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Industrial water demand management and cleaner production potential: a case of three industries in Bulawayo, Zimbabwe

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Abstract

The combination of water demand management and cleaner production concepts have resulted in both economical and ecological benefits. The biggest challenge for developing countries is how to retrofit the industrial processes, which at times are based on obsolete technology, within financial, institutional and legal constraints. Processes in closed circuits can reduce water intake substantially and minimise resource input and the subsequent waste thereby reducing pollution of finite fresh water resources. Three industries were studied in Bulawayo, Zimbabwe to identify potential opportunities for reducing water intake and material usage and minimising waste. The industries comprised of a wire galvanising company, soft drink manufacturing and sugar refining industry. The results show that the wire galvanising industry could save up to 17% of water by recycling hot quench water through a cooling system. The industry can eliminate by substitution the use of toxic materials, namely lead and ammonium chloride and reduce the use of hydrochloric acid by half through using an induction heating chamber instead of lead during the annealing step. For the soft drink manufacturing industry water intake could be reduced by 5% through recycling filter-backwash water via the water treatment plant. Use of the pig system could save approximately 12 m^3/month of syrup and help reduce trade effluent fees by Z\$30/m^3 of "soft drink". Use of a heat exchanger system in the sugar refining industry can reduce water intake by approximately 57 m^3/100 t "raw sugar" effluent volume by about 28 m^3/100 t "raw sugar". The water charges would effectively be reduced by 52% and trade effluent fees by Z\$3384/100 t "raw sugar" (57%). Proper equipment selection, equipment modification and good house-keeping procedures could further help industries reduce water intake and minimise waste.

Keywords: Cleaner production; Industrial processes; Waste minimisation; Water demand management

1. Introduction

The city of Bulawayo (and many other cities in developing countries) is faced with extensive deterioration of its sewerage infrastructure within an environment of severe water scarcity. To finance the rehabilitation or reconstruction of the public sewer system, substantial increases in water and effluent tariffs would be inevitable (Box 1). Any increase in tariffs by the local authority will directly affect manufacturing industries and the industrialist in turn would need to make informed decisions regarding their future water use and effluent discharge. Industries might consider investing in water saving and waste minimising technologies to reduce costs. These technologies would also bring the benefits of increased production efficiency as a result of reduced raw materials usage, other inputs and energy consumption. This quest towards zero discharge or emission by industries has a secondary spin-off in terms of environmental protection. Many industrial managers today understand that waste is simply a resource out of place—a symptom of bad management that hurts the bottom line (von Weizsacker et al., 1997). Moreover industries that invest in water saving and waste minimisation techniques could put themselves in a better marketing position as people are becoming more concerned with the rational use of natural resources and environmental degradation.

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Box 1. Penalty for Bulawayo toxic discharge, The Standard, Sunday 9 June, 2002

By Loughty Dube THE cash-strapped Bulawayo city council is set to rein in companies guilty of discharging toxic waste into the city's water system with its introduction of a new Trade and Effluent Tariff Scheme, expected to rake in the $300 million needed for the upkeep of the city's aging wastewater treatment plants. The scheme, introduced in April under the council's by-laws will see companies pay between $500 000 and $1 million for the discharge of untreated industrial waste into the wastewater system. The city has so far identified 41 companies it deems responsible for the pollution bedevilling the city's water system. "The new tariffs are aimed at industries which are discharging toxic effluent into the system and these will be charged fines depending on the quantity and quality of effluent they discharge because, as it is, some companies release more toxic effluent than others," said Peter Sibanda the new director of the city's Engineering Services Department. He added that under the new scheme, all industries found to be generating toxic effluent, would be made to contribute towards the conveyance and treatment of the effluent in the city. This has seen the council spending $800 million annually in the treatment of effluent and the maintenance of sewers. The city of Bulawayo is also awaiting local government approval of a $2 billion loan from the open market for the financing of its capital projects. It hopes to use $300 million of this in upgrading the Aisleby wastewater treatment plant, the main sewage treatment plant in the city. www.thestardard.co.zw

Cleaner production in industrial processes seeks to deal with the operations of an industrial process in many levels at once. It is an integrated approach requiring cooperation from all and commitment from the top tier of management to implement and sustain policies that aim to ensure that production is carried out in a manner that is both cost-effective and environmentally sound. Unlike end-of-pipe treatment systems, cleaner production in most industrial processes can be applied to different stages of the process, and a project implemented by stages according to a company's needs and possibilities (USEPA, 1988). Cleaner production is a concept that many embrace as an unavoidable ingredient for sustainable (industrial) development. To a large extent, cleaner production is about efficiency; efficiency of industrial production.

The concept of water demand management generally refers to initiatives, which have the objective of satisfying existing needs for water with reduced consumption, normally through increasing the efficiency of water use. Water demand management can be considered a part of water conservation policies, describing initiatives with the aim of protecting the aquatic environment and making a more rational use of water resources (Brooks et al., 1997; Macy, 1999). The reasons and instruments for demand management within industries vary; they include financial incentives, environmental balance, image and competitiveness, environmental stewardship and moral responsibility (Lallana et al., 2001).

Water demand management particularly in the form of water recycling and reuse has many advantages which include reduced water intake and minimisation of undesirable pollutants which are discharged into the environment. Examples of industry based recycling and reclamation include (WRC, 1987):

- direct reuse of non-contaminated process water; for example, cooling water for general factory use.
- cascading of process water used on a high quality process to another requiring only low quality water; for example, final rinses to first rinse operations.
- counter-current flow—this type of technique could be implemented in the truck washing bay where dirty water could be used as a pre-wash.
- treatment of wastewater from one source for reuse in another process; for example, removal of suspended solids.
- end-of-line mixed factory effluent treatment reuse.
- closed loop treatment and recycle of wastewater from a particular source for direct reuse in the process. This is often accompanied by recovery of process chemicals, by-products and heat energy.

This paper investigates the feasibility and benefits of combining water demand management and cleaner production techniques for three industries in Bulawayo, Zimbabwe. The general view is that when a series of linked efficiency technologies are implemented in concert with each other, in the right sequence and manner and proportions, there is a new economic benefit to be reaped from the whole that did not exist with the separate technological parts (von Weizsacker et al., 1997).

2. Background of Bulawayo city

The city of Bulawayo is Zimbabwe's second largest with an estimated population of 1 million (Fig. 1). The city is situated in a semi-arid and drought prone region with an average annual rainfall of about 520 mm. It lies near the divide of the catchment area draining to Zambezi River and the southern catchment area draining to Limpopo River. Its location near the water divide has significantly contributed to its water problems as all rivers within easy reach are small with small catchment

Fig. 1. The location of Bulawayo in Zimbabwe.

areas. The city is presently mainly relying on water from five dams located in Matabeleland South in the Limpopo catchment area and a groundwater source north-west of Bulawayo. For a long period, the city has experienced severe water supply deficit (Binnie et al., 1993; Gumbo, 1994). Bulawayo is a major industrial centre (both heavy and light industries) and a focal point of national and international communications.

The city supplies treated water to industries although some industries have their own supply sources in the form of boreholes. Several studies carried out in Bulawayo indicate that industries currently consume about 30,000 m^3/day (25% of total consumption) (Stewart Scott, 2001; Norplan et al., 2001; SWECO, 1996; GKW et al., 1988). According to June 2002 water tariffs, the city council is charging industries a basic fee of Z\$706.00 and a flat rate of Z\$81.60/m^3 of water consumed (the official exchange rate in August 2002 was 1US\$ = Z\$55.00, although in the black market or parallel market 1US\$ = Z\$800.00). The use of groundwater is regulated by the Gwayi catchment council on behalf of Zimbabwe National Water Authority (ZINWA). At present groundwater is a "free" resource although provisions have been made under a new Water Act and the ZINWA Act to control its usage and expropriation.

A number of heavy industries in Bulawayo are a major source of water pollution. Most wet industries discharge their effluents untreated to the municipal sewers. Some studies indicate that industry only contributes about 9% of the revenue for sewerage and sewage treatment, while it contributes approximately 20% of the effluent volume and the COD load received at various municipal sewage treatment works (Stewart Scott, 2001; Norplan et al., 2001). Industrial effluents

Table 1
Trade effluent standards: Bulawayo (Sewerage, Drainage and Water) by-laws, 1980

Parameter	Limit[a]
pH (pH units)	6.5–12
Temperature	<45 °C
Total solids	<2000
Conductivity (mS/m)	<300
Suspended solids	<600
Chemical oxygen demand	<2000
Soap, oil, grease, fat	<10
Dissolved sulphates	<300
Iron	<25
Cyanide	<10
Zinc	<15
Cadmium	<10
Chromium	<10
Copper	<10
Lead	<10
Nickel	<10

[a] All values in mg/l unless stated otherwise.

are regularly monitored by the Trade Waste Inspectorate to ensure compliance with the municipal by-laws. In terms of section 8 of the Bulawayo (Sewerage, Drainage and Water) by-laws, 1980, the general acceptance of trade effluent into municipal sewer is based on the quality limits as presented in the trade effluent standards shown in Table 1. The city of Bulawayo has drafted new by-laws that have introduced a tariff charge for receipt of industrial effluents. The full tariff system implementation is expected to take 27-months beginning from June 2002. The proposed tariff structure includes a charge for conveying industrial effluent and a charge for treating this effluent.

3. Background of industries investigated

The three industries were selected on the basis of either being large water consumers (wet industry) or discharge of toxic effluents into the municipal sewer. The wet industries being a soft drink manufacturing company and the sugar refining industry whilst a wire galvanising industry (dry industry) though using relatively less water produced toxic waste by-products. The three industries also offered their support to the investigation, allowed access into their premises and co-operated well during the field studies.

Galvanised wire manufacturer—The enterprise produces wire products that are used in a wide range of generalised and customised applications, particularly in agriculture and security fencing. The manufacturing process involves drawing 5.5 mm diameter steel rods into smaller wire sizes that are galvanised and made into netting of various types. Water is mainly used in the acid pickling, quenching and rinsing processes and relatively large volumes of effluent are produced from these processes as well. The industry discharges acidic wastewater (with an average pH of 1.4) which also contains heavy toxic metals namely, lead, zinc, and iron to the municipal sewer.

Soft drink manufacturer—This industry manufactures carbonated soft drinks. The production process essentially involves blending of a concentrate and additives with treated municipal water and carbon dioxide. Water is mainly used in the processes of bottle washing, product manufacturing, filter back washing, steam production in boilers and for floor washing. The major effluent generating processes are bottle washing, filter backwashing and washing of bottling machines and pipe work during flavour change over. The major contaminants in effluent are the caustic soda and sucrose.

Sugar refinery—The refinery produces white sugar and molasses from brown sugar. Water use is mainly in the processes of steam generation, cooling system, bone char regeneration, muds de-sweetening and raw sugar melting. The effluent is mainly generated from cooling tower blow-down and bone char regeneration processes and the major contaminant in effluent is sucrose. For economic reasons, the wire manufacture and sugar refinery augment municipal water with borehole water. The soft drink manufacturer utilises municipal water only because of the strict quality standards of the soft drink industry worldwide.

4. Methodology

For the three industries, an industrial water use survey was carried resulting in creation of water flow balances. Water quality sampling points were identified within each process train and in combination with material flow accounting (MFA) flow-and-material-balance diagrams were created. The flow diagram indicates process and material flow, water and wastewater streams and flow rates and points where effluents could be sampled and analysed for relevant chemical parameters. This approach was deemed to be necessary in this analysis to enable the identification of areas where water could be recycled, use of raw materials and other inputs optimised and where closed loop systems could be implemented. MFA is a technique of increasing prominence and consequence throughout the world in the fields of industrial ecology and cleaner production. In combination with systems analysis it allows a comprehensive rather than ad-hoc view of the sources (inputs), processes (throughputs) and sinks (outputs) (Ayres and Ayres, 1998; Baccini and Brunner, 1991). This task was extremely difficult especially for the sugar refinery, which had many unknown water in-feeds due to many years of retrofitting and not having proper records of the entire production process. This was exacerbated by the obsolete equipment and machinery in operation, estimated to be a 1940s invention (Mlilo, 2002).

For the three industries, using flow-and-material balance diagrams possible cleaner production and water demand management measures are suggested; mostly in the areas of management, process control, and recycling and reuse of effluents (Mlilo, 2002). The findings and proposed water demand management and cleaner production measures for the three industries in Bulawayo are described in the following sections.

5. Results and discussion

5.1. The galvanised wire manufacturer

This enterprise is utilising about 2.104×10^{-4} m^3/m^2 "galvanised wire surface" municipal water and 0.058 m^3/m^2 "galvanised wire surface" borehole water for the production process. The calculated specific water intake (SWI) for the industry is 0.059 m^3/m^2 of wire surface area treated. The SWI value is the ratio of the volume of water used to the surface area of wire galvanised. According to research carried out in South Africa, the target SWI value for wire galvanising industries should be set at 0.100 m^3/m^2 for operations treating in excess of 10,000 m^2/month and 0.200 m^3/m^2 for factories treating less than of 10,000 m^2/month (Binnie, 1987a). The industry is treating in excess of 10,000 m^2/month and it therefore evident that the industry is operating well below the target value. However, there is still some opportunity to lower the current SWI value.

5.1.1. Water conservation potential

During the process of drawing and galvanising wire, after the annealing step (Fig. 2), the wire is quenched in a water bath. This step is necessary to prevent overheating of the acid bath, the next step in the process. When the temperature of water in the water bath has risen to a level that renders the quenching capacity of water ineffective, water is discharged as wastewater into the municipal sewer.

From the water balance for the wire manufacturing industry, the quench process consumes approximately 0.010 m^3/m^2 "galvanised wire surface" (17%) of total water intake. Instead of discharging hot quench water (≅40 °C) as wastewater, hot quench water can be recycled through a cooling tower (or similar system) and then be used as quench water again. The industry would realise about 0.009 m^3/m^2 "galvanised wire surface" (15%) reduction in water intake and effluent volumes. The effectively further reduces the SWI to 0.050 m^3/m^2.

5.1.2. Waste minimisation and resource use potential

The galvanising process can be designed using the concepts of cleaner production such that the annealing step can be performed without lead in an inert atmosphere of hydrogen and nitrogen. This would eliminate the need for lead usage (28,000 kg/year), ammonium chloride (6000 kg/year) and reduce the usage of hydrochloric acid by about half. This recommended process of wire galvanising reduces the potential worker exposure to hydrochloric acid, lead and ammonium chloride and the discharge of these toxics to the municipal sewer. The process also utilises 50% less electrical energy compared to the conventional process (Knatt, 2000).

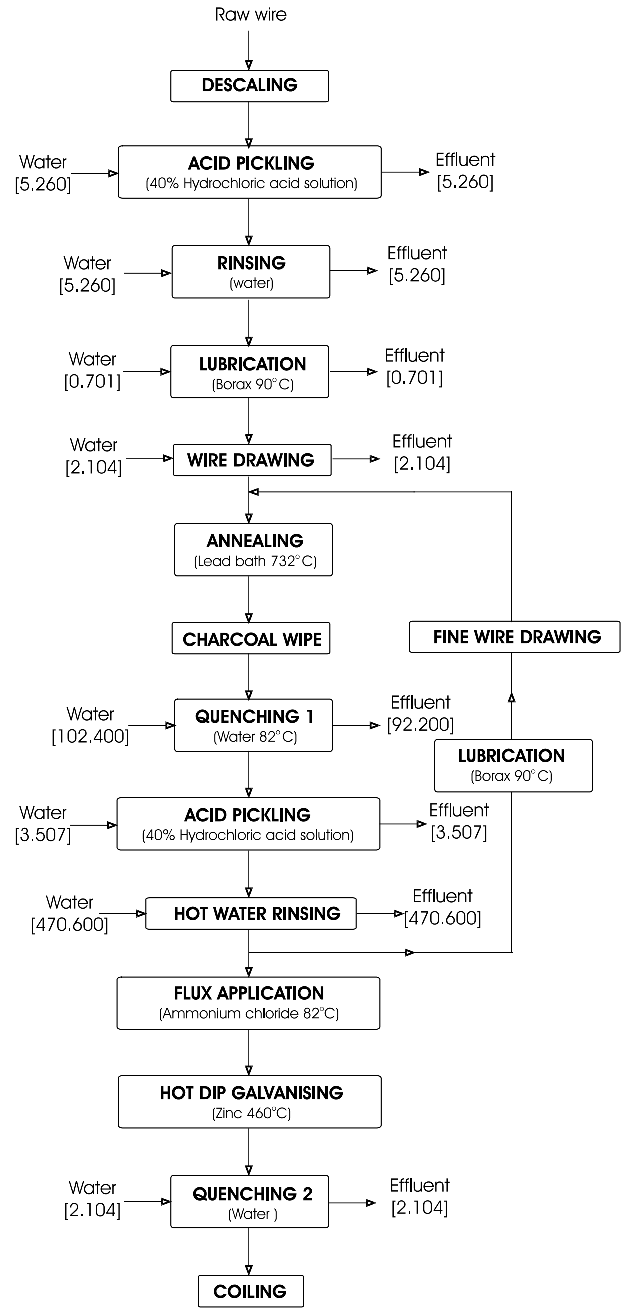

Fig. 2. Simplified flow diagram for the wire galvanising process (figures in 10^{-4} m^3/m^2 "galvanised wire surface area").

5.2. The soft drink manufacturer

The manufacturing of soft drinks requires large volumes of water. The water is pre-treated on-site to meet product quality requirements before being used in the manufacturing process (Fig. 3). There are potential opportunities for reducing water intake and minimising waste.

The plant pre-treats municipal water at an average of 1.16 m^3/m^3 soft drink produced by using a conventional flocculation and filtration plant. Three types of filters are used—sand, carbon and polishing filters (cartridge type). Backwash water is discharged into a sewer. The industry cleans four carbon and four sand filters on a daily basis by forcing water back through the filters. The generation of backwash water is dependent on production levels, but is estimated to reach 40 m^3 per day. The cleaner production approach which the industry can implement involves recycling filter backwash water through the water treatment plant, allowing it to be used in the manufacturing process. The recycled water has to

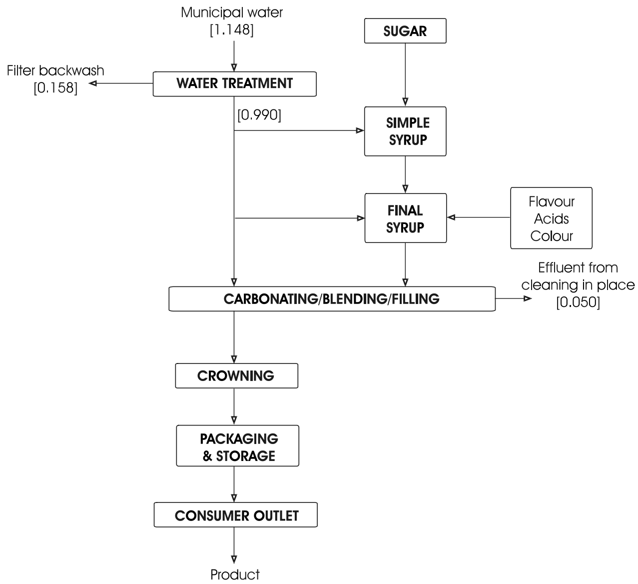

Fig. 3. Simplified flow diagram for the soft drink manufacturing process (figures in m^3/m^3 "soft drink produced").

meet strict quality standards and can be used in the ratio of 10–20% with non-recycled water to ensure that there is no compromise in the final product quality. The industry would realise savings of about 1050 m^3/month and 5% reduction in water fees.

5.2.1. Water conservation potential

According to research carried out in South Africa, the average SWI for soft drinks manufacturing industries should be set at 2.3 m^3/m^3 of soft drink produced (Binnie, 1987b). The specific water intake is the ratio of the volume of water used to the volume of soft drink produced.

At present the plant is operating at 3.5 m^3/m^3 of soft drink produced. When the system of recycling filter backwash is implemented, the SWI value could drop to 3.3 m^3/m^3 soft drink produced. This reduction in SWI is not significant because the backwash process (consuming about 5% of total water intake) is not a major water user in the plant. Alternatively, a large percentage of filter backwash water can be cascaded for use as service water. Once the initial high solid content dirty water has gone to drain, the remaining water used in the backwashing process can be reclaimed into a recovery holding tank and then used for services requiring lower quality water e.g. floor washing. An over-capacity water treatment plant can often result in large water wastage due to the backwashing of unnecessary sand and carbon filters. The industry therefore has to optimise on the amount of water for treatment and the backwashing process.

Water usage should be included as part of the selection criteria when purchasing major equipment such as bottle washers, sprays and bottling machines. Of particular importance is the water usage efficiency in the bottle-washers as they are responsible for a large percentage of water intake (about 13,300 m^3/month or 54%). Older bottle washers should be modified to ensure that bottle spraying is discontinued once the machine is shut off. Automatic shut-off valves and high pressure, low-volume jets for hose pipes could also prove to be effective in helping reduce water intake. Attention should also be paid to future developments such as varying heat transfer systems, e.g oil as a substitute for steam. At present steam is used for heating up the caustic soda solution in the bottle washing machines. Steam is generated from boilers that use about 0.354 m^3/100 t "raw sugar" or 10% of total water intake.

5.2.2. Waste minimisation and resource use potential

Efforts could also be made to reduce the amount of material that contributes to the high Chemical Oxygen Demand (COD) levels entering the effluent stream. This includes the addition of a pig (pipe cleaning system) that physically forces residual syrup out of pipework and into the production process, thus reducing the amount that is discharged to sewer during cleaning. This will result in cost savings from reduced syrup wastage, about 11,700 l/month and from reduced trade waste fees. The amount of water used during the cleaning process would also be reduced. From the estimates made, the industry could realise a Z$155,000.00/month (or 19%) reduction in trade effluent fees. However, the industry would need to carry out a thorough chemical analysis of the syrup discharged as effluent in order to come up with an accurate figure of the COD of the syrup.

5.3. The sugar refinery

The process of refining sugar consists of four basic steps: (1) washing the raw sugar crystals; (2) adding water to crystals to form a solution; (3) clarifying and decolourising the solution; and (4) re-crystallising and finishing the sucrose. Cooling water from cooling towers water is used to condense the water vapours that boil out of the sugar solution during the re-crystallisation step (Fig. 4).

The condensed vapours, the condensate, that mixes with cooling water is contaminated with sugar (in an amount the refiner desires to minimise for business reasons), which contributes substantially to the COD of wastewaters. Because of this contamination, water from the cooling circuit has to be periodically discharged (cooling tower blow down) as wastewater, otherwise the sucrose content and the COD of cooling water would become excessive. There are a number of ways that water consumption can be reduced. At present, the refinery is utilising approximately 166 m^3/100 t "raw sugar" of municipal water and 169 m^3/100 t "raw sugar"

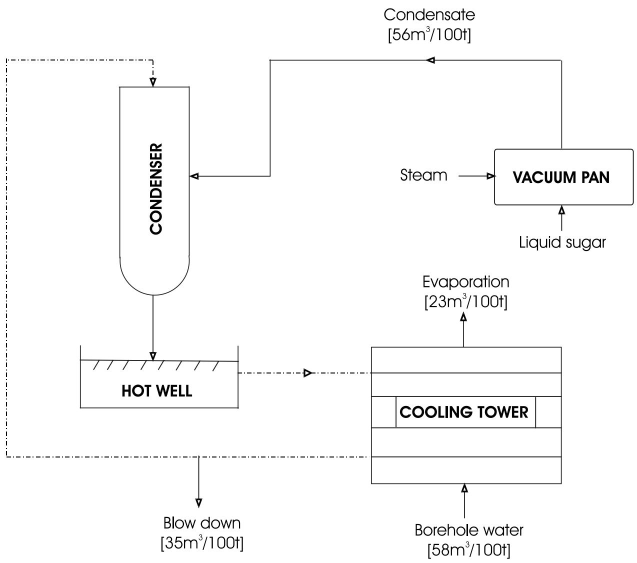

Fig. 4. The existing cooling water and condensate system.

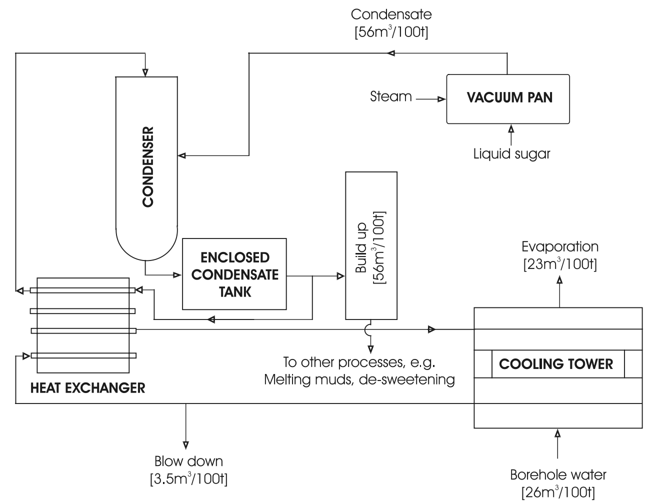

Fig. 5. The proposed cooling water and condensate system.

of borehole water. About 7400 t/month of raw sugar is refined.

5.3.1. Water conservation potential

Cooling water can be separated from the vapour by introducing heat exchangers to separate the condensate from the cooling circuit. The condensate will be contaminated with sugar carried over with the vapour from the vacuum pans, but can be utilised within the process as "sweet water" for dissolving sugar or de-sweetening muds. The cooling water to the heat exchanger would be that from the current cooling water circuit. From the heat exchanger, the now hot cooling water would pass to the cooling towers, after which it would return to the cold water inlet of the heat exchanger. In the condensers, cooling water currently enters at 29 °C and after contact with hot vapour, exits at 49 °C. The design characteristic of the heat exchanger is to provide a similar temperature for the cooling of the condensate. As occurs in the cooling water system, the volume of condensate would increase at the rate at which the water vapour currently condenses and is entrained (137 m^3/day or 56 m^3/100 t "raw sugar"). This system could also help reduce amount of cooling tower blow down because cooling water contamination would be minimised. Figs. 4 and 5 show the existing and the proposed non-mixing system incorporating a heat exchanger, respectively.

5.3.2. Waste minimisation and resource use potential

From the COD balance of wastewater streams within the plant, the COD in the combined effluent is expected to drop from 3050 to 2930 mg/l when the heat exchanger is introduced. The COD load of wastewater from the plant could be reduced from 214 kg/100 t "raw sugar processed" to 86 kg/100 t "raw sugar processed" as a result of reduced amount of cooling tower blow-down. Water intake and effluent volumes are expected to decrease by 4230 m^3/month (17%) and 2080 m^3/month (46%) respectively. The savings in water charges and trade effluent fees amount to Z$163,700.00/month (8% reduction) and Z$280,600.00 (57% reduction) respectively. However, the disadvantage would be the cost of purchasing, installing and maintaining the heat exchanger.

6. Conclusions

For the three industries studied, there is no doubt that the identified water demand management and cleaner production techniques show potential for savings in water, water and effluent fees and minimisation of waste produced. This paper illustrates that there is a lot which manufacturers can achieve by firstly carrying out audits to identify areas of improvement within the manufacturing process. This exercise can then be used to prioritise measures with the best returns within a certain time period, and financial regime. In the absence of actual costs to implement the structural measures (retrofitting and maintenance) it is difficult to provide a full evaluation of the water demand management and cleaner production techniques which are being recommended in this paper. Nonetheless the procedure outlined here for the three industries demonstrate that industries can do things differently in an ecologically friendly and sustainable manner. A full cost and benefit analysis would also require an indication of the actual costs of damage to the environment and the real long run marginal cost of water which reflects the scarcity of the resource in the case of Bulawayo. The cost of other resource inputs e.g. energy need to be considered.

Life-cycle assessment becomes important in such analysis and more data would be needed besides water use and effluent charges.

Regular, simple water monitoring surveys (quality and quantity) of the different water-using areas could be devised to assist in the monitoring of water consumption, as well as to supply information as to the state of equipment e.g. taps, pipes and valves. Initial selection of water using equipment is also crucial. Modifications can also be done although usually costly in the short-term to incorporate recycling and reuse (closed-loop systems). Above all, good house keeping and awareness training for personnel could further help industries practice water demand management and cleaner production.

The water demand management and cleaner production initiatives could help reduce the strength and volume of industrial effluents and probably eliminate the use of toxic substances through substitution. The benefits do not accrue only to the industry but to the local authority through reduced costs of conveying and treating industrial effluents. Subsequently, the quality of effluent discharged from municipal sewage treatment works to the environment would improve, thereby limiting environmental damage and social costs leading to sustainable development.

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