

IMPLEMENTING A ZERO EFFLUENT PHILOSOPHY AT A CANE SUGAR FACTORY

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Abstract

Towards the end of 1998, capital was approved to implement zero effluent technology at Maidstone Mill, South Africa. In order to minimise the risks associated with the technology, the project was split into 2 phases. The first phase involved containment and recycle of spillages, the minimisation of external water supplied to the factory and the re-processing of factory effluent. The primary aim of phase 1 was to achieve the situation where all surplus water leaves the factory as cooled condensate. Phase 2 of zero effluent includes, *inter alia*, the physical removal of COD from the cooled condensate to meet general discharge standards. This paper discusses the design, implementation and performance of phase 1 of the zero effluent, which was completed during 1999. The performance of the zero effluent system at Maidstone, provides clear evidence that zero effluent is in fact achievable at a cane sugar mill over a range of normal operating conditions, including maintenance shutdowns. Over and above the environmental benefits, zero effluent is shown to have real commercial and operational benefits.

Introduction

During the 1990s, Maidstone Mill came under increasing pressure from the Department of Water Affairs and Forestry regarding its negative impact on the environment. This was mainly related to liquid effluent disposal problems. Crisis level was reached in September 1996, when the mill was threatened with closure if adequate steps were not taken to rectify the problem. The nature of the environmental problems, and the effluent disposal options available to Maidstone mill, are discussed elsewhere (Meadows *et al.*, 1999).

At the same time, there was a growing belief within Tongaat-Hulett that a factory without an effluent stream was practically achievable, fuelled by the success of piloting aspects of the 'zero effluent' philosophy at various factories. By 1998, Maidstone Mill had decided to pursue the 'zero effluent' approach, instead of following the conventional route of effluent treatment.

In November 1998, capital was approved for Phase 1 of the zero effluent project. This involved the containment and recycle of spillages, the minimisation of external water supplied to the factory and the re-processing of factory effluent. The primary aim of Phase 1 was to achieve the situation where all surplus water leaves the factory as cooled condensate. The cooled condensate surplus would continue to be disposed of by irrigation (the existing method of effluent disposal). Phase 1 was completed during 1999 at a cost of approximately US\$550 000.

The shift from effluent treatment to prevention

Currently the concepts of 'clean' production, waste prevention and effluent elimination are high on the agendas of environmental and statutory organisations. In a recent review, Purchase (1995) studied the methods for liquid effluent disposal from cane sugar

factories in 11 countries. He identified that elimination of BOD (biological oxygen demand) from effluent, and optimisation anaerobic pond design were the highest priority items at that time. Subsequently, however, the focus of research in the sugar industry has shifted from effluent treatment, to conform with legal standards, to effluent elimination/minimisation.

Hsieh *et al.* (1995) introduced the concept of a 'zero effluent' sugar factory. They identified that the water content of cane is more than sufficient to supply all the water requirements of a sugar factory. A zero effluent system was proposed, which re-uses treated effluent (using a facultative-aerobic system) in factory water circuits to minimise the need for an external supply of water. Wright and Miller (1999) discussed strategies for water management and effluent minimisation in the sugar factory. They suggested that a 'process water audit' be carried out in a factory to determine the quality and quantity of water available, as well as the water requirements of individual cooling water circuits and other users of water. The intention was the reclamation of water for re-use in the appropriate water circuit.

Definition of terms

A 'zero effluent' sugar factory, as defined in this paper, is one where all surplus water leaving the factory meets the general discharge standards, without requiring conventional downstream effluent treatment. It does not mean that the factory has no exit water stream, as the water balance of any cane sugar factory results in a water excess due to the high water content in cane (Hsieh *et al.*, 1995).

To avoid possible ambiguity, some of the terms used in the paper are defined:

- Service water: raw river water used in the factory.
- Filtered water: treated/potable water.

KEYWORDS: Environment, Minimisation of Water Use, Recycle, Effluent.

- External water: water entering the factory, other than water contained in the cane (i.e. service or filtered water)
- Injection cooling system: factory condenser cooling water circuit.
- Service cooling systems: vacuum, crystalliser and bearing cooling water circuits.
- Process water: any source of water produced by factory operations (i.e. excludes external water and water from the service cooling systems).

Zero effluent design philosophy

Both Hsieh *et al.* (1995) and Wright and Miller (1999) focused on the reuse of water in factory cooling water circuits. However, the primary internal use of water at a sugar mill is the imbibition water used by the extraction plant. In 'traditional' sugar processing, the best water (condensate) is used as imbibition. The crux of the zero effluent strategy presented here is that all effluent is recycled to the diffusers as imbibition. This in turn reduces, by an equal amount, the demand for condensate as imbibition, resulting in surplus condensate. The surplus condensate may then be steam-stripped of volatiles and cooled to conform to general discharge standards. This approach represents a paradigm shift for the sugar industry as the best water is saved for discharge (excess condensate), while the worst water (effluent) is recycled in the process. This fundamental change means that poor mill operations yielding large quantities of effluent will impact upon production instead of the environment. Therefore, under zero effluent, the incentive for minimising effluent is no longer environmental legislation, but factory performance itself.

By recycling sugar mill effluent back to the process, the impurities present in effluent are treated in the same way as those impurities already present in the cane:

- Insoluble non-combustible material ends up in boiler smuts or surplus bagasse.
- Soluble impurities end up in molasses.
- Volatile impurities are eliminated by evaporation (e.g. in the cooling towers).

In this way, conventional sugar mill equipment is used to separate the impurities from the water portion of the liquid effluent. The result is a condensate stream, which, after being stripped of any remaining volatile components, is suitable for discharge.

The negative impact of recycling effluent back to the process is a loss of overall recovery as a result of adding organic and inorganic impurities to the cane juice (in addition to those already present in the cane), and a possible decline in sugar quality. The real challenge in implementing the zero effluent system is to minimise the negative impacts on factory performance.

With a conventional effluent treatment system, effluent treatment is the responsibility of the operator at the treatment works. However, he has little control over the quantity and quality of the effluent feeding the plant, which if overloaded may contaminate the environment. In contrast with zero effluent, both

effluent minimisation and treatment become the responsibility of operators throughout the factory. However, there are also disadvantages with integrating the effluent handling system into the mill operations. With zero effluent, problems/breakdowns in the factory are also likely to affect the ability of the factory to reprocess effluent. Furthermore, it is often during mill breakdowns when the quantity of effluent produced increases.

For this reason the zero effluent system at Maidstone is split into three levels, called nets:

- The first net: containment and recycle.
- The second net: minimisation and re-use.
- The third net: External recovery and condensate treatment.

The first net is highly integrated with factory operations and has negligible buffer capacity. It is intended to be visible to all factory staff so that problems are quickly identified and corrected (e.g. a sump overflowing). The second net has sufficient buffer capacity to cater for the commonly occurring stoppages in the factory, but it cannot cater for every eventuality. The second net, although integrated with factory operations, is fully automated and 'invisible' to factory staff. Finally, the third net, like conventional effluent treatment equipment, is independent of mill operations. Phase 1 of zero effluent includes the first two nets, while installation of the third net falls under Phase 2.

The first net

The aim of the first net is to eliminate the majority of the COD present in 'ordinary' sugar mill effluent at source. It consists of a system of drains, sumps and pumps, which contain, and then recycle the spills back into the process so that the sugar is recovered. Effective operation of the first net is critical to minimise the negative impacts of second net effluent recycles on factory operations.

The key elements of the first net are as follows:

1. All factory areas are bunded and drained to recycle sumps. There are no areas in which liquid on the floor 'just goes down to effluent'.
2. In order to minimise the negative impact of recycling on mill performance, bunded areas are separated according to the nature of likely spills or washings. Depending on the nature of the spill, it is recycled to a different point in the process.
3. The sumps are generally small and are epoxy lined (to protect the concrete and to allow for easy cleaning). This minimises bacteriological degradation and ensures that spillages are recycled rapidly to the process.
4. Maidstone had a complex system of interconnecting underground drains, which communicated with the stormwater drains. An important part of installing the first net was to isolate factory drains from the stormwater drainage system.

The negative impacts of the first net are the recycle of degraded sugar products back into process, and dilution of factory streams which increases the

evaporation load. However, the first net has the significant advantage that sugar that would otherwise be lost is recovered and put back into process.

The second net

While the aim of the first net is to return any overflows to the process immediately, this approach is not possible (or desirable) for the second net. For example, if a large volume of water suddenly escapes the first net, either due to a tank overflow or the draining of a vessel, it is unlikely that there is sufficient space available in the factory to return the water immediately. Instead, the second net is designed to contain any water escaping the first net, and then bleed the water back into the process as the factory allows. The water caught in the second net is pumped via the scrubber circuit back to the diffusers as imbibition. Much of this water is evaporated in the scrubbers, while the remaining water provides a means of removing Ca²⁺ and SO₄²⁻ ions from the scrubber circuit.

The water that is caught in the second net includes: any overflows from the first net; the excess injection water, service cooling tower overflows/blowdown; water used during evaporator cleaning, and first-flush (contaminated) stormwater run-off. Therefore, provided that the first net is operating effectively and that sugar levels in the injection system are low, the water that enters the second net should contain little more than a trace of sugar.

A water management system which integrates process water and external water requirements falls at the heart of the zero effluent philosophy. Some of the key principles of the water management program are given below:

1. Eliminate water usage where possible. (e.g. water-cooled air-compressors were replaced with air-cooled compressors.)

2. Minimise usage where external water is essential. (e.g. high pressure water-jetting machines are used for factory cleaning.)
3. Minimise water losses from service cooling water circuits.
4. Substitute external water with a process water stream of the minimum required quality.
5. Substitute condensate with lower quality process water where appropriate. (This increases the amount of condensate available for users which require high quality water.)
6. Monitor the use and availability of process water throughout the factory to ensure that factory users have an adequate supply of water at all times. Flowmeters are used to monitor water usage; and level transmitters, on storage tanks/sumps, are used to monitor water availability. Sufficient storage capacity or some form of make-up facility is provided for each source of process water, such that unsteady operating conditions are catered for.

Figures 1 and 2 contain a list of the primary users of external water and potential sources of effluent production at Maidstone. A comparison of Figures 1 and 2 provides a summary of the changes to water management at Maidstone as a result of zero effluent.

- Imbibition supply—Although a factory will generally have an excess of imbibition water, at times there will be a shortage of imbibition water, requiring a service water make-up.
- Boilers and scrubbers—The boilers normally have an adequate supply condensate, but there also are times when it is necessary to add filtered (softened) water to the boiler feed water tank. The boilers do produce a small quantity of effluent as blow-down water. The scrubbers on the other hand require make-up water continually and have a large blow-down requirement.

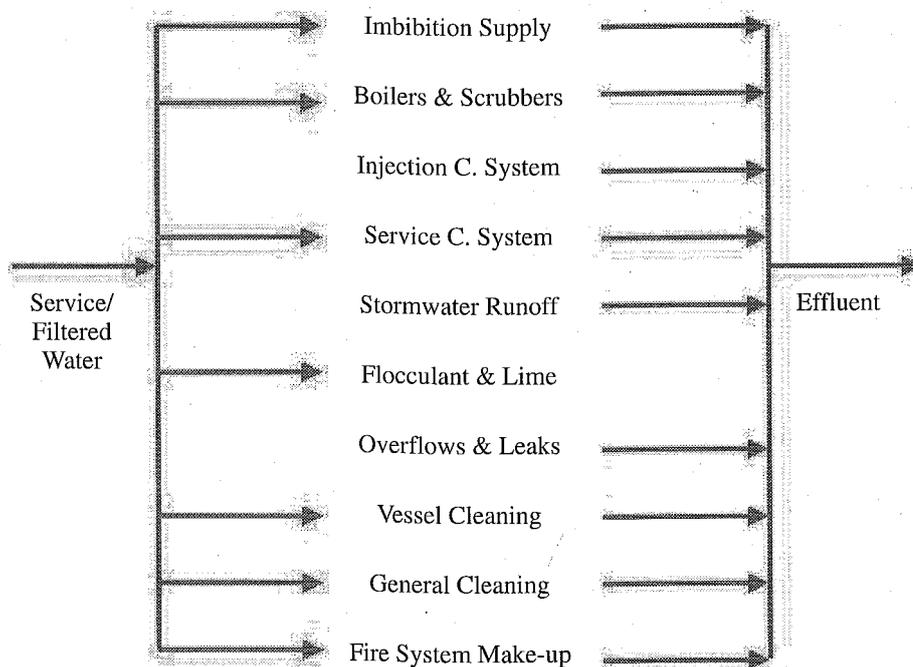


Fig. 1—Maidstone Water Management System (pre zero effluent).

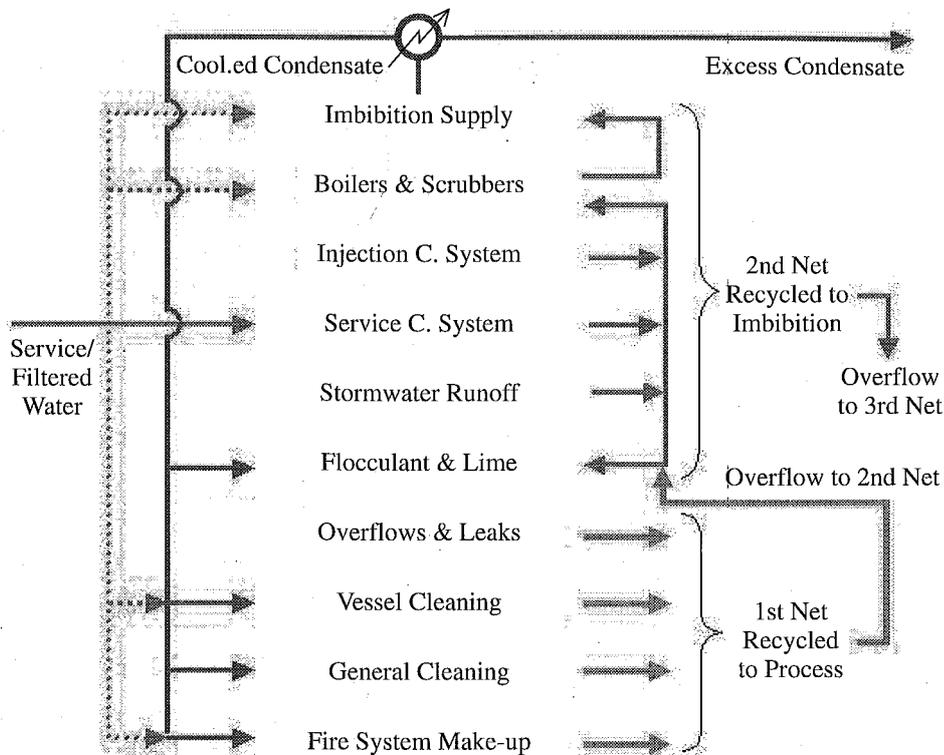


Fig. 2—Maidstone Water Management System under zero effluent.

- Injection towers—The primary make-up to the injection water system is the vapour condensed in the factory condensers. More water is condensed in the factory condensers than is evaporated in the towers; therefore, this system has a net overflow.
- Service cooling towers—The service cooling towers have both water make-up and blow-down requirements. (For corrosion control purposes the filtered water make-up was not removed from this application in Figure 2)
- Stormwater run-off—Stormwater (first-flush only) run-off is included as a source of effluent.
- Flocculant mixing and lime slaking—These systems require water, but do not produce effluent as the water eventually ends up in the process. (Flocculant mixing requires higher quality water than lime slaking.)
- Overflows and leaks, vessel cleaning, general cleaning—all these activities result in the production of effluent.
- Fire system make-up—this refers only to the quantity of water required to maintain fire system pressure, and not the water that would be used in the event of a fire.

The challenge in designing the zero effluent water management system at Maidstone, which includes a PLC/SCADA control system, was to make the Figure 2 flowsheet workable in practice, with little or no operator intervention.

Performance of the system

Table 1 shows the reduction in effluent production and external water usage in the factory since 1997. (The service water meter was installed in 1997. In 1999, for corrosion control purposes, the service cooling towers were switched from service to filtered water.) It should be noted that the effluent figures reported here include contaminated stormwater run-off from both the Maidstone Mill site and a neighbouring animal feeds factory.

During the 1998 season some of the first net recycles were installed, and the installation was completed during the following offcrop. The impact of the first is evident from large reduction in COD from the 1997 and 1998 seasons, to 1999. The second net was commissioned mid-way through the 1999 season. The reason for the increased effluent flow between 1998 and 1999, was that with the installation of the Zero effluent system, a number of 'back-doors'

Table 1—Average effluent production and factory service water usage at Maidstone.

Year	Effluent out, t/day	COD out, tpd	External water, tpd		
			Service	Filtered	Total
1997	2268	4.6	2040		2040
1998	1213	3.6	1365		1365
1999	1365	1.6	729	387	1116
2000	625	1.0	356	304	662
Nov & Dec 2000 only	561	0.8	178	272	450

were discovered and eliminated. These 'back-doors' allowed operators to mix unmetred quantities of effluent with the river water supplying the irrigation system. Table 1 shows the significant reductions in effluent tonnages and external water usage in 1999 and 2000 as a result of Zero effluent.

By November 2000, Maidstone effluent was almost exclusively contaminated stormwater. Figure 3 shows the daily factory effluent and excess condensate flows for this period. (Under Phase 1 of zero effluent, factory effluent refers to that water which overflows from the second net. Although the first net drains have been separated from the stormwater drains, it was not possible to isolate the second net from the stormwater system. Therefore, rain has the effect of overloading the second net, forcing the production of effluent.) In addition to showing the link between rainfall and effluent production, Figure 3 shows a few small excess condensate tonnages. Over this period the water balance at Maidstone was such that the factory was a net user of water.

Impact of zero effluent on sucrose recovery

The primary negative impact of the zero effluent system is the recycle of ash contained in the scrubber circuit back to the diffusers. This stream was sampled daily for a full ionic analysis. The scrubber water contained primarily SO₄²⁻ and Ca²⁺ at concentrations of 600 ppm and 550 ppm on average, respectively. The presence of SO₄²⁻ is a consequence of the SO₂ produced by coal burning, and much of the Ca²⁺ present is a result of neutralisation with lime.

The average total ash content of the scrubber water was 1600 ppm, and the average daily recycle was 1000 tons per day. This corresponds to 1.6 tons of ash recycled per day. The increased total ash processed by the factory is about 2%. Using the target purity equation proposed by Rein and Smith (1981), it is estimated that the ash recycled during the 2000

season resulted in a 0.13% loss in overall recovery as a result of a 0.15% rise in final molasses purity and the increased non-pol loading. Notwithstanding this loss, the factory performance figures at Maidstone were the best in the South African industry for the 2000 season.

Conclusions

The performance of the zero effluent system at Maidstone provides clear evidence that zero effluent is in fact achievable at a cane sugar mill over a range of normal operating conditions, including maintenance shutdowns. Questions that still need to be handled under Phase 2 are, the disposal of contaminated stormwater run-off, and the effluent produced during the end of season boil-off.

Although there is a loss in recovery as a result of scrubber recycle, this loss must be viewed in the light of the benefits of zero effluent:

- Reduced sugar losses to effluent as a result of the first net (Table 1).
- The costs of installing and running an effluent plant are avoided.
- Odour and other problems associated with effluent ponds are eliminated.
- Greatly reduced factory service water requirements.
- Guaranteed to meet even the strictest environmental legislation.

Furthermore by improved factory operations (e.g. minimising of overflows and coal burning) and good housekeeping, it is should be possible to virtually eliminate the negative impacts of zero effluent on sucrose recovery.

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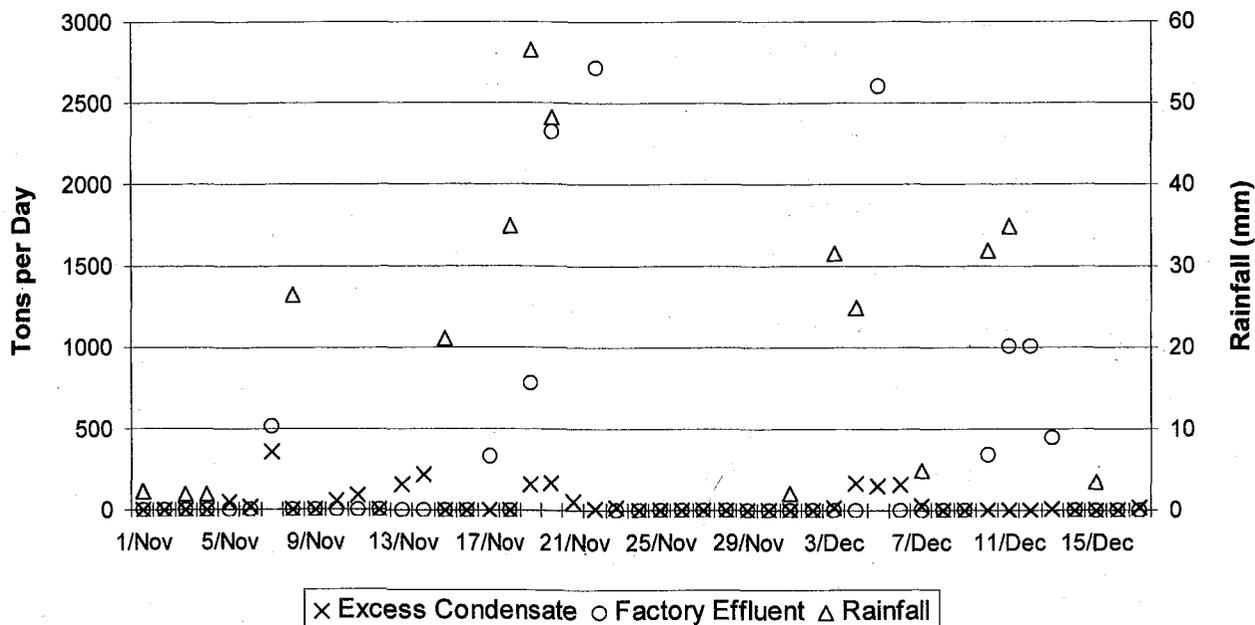


Fig. 3—Maidstone effluent, excess condensate and rainfall November/December 2000.

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ZÉRO EFFLUENT: UNE PHILOSOPHIE POUR SUCRERIE DE CANNE

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Resumé

Vers la fin de 1998 le sucrerie de Maidstone en Afrique du Sud, a pu financer la réalisation d'une technologie appelée "Zero Effluent". Pour minimiser les risques, on a divisé le projet en deux phases. La première phase couvre le recyclages des liquides répandues a terre, la réduction des eaux d'entrée a la sucrerie et le traitement des effluents. L'objectif de la phase un a été d'arriver à la situation ou toute l'eau quittant la sucrerie est du condensat. La phase deux comprend le traitement du condensat pour enlever la DCO. Le papier présente l'introduction et les performances de la phase un, appliquée en 1999. Les résultats obtenues a Maidstone montrent que cette philosophie est réalisable dans une sucrerie de canne. Elle est avantageuse non seulement pour l'environnement mais aussi aux points de vue commercial et operationel.

Mots clefs: Environment, utilisation des eaux, recyclage, effluent.

IMPLANTANDO UNA FILOSOFÍA DE CERO AGUAS RESIDUALES EN UNA FÁBRICA DE CAÑA DE AZÚCAR

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Resumen

Hacia fines de 1998, se aprobó algún capital para implantar una tecnología de Cero Aguas Residuales en el Ingenio Maidstone, en Sudáfrica. Con el objeto de minimizar los riesgos asociados con la tecnología, el proyecto se dividió en dos fases. La primera fase implicaba la contención y reciclaje de los derrames, la minimización del agua externa que se suministraba a la fábrica y el reproceso de las aguas residuales de la fábrica. El objetivo primario de la fase 1 fue lograr una situación en la que toda el agua excedente saliera de la fábrica como un condensado enfriado. La Fase 2 de Cero Aguas Residuales incluye, entre otras cosas, la eliminación física de COD del condensado enfriado, para cumplir con los estándares generales de descarga. Este documento trata sobre el diseño, implantación y desarrollo de la fase 1 de Cero Aguas Residuales, la cual se terminó durante 1999. El desarrollo del sistema de Cero Aguas Residuales en Maidstone, proporciona una evidencia clara de que es de hecho posible lograr este propósito en un ingenio azucarero en un rango de condiciones normales de operación, incluyendo los cierres por mantenimiento. Sobre y por encima de los beneficios ambientales, se demuestra que las Cero Aguas Residuales proporcionan beneficios operativos y comerciales reales.

Palabras claves: Medio Ambiente, Minimización del Uso de Agua, Reciclaje, Aguas Residuales.