by regulatory authorities due to excessive water consumption. In order to keep healthy competion Pepsi Co international started competion among its plantsin India with respect to water saving initiatives. As a result of this compitition, Pepsico-Palakkad Hyderabad, India reduced its WUR from 4.5 to 1.5 by taking various measures within their beverage plant [13].

Few beverage plants are even aspiring for a zero wastewater discharge by reusing all the wastewater generated within the plant, thus conserving the fresh water. Studies in a soft drink plant in Bangkok revealed that out of the total freshwater used (5,598 m^3/day), 75.7% appeared as wastewater (4,243m^3/day). Water recovery and reuse strategies were drawn through this study that may lead to zero discharge, through polishing of wastewater.

Various technologies like microfiltration (MF) and reverse osmosis (RO) may be used for polishing treated wastewater. It is estimated that by the application of MF/RO, freshwater input may be reduced by 40% with considerable reduction of about 56% in wastewater generated during beverage manufacture. The MF/RO system also recovers caustic solution in addition to water. This caustic solution may also be reused in beverage plant for bottle rinsing [14].

Keeping in view the above efforts for water conservation undertaken at global level, the present study was undertaken to study water usage in different section of a local beverage plant, work out and apply water conservation measures and evaluate the results. In addition, the performance of wastewater treatment plant was also evaluated for compliance with National Environmental Quality Standards (NEQS) [15].

2. Description of the Beverage Plant

A beverage plant situated in Lahore was selected for this study. Fig 4 shows a concept diagram of beverage plant and various water usages in different processes during beverage manufacture. In this plant, freshwater is extracted through 3 tube wells installed inside plant premises. Average total water extraction per day is 3,015 m^3 which is used to produce approximately1410 $m^3$of soft drink [16].

Freshwater (FW) after extraction has three major uses; (1) supply to reverse osmosis (RO) plant; (2) supply to water softener and (3) supply for

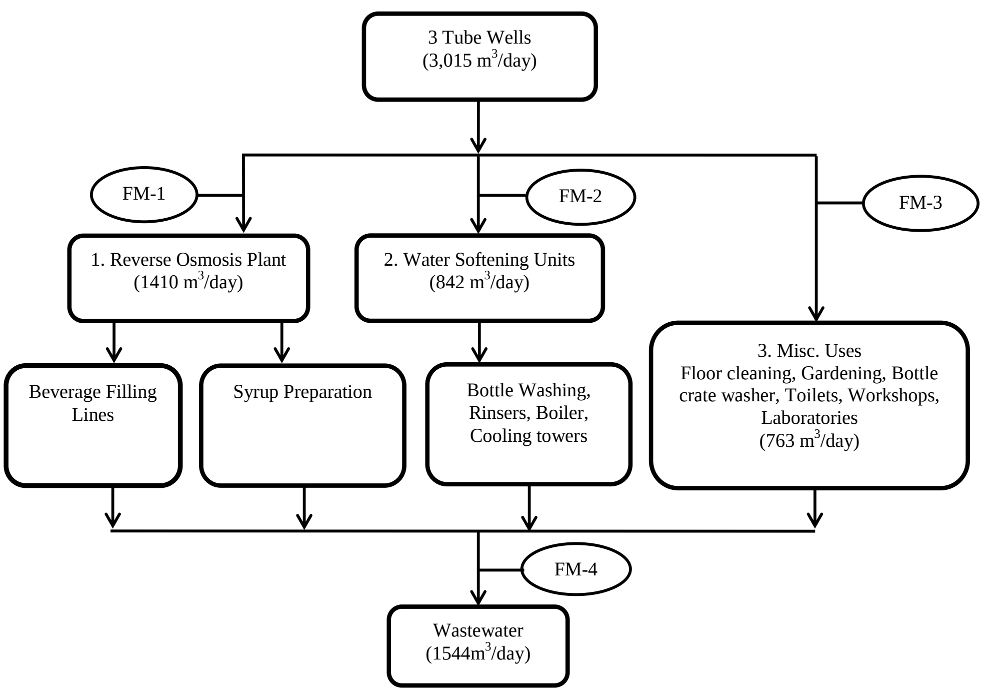

Fig. 4: Flow chart of beverage plant under study and various water inputs in beverage manufacturing processes

miscellaneous uses (Fig. 4). FW after treatment in RO plant is used for syrup manufacturing, which is used for soft drink production. FW supplied to softener is used for bottle washers/rinsers, boilers and cooling towers/circuits after softening. Miscellaneous uses of water in the plant include floor cleaning, gardening, toilet operations, bottle crate washing etc. Wastewater generated from all the above uses is treated in a wastewater treatment plant (WWTP). Flow meters FM-1, FM-2 and FM-3 measure the fresh water flow for each of the above three uses, respectively. Wastewater flow is measured using FM-4.

The quality of groundwater used for beverage manufacturing was also tested and is shown in Table 1.

The wastewater treatment plant is based on activated sludge process. A concept diagram of the plant installed is show in Figure5.

3. Material and Methods

3.1 Methodology Adopted for Water Conservation

3.1.1 Flow monitoring

As mentioned in section-2, four flow meters (FM) were installed in the plant. These were used to measure water flows to different section of the plant during this study. FM-1 gives the consumption of treated water. FM-2 gives the consumption of soft water. FM-3 gives the consumption of miscellaneous water and FM-4 gives total wastewater generation in beverage plant. Flow monitoring helped in making a mass balance of water usage in the plant. Flow monitoring was done at FM-1, 2, 3 and 4 locations as stated above for consecutive 11 days starting from 7.09.2011 to 17.9.2011.

Table 1 Groundwater Quality of the well water at beverage plant

Sr. No.	Ground water quality parameters	Units	Value	NSDWQ*
1	pH	-	7.5	6.5-8.5
2	Total Dissolved Solids	mg/L	430	<1000
3	Sodium	mg/L	232	No Standard
4	Total hardness (as $CaCO_3$)	mg/L	168	<500
6	Bicarbonate	mg/L	250	No Standard
7	Sulphate	mg/L	130	
8	Chloride	mg/L	200	<250

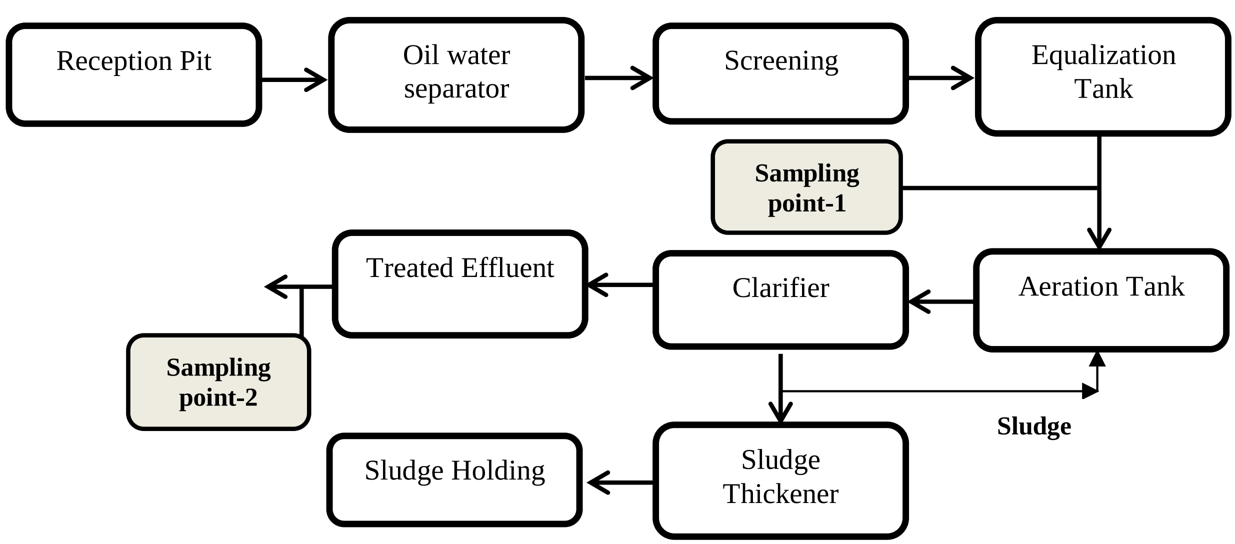

Fig. 5: Flow chart of wastewater treatment system used in the beverage plant

3.1.2 Calculation of water usage ratio

In soft drink beverage industry, key process indicator (KPI) to measure the performance of water usage, is water usage ratio (WUR).Water usage ratio is calculated for all individual processes and equipment which sums up into total water usage ratio,

$$\text{W.U.R.} = \frac{\text{Amount of water used (L)}}{\text{Amount of Beverage Produced (L)}}$$

A lower WUR is desirable not only to conserve water use but also to generate less quantities of wastewater to be treated. This, in turn, holds promise for lower costs to be incurred in wastewater treatment plant construction and operation.

In order to conserve water, first of all water mass balance was carried out with the help of flow monitoring. In the light of the results achieved from water mass balance a study was carried out to identify major potentials areas of water conservation in beverage industry. This study was based on leading operational excellence (OE) tools like six sigma and lean manufacturing. Six sigma techniques highlight deviations of process values of various operational parameters from their set values, whereas lean manufacturing concept explains control measure for various process wastages. Application of OE tools in various processes helped in water conservation.

3.1.3 Interventions for water conservation

Interventions applied for water conservation included the use of product water from RO in heat exchanger, adjustment in the backwash frequency of pre-RO sand filter, modifications in the operational mechanism of glass bottles washer, use of pneumatic rinser for PET bottle rinsing, installation of new package type RO plant, conversion of open loop to close loop clean in process (CIP) system and the use of a suitable dry lubricant for conveyers of glass and plastic bottles. All these interventions and the water conserved have been presented in section 4.

3.2 Wastewater Sampling and Testing

In order to evaluate the performance of WWTP, wastewater samples were collected from equalization tank (Sampling point-1) and treated effluent channel (Sampling point-2) as shown in Figure 5. Eleven composite samples were collected at different timing spread over the entire year. It was done to take into account the changes that occur in wastewater due to production changes, which depends on the season of the year. The parameters tested were pH, total suspended solids (TSS), five day biochemical oxygen demand (BOD) and chemical oxygen demand (COD). Mean values of these eleven samples were used to report the performance of WWTP. Mean values of eleven samples from sampling point-1 also showed the characteristics of raw beverage wastewater. All the tests were performed as per procedure laid down in Standard Methods (1998) [17]. The testing procedures are mentioned in Table 2.

Table 2 Testing procedures adopted

Sr. No.	Parameters	Unit	Test Method
1	pH	--	pH meter, Model 51935-00, HACH Sension3, Standard method (1998)
2	Total Suspended Solids (TSS)	mg/L	2540C, Standard method (1998)
3	Biochemical oxygen demand (BOD)	mg/L	5210B, Standard method (1998)
4	Chemical Oxygen Demand (COD)	mg/L	2520C, Standard method (1998)

Testing was carried out at the laboratory of Institute of Environmental Engineering and Research (IEER) at UET Lahore and Laboratory of selected beverage industry. Collected data were analyzed to check the performance of wastewater treatment plant.

4. Results and Discussions

4.1 Flow Monitoring

Table 3 shows the mean values of water usage in the beverage plant. It can be seen in the table that of the total fresh water consumed, 46.8% is converted to beverage, while 27.9% of water goes to water softener. After softening this water is used for rinsing bottles, boilers, cooling towers, equipment and backwash while the balance 25.3% is used for the miscellaneous purposes.

4.2 Water Usage Ratio

During study period, average beverage production was 1410m^3/day. Average daily water consumption was 3,015 m^3/day. Thus, the W.U.R came out to be 2.14 (3015/1410).

Table 3 Mean results of flow monitoring in selected beverage plant

Flow Meter	Major use	Flow rate (m^3/day)	% of total water consumed (%)
FM-1	Product Water	1410	46.8
FM-2	Water to softener	842	27.9
FM-3	Misc. water uses	763	25.3
	Total water consumption	**3015**	**100.0**
FM-4	Wastewater generated	1544	51.2

4.3 Results of Intervention for Water Conservation

a) Heat Exchangers

Heat exchangers in sugar pasteurization section were identified as a major source of water wastage. Previously fresh water was used for cooling hot sugar syrup. Water temperature reached upto 45°C at the exchanger exit and was wasted after being used in exchanger. There was no mechanism available to save this water for reuse. In each batch, containing 12,000 Kg of sugar syrup, 5 m^3 water was used as once through cooling purpose. On average10 batches of sugar syrup per day were produced in the beverage plant, therefore average amount of water wasted per day was 50m^3.

In order to conserve water, old exchangers were replaced with those in which hot water from exchanger exit was re-used in preparation of next sugar syrup batches. In such exchangers, instead of fresh water, RO treated water is used, which after passing through heat exchangers can be used for syrup production. As the temperature of this water is raised to 45°C during the process, it also results in conserving energy during syrup preparation. Thus 50 m^3per day water was saved by this intervention.

b) Backwashing of Pre – RO Sand Filters

It was observed that backwashing of pre-RO sand filter was done once daily without evaluating the requirement for backwashing. It resulted in huge amount of water used for back washing. In order to standardize the procedures of backwashing, validation study was carried out. The study revealed that backwashing is required when the differential pressure (ΔP) reaches upto 0.5 bar across sand filter. On the basis of the findings backwash frequency was reduced from once per day to once every sixth day. This intervention resulted in saving 30% of total backwash water amounting to 10m^3/day.

c) Glass Bottle Washers

It was observed that bottle washers not only consumed enormous amount of water during their operation but also when idle. It was found out that stoppage time for 3 bottle washers was 3 hours during the day. The water used during this period was calculated to be 120 m^3and75 % of this water (90 m^3/day) could be saved by installing an arrangement to stop water to the washers during idle period. This wastage was saved by automating the working of bottle washer with feeding pumps. After implementing this automation, the feeding pumps shut down as soon as the washer machine drive was stopped and remained idle. Thus this intervention saved 90 m^3/day of water.

For future, the plant management was proposed to replace the existing bottle washers with automated one. Such a washer uses 60% less water as compared to the one being currently used. In automated bottle washer, orifice of water jet nozzles (nozzle size) is optimized in such a manner that it discharges low volume of water from jets with high pressure and achieves required cleaning of glass bottles.

d) PET Bottle Rinsers

The beverage plant used two PET bottle rinsers to ensure the internal cleaning of the bottles before beverage filling. Average water consumption by these rinsers was 40 m^3/day. In order to conserve water, it was proposed to use pneumatics rinsers. Their installation resulted in water saving of 40 m^3/day.

e) Reverse Osmosis Plant

RO plant is used to produce treated water which is also called as “product water” because it is used in beverage production as main ingredient. The RO plant after treating water produces a portion of water as RO reject (water with high salt concentration). The reject water joins the wastewater stream and disposed in sewers leading to wastewater treatment plant.

About 20% of the water intake in an RO plant comes out as RO reject. Average raw water intake of three old RO plants was 1762m^3/day. Thus 20% of water intake i.e. 352 m^3/day went as waste.

The plant management was advised to switch to use new package type RO plant with three units. Such plants recycle RO reject thereby reducing its quantity. It was worked out that new plant will reduce RO reject from 352 to 206 m^3/day (a reduction of about 41.6% in RO reject) and would save 146 m^3/day of water.

f) Cleaning in Process (CIP)

Cleaning in process (CIP) involves washing of equipment before switching to new beverage type. CIP is carried out during changeover of sugar and sugar free products and this activity is carried out at beverage mixers, fillers, syrup storage tanks and in related piping. CIP can be performed in open loop as well as closed loop system. In open loop CIP system all process streams work as once through streams which means in each step of CIP, cleaning media is drained. Whereas in closed loop CIP system cleaning media is wasted only when contaminated. Previously open loop CIP was carried out on two local production lines and also the frequency of product changeover was high to meet rapidly changing sales requirements. Study was carried out to evaluate water saving by converting open loop CIP to close loop CIP and also by rationalizing product changeovers on the lines with good production planning.

Intervention of converting open loop CIP system to close loops CIP system on two local lines and by improving production planning to minimize changeovers frequency on production lines saved 25 m^3/day of the product water.

g) Conveyor Lubrication

It was observed that significant amount of water was used for lubrication of glass and plastic bottle conveyors. During the study various trials with large number of dry lubricants were made by the plant team to achieve the desired level of skidding of bottles. Finally a suitable dry lubricant conveyor was developed which consumed significantly less amount of water. This change saved a water quantity of around 14 m^3/day.

4.4 Summary Results of Water Conservation Interventions

The cumulative effects of all the above water conservations interventions are shown in Figures 6 and 7. Fig. 6 shows water saved per day from interventions in different equipment/process. It can be seen in Fig.6 that 375m^3/day of water was saved through water conservation interventions and now instead of 3015m^3/day, 2640m^3/day of water is required to produce 1410 m^3/day of beverage. It shows water saving of 12.5%.

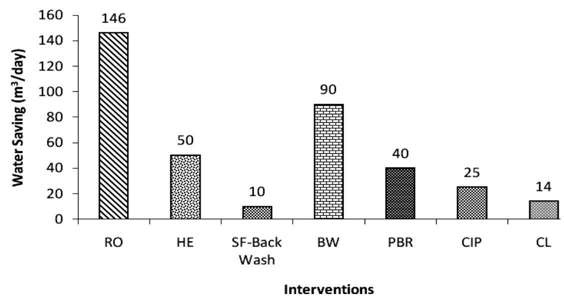

Fig. 6 Water saved per day with interventions in different equipment/process

(RO= Reverse osmosis; HE= Heat exchanger; SF= Sand filter; BW= Bottle washer; PBR = PET bottle rinser; CIP= Cleaning in process; CL= Conveyor lubrication)

Fig. 7 shows the impact of water conservation measures on WUR. It shows WUR before and after the interventions. The WUR reduced from 2.74 to 2.4. This improvement shows that WUR of under discussion plant is comparable with the results of 2008 for Coca Cola International system as shown in Fig. 3.

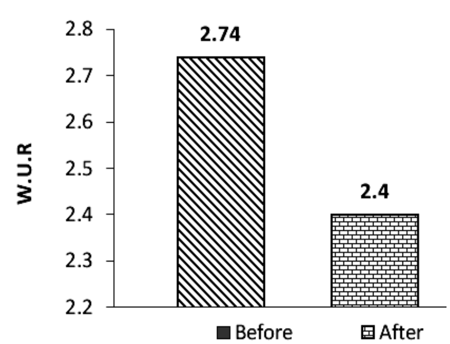

Fig. 7 WUR before and after water saving interventions

4.3 Economic Analysis of Water Conservation

An economic analysis was also carried out in term of energy saving resulting from less pumping of water. The water consumption before and after applying water conservation measures was 3015 and 2640 m^3/day, respectively. Thus tube well pumping hours reduced. The horse power of motor, driving the tube well, was 30 BHP (Break Horse Power). The commercial tariff for electricity is Rs 10 per unit. The beverage factory works for 24 hours and 300 days per year. Based upon the above data, the Fig. 8 shows the annual energy bills, for the tube well, before and after water conservation measures. It can be seen that a saving of 0.2 million/year was achieved after apply conservation measures.

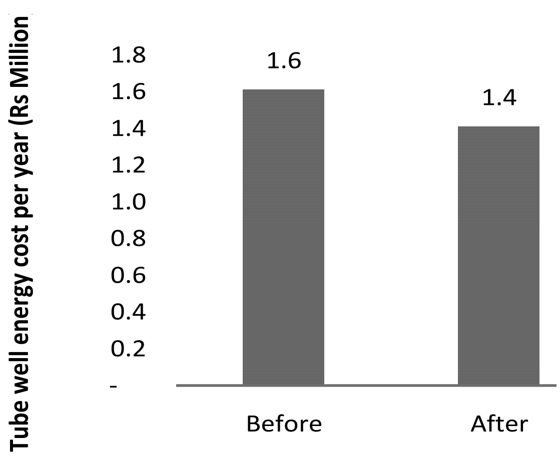

Fig. 8 Energy cost for tube well, before and after applying water conservation measures

4.6 Wastewater Characteristics of Beverage Industry

Wastewater sample from sampling point-1 shows the raw wastewater characteristics of the selected beverage industry. The characteristics are shown in Table 4. It can be seen in Table 4 that pH of equalized water is mostly at lower side of the acidic range. The TSS varied in a range of 73-161 mg/L, BOD_5 varied from 83 to 142 mg/L while COD varied from 297 to 1239 mg/L. The mean value of TSS, BOD_5 and COD was 100, 112 and 689 mg/L. Standard deviation (SD) shows that maximum variation occurred in COD with SD value of 246.Possible source of high BOD and COD is dirty glass bottle washing machines and equipment cleaning with chemicals during flavor change over.

Table 4 Wastewater characteristics of the selected beverage industry

Sample No.	pH	TSS	BOD	COD
		(mg/L)	(mg/L)	(mg/L)
1	7.5	82	102	726
2	6.2	81	117	297
3	6.8	77	119	670
4	7.2	147	142	370
5	6.5	112	109	841
6	6.1	161	124	1239
7	5.9	130	112	623
8	6.2	77	83	722
9	7.3	88	133	657
10	6.4	77	97	800
11	7.5	73	89	637
	Mean	100	112	689

4.7 Performance Evaluation of WWTP

Eleven samples of raw wastewater (Sampling point-1) and treated wastewater (Sampling point-2) were collected and tested for pH, TSS, BOD and COD. The mean values of %age removal for TSS, BOD and COD have been shown in Fig. 9. The error bars show the maximum and minimum value of these parameters above and below the mean value.

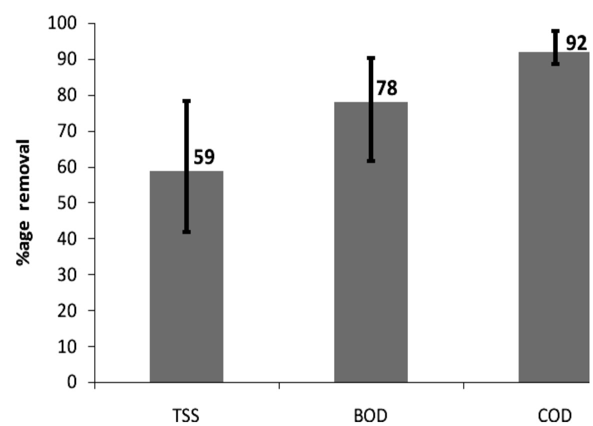

Fig. 9 Percentage removal of pollutants in WWTP of selected beverage industry

The mean concentrations of TSS, BOD and COD for the treated wastewater were 39 mg/L, 24 mg/L and 52 mg/L, respectively and pH was 7.7. All these are within the limits prescribed by NEQS (pH=

6 ~ 9, TSS=200 mg/L; BOD=80 mg/L; COD=150 mg/L).

The pH variation for treated effluent lied in a range of 7.5-8, TSS within 21-66 mg/L, BOD within 7-40 mg/L and COD within 32-81 mg/L. Thus the minimum and maximum values of the above parameters for treated effluent also remained within NEQS limits. Thus the functioning of WWTP was satisfactory for the parameters analyzed.

6. Conclusions

Following conclusions can be drawn from the present study:

1. Flow monitoring and making a water mass balance is the key step in initiating a water conservation program in soft drink beverage industry in particular and any other water conservation initiative in general.

2. Out of the total water consumed in a beverage industry, on average, around 45% water is converted to soft drink while other is utilized in allied uses.

3. Various water saving interventions can be applied to different equipment in a beverage industry which include: RO plants, glass bottle washers, PET bottle rinsers, heat exchangers, cleaning in process, and conveyor lubrication system. By applying these methods water saving of 375 m^3/day was achieved in the beverage plant under study. This amounts to water saving of 12.5% of the total water used. In addition, annual saving of Rs 0.2 million was achieved in the energy bill of tube well.

4. By applying water conservation interventions WUR reduced from 2.74 to 2.4 which is close to the value attained in international plants.

5. Wastewater treatment plant produced effluent conforming to the enforced NEQS in terms of pH, TSS, BOD and COD.

6. Replication of above interventions is suggested in all local beverage manufacturing industries for conserving water.

7. Acknowledgements

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