MILL-WIDE WATER MANAGEMENT IN THE SOUTH AFRICAN SUGAR INDUSTRY

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Abstract

Increasingly stringent environmental constraints, as outlined in South African water and environmental law, require industry to improve water management in a sustainable and equitable manner. There are opportunities to review water utilisation, re-use and discharge.

In this paper the past and present trends in management practices and technology applicable to water utilisation in South African sugar mills are briefly summarised. Technologies to enable higher levels of water recovery and re-use are reviewed in terms of their current and future application in the sugar processing cycle. The important aspects mills should consider when evaluating the impact, benefits and costs of alternative technologies are discussed.

Keywords: sugarcane wastewater, mill water management, minimisation, segregation, re-use, recycling, treatment technologies

Introduction

The sugar industry in South Africa is about 165 years old and located predominantly along the east coast, where the mean annual rainfall is generally the highest. Due to its close proximity to readily available water resources, the shortage of process water has been of little concern to sugar technologists. It was, however, because of the severe drought of 1966, and the growing demand for industrial water, that a commission of investigation into water matters was first appointed. Since the earlier years, a heightened awareness of water management in the industrial sector was promoted and 'Management of the Water Resources of the Republic of South Africa' began.

The drive and approach to zero-discharge

The primary water source to a sugar mill is the sugar cane; as much as 70% of the raw material is water. Since the mean water intake by sugar mills, referred to as the Specific Water Intake, is recorded at 60 m^3/100 t cane (NATSURV 11, 1990), it can be inferred that, theoretically, most sugar mills should cope without the additional sources of water. These alternative water sources have been relied on and include surface water (rivers and lakes) and ground water (boreholes).

The industry is committed to the conservation of water resources and the protection of the environment in the drive towards zero liquid discharge, due mainly to the following pressures:

- The National Water Act and Discharge Compliance
  In terms of the Constitution of the Republic of South Africa, Act No. 108 of 1996 is an exclusive National competency. This is incorporated in the National Water Act (NWA)

(Act No. 36 of 1998), which mandates the Minister of Water Affairs and Forestry to ensure that water is protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner for the benefit of all persons.

- Reduced fresh water availability
  South Africa is a water scarce country where water apportionment will favour the environment and the community, especially during the droughts.

- Economics
  In addition to funding water resource management, a pricing strategy is being established to "..ensure compliance with prescribed standards and water management practices." (NWA, 1998). With the deployment of the already drafted Waste Discharge Charge System (WDCS) (WDCS, 2004), which is based on the user pays and polluter pays principle, some of the aims are to:
  - Promote efficient utilisation of water resources.
  - Promote the internalisation of environmental costs by impactors.
  - Create financial incentives to encourage the optimal utilisation of water resources and the reduction of waste.

- 'Good neighbour' policy
  To recognise the wider social responsibility by making a positive and constructive contribution to society in addition to generating economic benefits for the business.

Although 'zero discharge' is the term often used in promoting environmental conservation it can have several different meanings in different contexts.

Usually, one of several working definitions apply in terms of liquid discharge:

- Elimination of certain priority pollutants. The main water-borne pollutant from a sugar mill is sugar or its degradation products.
- No effluent.
- Compromises of the above two where water is discharged but in which the levels of the contaminants do not prevent it from direct downstream re-use.

The five steps commonly encountered in approaching a close-to-ideal yet practical zero-liquid-discharge are given in the following sequence:

Step One: Minimise water abstraction and wastewater generation.

Step Two: Segregation and holding of the major wastewater streams to facilitate their re-use with minimal pre-treatment.

Step Three: Re-use and/or recycle the wastewater streams to the maximum without adversely affecting product quality or plant integrity.

Step Four: Effluent treatment by physical unit operations and biological and/or chemical unit processes.

Step Five: Disposal in conformance with environmental requirements.

In Figure 1 below, a generalised impression of the cost of effluent treatment versus the quantity of effluent to be treated is illustrated. Should an existing plant undergo expansion it is expected to produce more effluent, thereby requiring additional effluent treatment facilities. On the other hand, a mill having to drastically curb its wastewater discharge would require a pursuit of the five steps towards zero discharge.

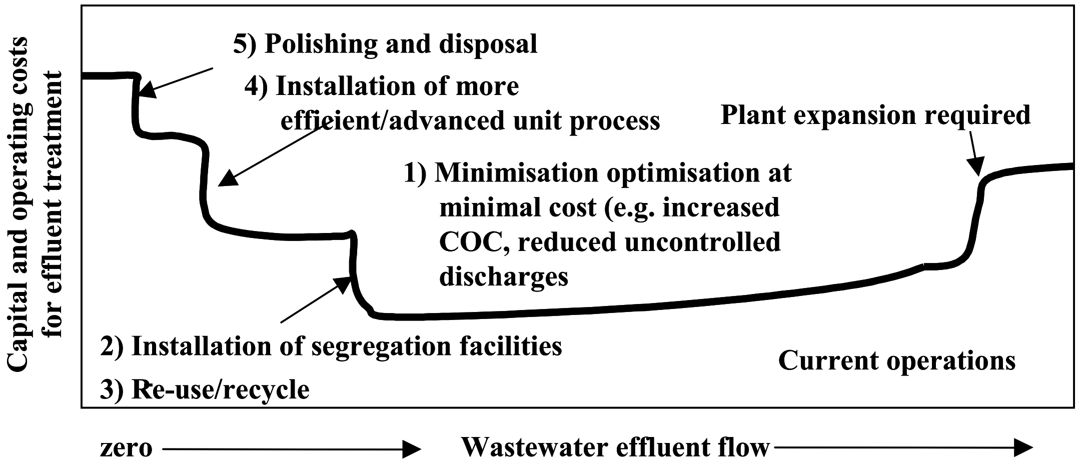

Figure 1. General impression of total cost of effluent treatment versus effluent flow reduction (adapted from Daigger and Bultz, 1992).

Mill-wide water management strategies

Minimisation

An essential activity to be encouraged in the efficient utilisation of water is by minimising the abstraction of water from the primary sources (i.e. plant intake) and reducing the contamination of on site available water (internal water use). This usually entails minimal or no additional cost and often leads to an initial saving, attributable to reduced water intakes. Additional reductions in wastewater flow would most likely require the construction and operation of additional unit operations that without doubt will incur higher effluent treatment costs.

Some suggested housekeeping-related measures in pursuing this option include the following:

- Monitoring of the major use areas.
- Use of pressurised general washing.
- Mechanical clean-ups (avoid wet clean-up operations).
- Substitute, when possible, fresh water with excess hot condensate.
- Installing self-closing nozzles.
- Providing training on savings.
- Conducting regular cleaning of cooling towers (tower fill and sumps).
- Collection for re-use of initial tank and pipe washings.
- Closing cooling circuits and using air-contact coolers.
- Automated clean-in-place (CIP) of vessels and pipes.

Re-use

Once waste streams have been segregated, it is often possible to recycle water containing the waste through industrial processes. Most plants do operate with a water surplus. In addition to the benefit of water saving there could also be merit in product and by-product recoveries, if technically and economically feasible.

Common mill recycle streams include:

- Maximum use of condensates (i.e. as boiler feed, for filter washing, centrifugal washing, imbibition, and even in gas scrubbing).
- Barometric condenser cooling water (usually not very polluted).

- Crystalliser cooling and mill bearing cooling.
- Leaks, floor and yard washings and spillages trapped in clean sumps and returned to the process. Floor washings contaminated with oils and grease would, however, require treatment. In addition to internal wastewater re-use, there are also external re-use and reclamation options as listed in Table 1 (DWAF, 1996) with their respective potential constraints. The four principal water re-use categories are agricultural and landscape irrigation, industrial application, ground recharge and potable re-use.

Table 1. Wastewater re-use categories and their potential constraints.

Wastewater re-use categories	Potential constraints
Agricultural irrigation Crop irrigation Commercial nurseries	Surface-and groundwater pollution if not properly managed. Marketability of crops and public acceptance.
Landscape irrigation Park School yard Freeway median Golf course Cemetery Greenbelt Residential	Effect of water quality, particularly salts, on soils and crops. Public health concerns related to pathogens (bacteria, viruses and parasites). Use area control including buffer zone. May result in high user costs.
Industrial Cooling Boiler feed Process water Heavy construction	Constituents in reclaimed wastewater related to scaling, corrosion, biological growth, and fouling. Public health concerns, particularly aerosol transmission of pathogens in cooling water.
Groundwater recharge Groundwater replenishment Salt water intrusion control Subsidence control	Organic chemicals in reclaimed wastewater and their toxicological effects. Total dissolved solids, nitrates and pathogens in reclaimed wastewater.
Recreational/environmental Lakes and ponds Marsh enhancement Streamflow augmentation Fisheries	Health concerns of bacteria and viruses. Eutrophication due to N and P in receiving water. Toxicity to aquatic life.
Non-potable urban use Fire protection Air-conditioning Toilet flushing	Public health concerns on pathogens transmitted by aerosols. Effects of water quality on scaling, corrosion, biological growth and fouling. Cross-connection.
Potable re-use Blending in water supply Reservoir Pipe to pipe water supply	Constituents in reclaimed wastewater, especially trace organic chemicals and their toxicological effects. Aesthetic and public acceptance. Health concerns about pathogen transmission, particularly viruses.

In the first water re-use category, that is irrigation (agricultural and landscape), it is only in the last century that the quality of irrigation water has been recognised. As stated in the National Water Act (NWA, 1998) the "..irrigation of any land with waste or water containing waste generated through any industrial activity or by a waterwork" is considered a "controlled activity" and may only be undertaken if authorised to do so. Guidelines have been proposed for the benefit of plants, animals and humans. The main issues that have arisen are salinity, sodicity, specific ion toxicity, water infiltration rate and the potential risks to public health. Some of these constraints are equally relevant to groundwater recharge.

In addition to the re-use of factory produced condensates, in boiler feed and in the already mentioned factory processes, there are a number of cooling duties which can serve to significantly reduce the volumes of make-up usage and effluent discharged. A discussion and very succinct summary of the major process cooling circuits are given by Wright and de Viana (1993). Typically the systems covered are for the cooling of the condensers, mill brass bearing, mill turbine, powerhouse turbine, low-grade crystalliser, final molasses, vacuum pumps and boiler fan and feed pump bearings. Table 2 documents the typical water-related problems associated with inferior cooling water quality. The more common problems expected of a high COD water are most often corrosion, fouling, blockages, discolouration, foaming, gas production, turbidity, colour and biological growths.

Table 2. Potential water related problems.

Equipment problems	Process damage	Product problems
foaming	corrosion	inadequate treatment
sediments	scaling	sediments
gas production	fouling	foam
odours	blockages	colour
heat exch. impairment	resin film	odour/taste
resin impairment	resin poison	tarnish
competition	abrasion	coagulation
precipitates	embrittlement	turbidity
colour effects	discolouration	health hazards
interference		blemishes
contamination		process solutions

When water fails to meet the minimum quality requirements for use in different cooling system configurations or as boiler makeup, then Table 3 can be referred to as a guide on the majority of most appropriate treatment technologies available.

Chemical treatment suppliers (for example, Buckman Laboratories) are capable of predicting, aided by computer-modeling software, the scaling, fouling and corrosion tendencies of water. Appropriate scale and corrosion inhibitors, biodispersants and microbicides can then be applied to mitigate the negative impact of recycled water streams.

Occasionally it may not suffice to rely solely on computer modeling, in which case pilot scale trials can be performed to validate the results. The use of state-of -the-art SCADA controlled and real-time monitored pilot scale cooling systems permits the selection and optimisation of holistic internal conditioning treatment programmes. Amongst the various additional water treatment capabilities, a particularly relevant capability in water management is the use of computational fluid dynamics.

Table 3. Processes for treating make-up for cooling and boilers (adapted from National Academy of Science, 1972).

Processes	Cooling		
	Once through	Recirculated	Boiler make-up
Suspended solids and colloids removal			
Straining	X	X	X
Sedimentation	X	X	X
Coagulation		X	X
Filtration		X	X
Aeration		X	X
Dissolved-solids modification softening			
Cold lime		X	X
Hot lime soda			X
Hot lime zeolite			X
Cation exchange sodium		X	X
Alkalinity reduction cation exchange			
Hydrogen		X	X
Cation exchange hydrogen and sodium		X	X
Anion exchange			X
Dissolved solids removal			
Evaporation			X
Demineralisation		X	X
Dissolved-gases removal (degasification)			
Mechanical		X	X
Vacuum	X		X
Heat			X
Internal conditioning			
pH adjustment	X	X	X
Hardness sequestering	X	X	X
Hardness precipitation			X
Corrosion inhibition general		X	X
Embrittlement			X
Oxygen reduction			X
Sludge dispersal	X	X	X
Biological control	X	X	

The use of fluorescent tracers allows for:

- The detection of leaks.
- Determination of effluent flow rates.
- Establishment of hydraulic retention times of biological treatment processes (as well as short-circuiting in ponds).
- The mapping of discharge dilution in receiving water systems.

Wastewater reclamation technologies

Further to the previously discussed steps of minimisation, segregation and re-use/recycle, the final quest is to return to source (that is to the same catchment) as much of the abstracted water as possible. Most sugar mill effluent is known to be unacceptable for direct or diffuse discharge mainly due to an excessively high chemical oxygen demand (COD). Since the major contributor to the high COD is the soluble sugars, it is common to employ biological degradation either by anaerobic and/or aerobic processes.

Table 4 (Culp *et al.*, 1979) lists the most suitable unit processes and operations applicable for COD reduction in industrial effluent.

In biological treatment there are several technologies available and only those most common to South Africa are discussed:

- Primary treatment (for suspended solids removal)
- Aerobic treatment (usually used alone for less polluted waters)
- Activated sludge
- Trickling filters
- Pasveer ditches
- Anaerobic treatment (for treatment of highly polluted waters, COD contents of several thousand mg per litre)
- Anaerobic ponds (ash dams)
- Anaerobic filters
- Irrigation

Table 4. Unit processes and operations relevant to sugar mill effluent reclamation.

	Unit Process or Operation																	
Constituent	Primary Treat	Act Sludge	Nitrification	Denitrification	Trickling Filter	RBC	Clarification	C Adsorb	Filt after A/S	Chlorination	Ozone	Ammonia Strip	Select Ion Exchage	Breakpt Chlorin	RO	Overland flow	Irrigation	Infilt-percolatn
BOD	X	+	+	0	+	+	+	+	X		0		X		+	+	+	+
COD	X	+	+	0	+		+	X	X		+	0	X		+	+	+	+
TSS	+	+	+	0	+	+	+	+	+				+		+	+	+	+
Ammonia	0	+	+	X		+	0	X	X			+	+	+	+	+	+	+
Nitrate				+				0	X							X		
Phosphorus	0	X	+	+			+	+	+						+	+	+	+
Oil & Grease	+	+	+				X	X								+	+	+
T Coliform		+	+		0		+	+		+	+			+		+	+	+
TDS															+			
Colour	0	X	X		0		+	+	X		+				+	+	+	+
Foaming agents	X	+	+		+		X	+			0				+	+	+	+
Turbidity	X	+	+	0	X		+	+	+						+	+	+	+
TOC	X	+	+	0	X		+	+	X		+	0	0		+	+	+	+

Symbols: 0 = 25% removal, X = 25 to 50%, + = >50%, blank = no conclusive data

Anaerobic degradation of organic matter takes place in three stages: (i) hydrolysis and fermentation (the formation of alcohol and fatty acids), (ii) acetogenisis and dehydrogensis (acetic acid and hydrogen formation), and (iii) methanogenesis (methane or biogas production). Anaerobic treatment has been largely by anaerobic ponds or ash dams which have made them affordable to the industry.

Aerobic treatment is by Pasveer or oxidation ditch ('race-track' shaped pond with horizontal surface aerators and an intra-channel clarifier), activated sludge (aeration tanks with a separate clarifier) and more recently the trickling filter (Govender, 1992). The trickling filter was installed at a sugar mill in 1990 between an existing anaerobic dam and Pasveer ditch to assist in COD removal and improve overall performance in attaining the effluent quality required.

Artificial wetlands have been tested and successfully applied in many countries around the world, including South Africa. These artificial wetlands consist of reeds or bulrushes planted for their ability to transport oxygen to their roots, necessary for their growth. The COD breakdown in the water is by both aerobic and anaerobic bacteria living in the aerobic and adjacent anoxic areas respectively, in the soil (Schumann, 1991). Such a process is recommended where large areas are available and usually where the wetland does not receive a direct point source effluent.

Membrane technologies, such as reverse osmosis and membrane bioreactors, are currently under investigation and hold great potential in sugar-mill effluent reclamation.

Conclusion

Industries in South Africa that utilise process water, such as the sugar industry, have in recent years, given water management heightened attention. Increased environmental awareness, stricter discharge limits and the shortage of good quality water are continuing to increase the cost of water usage as well as water treatment. However, only through collaboration and a consideration of the water chemistries, utility and process design, treatment technologies and economics will it be possible to arrive at creative solutions in the sustainable and equitable use of water.

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