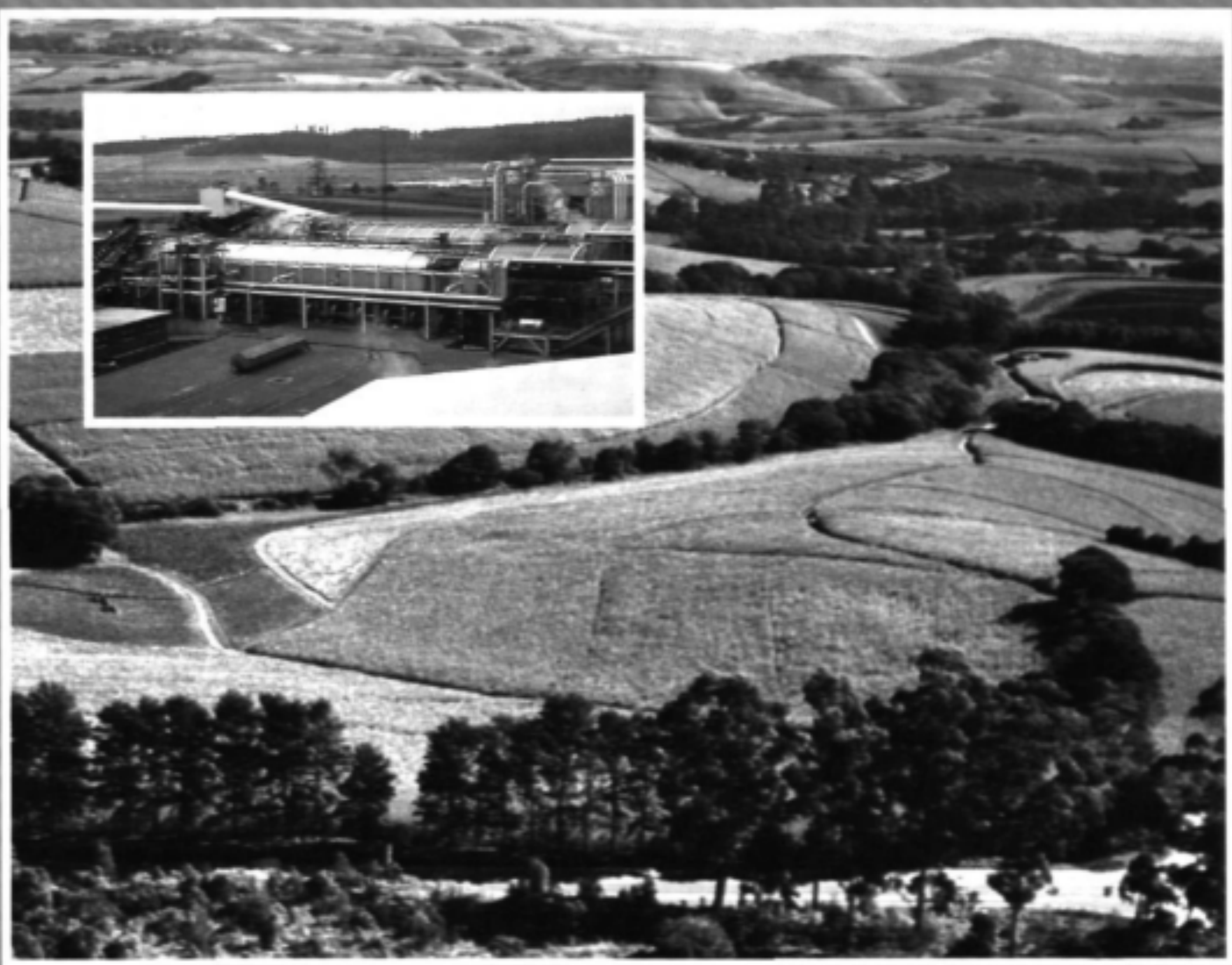
NATSURV 11

WATER AND WASTE-WATER MANAGEMENT IN THE SUGAR INDUSTRY



NATSURV 11

WATER AND WASTE-WATER MANAGEMENT

IN THE

SUGAR INDUSTRY

Prepared

for

THE WATER RESEARCH COMMISSION

By

STEFFEN, ROBERTSON AND KIRSTEN INC

Consulting Engineers

WRC PROJECT NO. 145

TT 47/90

JUNE 1990

PRETORIA

Steffen, Robertson and Kirsten Inc
16th Floor
20 Anderson Street
JOHANNESBURG
2001

P O Box 8856
JOHANNESBURG
2000
Tel : (011) 492-1316

Available from:

Water Research Commission
PO Box 824
PRETORIA
0001
Republic of South Africa

ISBN 0 947447 75 X

This publication stems from a research project entitled:

National Industrial Water and Waste-water Survey
that was carried out by: Steffen, Robertson and Kirsten Inc
Consulting Engineers

DISCLAIMER

This report has been reviewed by the Water Research Commission and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Water Research Commission, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

The need for guidelines to reduce water intake and waste-water discharge by industry is of national concern in view of South Africa's water scarcity. To establish norms for water intake and waste-water disposal, the Water Research Commission (WRC) in collaboration with the Department of Water Affairs (DWA) contracted Binnie and Partners (now amalgamated with Steffen, Robertson and Kirsten), a firm of consulting engineers, to undertake a National Industrial Water and Waste-water Survey (NATSURV) of the sugar industry. The results obtained in the survey form the basis of this guide on water and waste-water management in the sugar industry.

It is expected that this guide will be of value to the sugar industry itself and to other interested parties such as municipalities, administrators, researchers and consultants in the water and waste-water fields.

ACKNOWLEDGEMENTS

The preparation of this publication was constituted under the leadership of the following Editorial Committee:

Dr O O Hart	-	Water Research Commission
Dr B S Purchase	-	Director, Sugar Milling Research Institute
Mr D F Sutton	-	Department of Water Affairs
Mr P Skivington	-	Steffen, Robertson and Kirsten

GLOSSARY OF TERMS

BAGASSE	-	Cane fibre from which the sugar has been extracted.
BRIX	-	the percentage by mass of total soluble solids in solution.
IMBIBITION WATER	-	water used to wash the sugar out of the fragmented cane in the juice extraction process.
MAGMA	-	a mixture of sugar crystals and hot syrup produced by mechanical mixing.
MASSECUITE	-	the mixture of crystalline sucrose and a mother liquor resulting from evaporation of syrup.
MELT LIQUOR	-	a solution produced by dissolving sugar crystals in water in the sugar refining process.
MUD	-	sediment precipitated during the clarification of cane juice.

SUMMARY

There are 16 sugar cane processing plants and one stand-alone refinery in the Republic of South Africa which produce about 2 million tonnes of sugar per annum according to the 1985 figures. More recent production figures for the sugar industry are not available. Of the 16 processing plants 10 are mills only and 6 are mills with a so-called 'back-end' refinery. The latter situation is increasingly becoming the trend in the sugar industry worldwide.

The sugar industry is unusual in that the main raw material (sugar cane) contains very large quantities of water (about 70% by mass). As the main process in both a mill and a refinery is concerned with extracting sugar crystals from solution, the vast majority of this and any other water entering a plant is evaporated and can be recovered as condensate. Water from other sources (typically boreholes or river abstraction) is used only in applications such as cooling for condensation of vapours or domestic consumption. Specific water intake (SWI) was found to be 30 to 100 $m^3/100\ t$ of cane processed with a mean SWI of 60 $m^3/100\ t$.

Wastewater volumes are relatively small compared to the total volumes of water in circulation at any one time. Typically 750 to 1500 m^3/d of waste water (about 30% of the water intake) is generated with a chemical oxygen demand of 1 500 to 2 000 mg/ℓ. The main source of this chemical oxygen demand (COD) is sugar lost in washing and in cooling water overflows. Sugar plant waste waters are problematic in that the COD load present is almost totally soluble leading to sludge bulking and sludge loss problems in conventional biological treatment systems. They also tend to be deficient in nitrogen and phosphorus.

By-products from a sugar processing plant are molasses, which goes to animal feed or further processing to fermentation products, and bagasse which is burnt in the sugar plant boilers or can be further processed to paper and chemical products.

Solid wastes arising from sugar processing are boiler ash and smuts which go to landfill and filter cake (from the milling process) which may be used as fertilizer in some areas or alternatively is also disposed of as landfill.

TABLE OF CONTENTS

LIST OF TABLES

1 INTRODUCTION

The sugar industry in South Africa is about 150 years old. It is geographically located in Natal with the exception of 2 plants which are in the eastern Transvaal. Sugar cane is processed continuously from April to December, the other part of the year the plants are being maintained. Sugar cane can be cut at any time during the processing period but, having been cut, it should be processed within 72 h.

There are 16 sugar cane processing plants in South Africa and one stand-alone refinery. Six of the processing plants are mills and refineries combined which, mainly for energy efficiency reasons, is the modern trend in the industry. Sugar production stood at about 2 million tonnes per annum (1985) at which time the industry was operating at close to its capacity. Some expansion is planned to provide fermentable material for a fuel ethanol plant. Production data for individual processing plants are not available due to their sensitive nature.

The results in this document are based on data collected at 10 sugar processing plants in South Africa.

2 PROCESS RÉSUMÉ[1]

The processing of sugar from sugar cane takes place in two stages, namely milling and refining.

2.1 Milling

After harvesting and transport to the mill, the cane is chopped and shredded by revolving knives and shredders. The shredded cane is then milled between rollers and is counter-currently contacted with water to ensure the maximum possible juice extraction. A modern trend, used extensively in southern Africa, is not to use rollers but to simply percolate the water counter-currently through a bed of moving shredded cane. This water is known as the maceration or imbibition water. The bagasse is usually burned as a boiler fuel but can become a raw material in the manufacture of other products.

Following milling, lime is added to the juice to give a pH of about 8,5 and the solution is heated to boiling point. This results in the precipitation of calcium phosphates, denatured organic complexes and insoluble matter such as soil and fibre particles (mud) which are settled out in a clarifier. This mud is further processed in a vacuum filter to recover associated juice before being distributed on cane fields.

The clarified juice is then concentrated from about 15^0 Brix to 65^0 - 70^0 Brix in a multi-effect evaporator at which the concentrated juice is called syrup. The syrup is converted to a mixture of crystalline sucrose and a mother liquor (massecuite) in a single effect evaporator or vacuum pan. The crystalline sucrose is recovered by centrifugation. After a series of boiling operations the mother liquor is exhausted of crystalline sucrose and is known as final molasses. The recovered raw sugar crystals are dried in large drum driers before transport to refineries.

2.2 Refining

The objective of refining is to improve the quality of the sugar as a foodstuff and to improve its storage potential. In refining, the sucrose level is increased from about 99,3% to over 99,9% by removal of solid particles, organic and inorganic substances and micro-organisms.

The raw sugar is dissolved in fresh water to about 65^0 Brix. After screening to remove sand or scale, this process solution (known as a melt liquor) undergoes clarification. This is accomplished either by the addition of lime and phosphoric acid and subsequent flotation of impurities or by injecting carbon dioxide to precipitate calcium carbonate and impurities. The precipitate is removed by pressure filtration.

The clarified liquor may be further decolourised using ion exchange resin. It is then evaporated from 65^0 Brix to about 75^0 Brix. Some sugar loss occurs at this stage due to entrainment in evaporator vapours and can be a source of pollution. The resulting sugar concentrate is crystallized in vacuum pans and sugar crystals are recovered by centrifugation and dried.

3 SUMMARY OF SURVEY RESULTS

3.1 Specific water intake

In order to maintain the confidentiality of the individual sugar processing plants, the results are expressed in terms of the ratio of m^3 of water intake per 100 tons of cane processed. The quantity of sugar produced from 100 t of sugar cane is about 11,6 t.

Table 3.1 Specific water intake for Sugar mills in the RSA

	Sugar cane processed (t/h)	SWI (m^3/100 t)
Range	100 - 600	30 - 100
Mean	250	60

The mean SWI was found to be 60 m^3/100 t and the range of SWI was 30 to 100 m^3/100 t. Two outlying results were excluded from this range. These were SWI figures of 300 and 2 000 m^3/100 t which were for plants operating on a 'once through' cooling water system, either partially or completely.

Sugar cane contains about 70% water and theoretically all the water requirements of a sugar processing plant can be satisfied by utilizing the water in the cane. In periods of drought in the 1980s sugar plants in the RSA were forced to operate on this basis as rivers and dams dried up. For practical reasons however, it is usual for a sugar plant to take in some water from other sources such as rivers or boreholes. As the processing of sugar basically consists of a series of evaporation and cooling processes, considerable quantities of very high quality condensate is produced and this can be reused within the plant.

Energy conservation is the prime concern of sugar plants in the RSA and dictates the minimum volumes of water used. For plants in the USA figures of 396 to 1 340 m^3/100 t of cane crushed have been quoted[1]. As can be seen in Table 3.1, figures from South African mills compare very favourably with these. Plant size is only of secondary importance as the more cane a plant processes, the greater is the volume of water in the cane theoretically available for reuse.

Similarly, it should be possible for a mill with a back-end refinery to operate with a similar water intake to that for a mill only. Practical considerations may again make this unlikely but any additional water intake should be relatively small.

Boiler feedwater is often supplied directly by recovered condensate though care has to be taken to monitor the quality as reuse of contaminated condensate could cause a great deal of damage to boiler tubes. Systems which monitor condensate on the basis of conductivity and discard that portion which is not suitable for reuse are operating satisfactorily in several plants. Condensate not suitable for reuse as boiler feed can be pumped to hot water storage and from there reused for washing of filters and other factory cleaning duties.

Cooling water requirements for sugar processing plants depend largely on the temperature of the available water and to a large extent on management policy. Cooling water in the RSA is normally recirculated though in other countries this is not always the case. As a consequence of cooling water circulation, organic pollutants and micro-organisms tend to build up and blowdown of cooling water is required. This water is largely contaminated with sugar entrained from vacuum pans and evaporators and can have COD levels of 200 to 250 mg/ℓ. As such it is a considerable source of organic pollution.

Other requirements for water include sealing vacuum pumps and pump bearings, general washdown and imbibition water. Smuts control also requires considerable volumes of water but apart from evaporative losses, this water is recycled. Other minor sources of water loss from the system include water leaving with filter cake, in final molasses and that which is retained in the bagasse. For sugar refining the main water use is in redissolving the raw sugar for further processing and in the backwashing and rinsing of filters and ion exchange equipment used for colour removal in the refining process.

Methods of reducing water intake include:

a) Water used for general washing should be pressurized. Equipment is available for mixing a water jet and a compressed air stream close to the exit nozzle of hand-held sprays.

b) All hoses should be fitted with self-closing nozzles to prevent wastage when not in use. Where the hoses are in frequent use pistol grips should be used.

c) Loose dirt should be swept up dry prior to subsequent hosing down. This will also effect a reduction in the quantity of solid matter entering the final waste water.

d) Water meters should be installed at all the major water using areas and should be read regularly to monitor use.

e) Staff should be trained to increase their awareness of water saving methods.

f) The maximum possible condensate return should be strived for.

g) Cooling towers should be cleaned regularly to ensure that they continue to work efficiently.

h) Automated cleaning-in-place systems should be implemented where practical, for vessel, pipe and equipment cleaning where this has not already been done.

3.2 Waste-water discharge

As stated in the previous section most sugar plants operate with a water surplus and therefore waste water largely consists of surplus cooling water or condensate as well as cooling system and hot water system blowdown. Other sources of waste water include general washing water and backwash and rinse water from the water treatment and decolourization plant (in refining). Primary pollutants of sugar plant waste waters are entrained sugar and the various process liquors such as juice, syrup and molasses. Spillages and leakages of these materials should obviously be minimized as should loss of filter cake. Fortunately in the RSA, filter cake is extensively used as a fertilizer for cane fields and does not present a major disposal problem. Smuts disposal involves the discharge of considerable quantities of waste water but this is generally recycled for use again in the scrubbers. Volumes of waste water discharged by plants in the RSA are about 30% of the water intake or about 18 m^3 of waste water per 100 t of sugar cane processed but again this depends greatly on the energy and water management practiced by individual plants. *Typically therefore, the range of waste-water discharge* by plants in the RSA is 750 to 2 500 m^3/d with a COD in the range 1 500 to 2 000 mg/ℓ.

Sugar plant waste waters are problematic for a number of reasons:

a) Shutdown takes place for a brief period each week during which time waste-water pollution load can be minimal or very high if cleaning of process units is taking place (COD levels of up to 20 000 mg/ℓ can be discharged during these periods), making operation of biological treatment systems very difficult.

b) Sugar mill waste waters are difficult to treat biologically as they are deficient in nitrogen and phosphorus so nutrient addition is usually required.

c) Since sugar plant waste waters contain almost totally soluble pollutants, sludge bulking and sludge loss problems are encountered.

3.3 By-products and solid wastes

None of the materials which arise as a result of sugar processing need be regarded as wastes. The main materials are:

a) bagasse
b) smuts
c) filter cake
d) molasses.

Bagasse is usually burnt by the plant in its own boilers. It is not, however, a particularly clean fuel and large quantities of smuts arise as a result of wet scrubbing operations. Smuts is often disposed of in a mixture with filter cake which is sought after as a fertilizing mulch for cane fields. However, smuts has no fertilizer value and thus is problematic for plants which operate with diffuser mills as these produce very little filter cake for mixing with the smuts. In some of these cases smuts is disposed of as landfill.

Bagasse can also be used to produce paper or alternatively, chemical by-products. Molasses has many uses as a raw material, for instance in animal feeds or as a fermentation substrate for the production of ethanol, acetone, butyl alcohol, glycerol and citric acid.

3.4 Good pollution control practice[2]

Some good housekeeping methods are:

a) bunding of molasses storage areas;
b) removal of solids onto cultivated land at least 20 m from a river bank; and
c) ensuring that there is runoff of effluent used for irrigation and that stormwater runoff from the factory area does not enter nearby watercourses.

4 WASTE-WATER TREATMENT

4.1 Current situation

The sugar industry is about 150 years old but attention to waste-water treatment has only been given in the last 20 years. Since then the industry has devoted considerable time and effort to improving its waste-water handling facilities. This has met with significant success and some plants treat their waste water to such an extent that it can be reused for certain duties within the plant or discharged directly to a watercourse in compliance with the existing legislation.

Irrigation is still the most common final disposal route for sugar plant waste waters but upstream of this a number of different treatment routes are found including removal of suspended solids only, anaerobic treatment only and anaerobic treatment followed by aerobic treatment. It has been suggested, at least on a laboratory scale[2], that an activated sludge process is suitable for treatment of sugar plant waste water with a COD:N:P ratio of 100:2:0,4. As most plants are in rural areas they support a small community and treat domestic waste water as part of the servicing of these communities. Usually the domestic waste water is kept entirely separate from the industrial waste but it has been found in some cases that addition of domestic waste water increases the levels of nitrogen and phosphorus adequately so that no further nutrient addition is required. Addition of well-nutrified domestic waste water can also assist in reducing the potential for unpleasant smells encountered in the operation of many anaerobic pond systems[2]. These anaerobic systems are usually used as a pre-treatment to decrease the concentrations of reducing sugars.

In order to cope with the tremendous variation in waste-water quality and quantity sometimes encountered, sugar plants usually utilize large pond systems and in this regard, are fortunate to have large areas of land available for this purpose.

4.2 Anaerobic treatment [(4)]

The advantages of including anaerobic treatment in the system are:

(a) there is no capital or running cost for mechanical aerators;
(b) the nutrient requirements are lower than for aerobic digestion; and
(c) the large anaerobic dams buffer the hydraulic flow to the downstream aerobic system.

A disadvantage of anaerobic digestion is that it tends to produce unpleasant odours.

Sophisticated enclosed anaerobic digestors can consume as much as 25 kg of $COD/m^3.d$. Such facilities are difficult to operate and are too expensive to be justified in the cane industry (unless associated with distilleries). In South Africa simple open dams are used.

4.2.1 Design of simple dams

- Should be preceded by a grit/smuts settling pond to minimize silting of the main dam.
- Should be completely mixed rather than plug flow - ie multiple inlets.
- Inlet flow should be directed to the bottom to prevent thermal layering and to encourage mixing.
- Should be sized so that the loading is not more than 0,1 kg $COD/m^3.d$.
- Should have valve controlled, sub-surface outlet (to enable buffering of flow and prevent offtake of scum).

4.2.2 Overloading

Most of the anaerobic ponds in the industry are overloaded. Symptoms of overloading include:

- high lime consumption for pH control;
- unpleasant odour of volatile organic acids; and
- poor performance.

For many years one particular anaerobic dam was loaded with about 0,08 kg COD/m^3.d and it required no lime, produced no odour and consistently reduced the COD by 50% to 70%. Recent increases in loading to about 0,2 kg/m^3.d have caused the dam to "run sour" with only slight reduction in COD.

In a pilot plant treatment system which included facilities for settling sludge from the outgoing effluent so as to retain it in the digestor, a load of about 0,2 kg/m^3.d could be tolerated but the system was very sensitive to hydraulic overload, which caused loss of the sludge. When the digestor was packed with broken bricks it could tolerate a load of 0,47 kg/m^3.d without liming and with a COD reduction of about 75% (from 2 000 mg/ℓ). It was not sensitive to shock hydraulic loading because the sludge was attached to the bricks.

The fibrous roots of water hyacinth may also act as packing thus explaining why hyacinth covered dams have performed well with loads exceeding 0,1 kg/m^3.d.

4.2.3 Practical observations

Effluent is warm and if it is simply run onto the surface of a dam it tends to form a warm surface layer and thereby to short-circuit the dam.

Unexpectedly it is common to measure higher concentrations of COD at the outlet of dams than at the inlet. This is a result of catch sampling which tends to miss slugs of highly concentrated effluent leaving the factory over short periods. The slugs are however mixed with the body of effluent by the time sampling takes place at the dam outlet.

Unless there is a silt trap prior to the dam, the dam capacity steadily decreases, leading to overloading. (The difference between a silted up anaerobic dam and an ash dam being used for anaerobic treatment is that in the latter the effluent percolates through the ash thus ensuring good contact between the effluent and the microbes on the ash).

4.3 Aerobic treatment [4]

4.3.1 Pasveer ditch

Consists of a "race track" ditch with surface aerators which circulate the effluent round the ditch. The ditch is sized for a retention time of 2 to 3 d.

The effluent must move at least 30 cm/s so as to keep the sludge in suspension.

Older ditches use Kessener aerators ("brushes") consisting of rows of paddles rotating about a horizontal axis which is above the water. More modern aerators involve sets of perforated discs rotating on the axis.

The energy requirement for aeration is approximately 1,5 kW.h/kg COD load but this varies widely depending on conditions, such as COD concentration and COD load per unit of sludge.

The ditches have two internal settlers which can be used alternatively for settling the effluent whilst clear overflow is drawn off. The settlers usually consist of two lanes along one leg of the "race track", with gates to close one lane at a time.

4.3.2 Activated sludge

Consists of an aeration tank and separate clarifier. Aeration intensity and sludge concentration are higher than in Pasveer ditches, enabling a shorter retention time. Excessive sludge must be "wasted", unlike in a Pasveer ditch where it is produced more slowly and digested internally.

Aerators are vertical spindles which draw the effluent upwards and throw it outwards through the air.

Flocculating agents are sometimes added to the clarifier.

4.3.3 Trickling filter

Consists of a tank filled with broken rock onto which the effluent is sprayed. Air-vents at the base of the tank enable air to move counter-current to the effluent as it trickles over the microbial sludge on the rocks. The effluent is usually partially recirculated, this being dependent on its concentration.

Trickling filters can be operated either as high rate filters or as polishing filters. In the former, concentrated effluent is applied and high activity per unit volume is achieved but the final concentration is too high for release to a public stream.

The major advantage of trickling filters for the sugar industry is that the sludge is attached to the rocks and is therefore not difficult to keep in the system. With sugar factory effluent (mainly soluble) the formation of bulking sludge, which will not settle, is a persistent and serious problem with Pasveer ditches and activated sludge systems.

4.4 New developments

Very interesting developments in sugar plant waste-water treatment have taken place recently. These involve the use of an ash (smuts) disposal dam in combination with an artificial wetland for waste-water treatment and COD removals of up to 95% have been reported[3]. The system has been operational for some time and has successfully dealt with all the load conditions encountered.

The mechanism of treatment seems to be a combination of physical filtration through the granular bed, microbiological action by a diversity of microflora and microfauna contained in the ash bed and the vegetation growing on it and activated carbon adsorption.

The system is still only partially understood and a great deal of scope exists for further research and development of reliable design criteria. The apparent benefits of this innovative system include[3]:

a) ease of operation, does not need skilled supervision;
b) low installation and building costs;
c) low operation costs;
d) low energy costs;
e) insensivity to fluctuating loads;
f) environmentally acceptable, offering considerable potential for wildlife conservation; it therefore seems to warrant further investigation by the sugar industry.

An indicative set of chemical analyses for the system are included:

Table 4.1 Summary of analyses for December 1988[3]

Determinand	Influent to ash dam	Effluent from ash dam
pH	8,5	8,0
COD mg/ℓ	1 154	71
Suspended solids mg/ℓ	2 760	155
Phosphates (PO_4) mg/ℓ	12	10

The results indicate a healthy pH and a COD and suspended solids reduction of 94%.

5 REFERENCES

1. **Barns D, Forster CF and Hrudey SE** "Surveys in Industrial Wastewater Treatment" Vol. 1 "Food and Allied Industries" Published by Pitman. (1984)

2. **Murray KA** "Wastewater Treatment and Pollution Control", Published by the Water Research Commission, 1987.

3. **Vermeulen PLM and Vanda AS** "Efficient and Low Cost Effluent Treatment Using an Ash Disposal Dam" Proceedings of the South African Sugar Technologists' Association, June 1989.

4. **Personal communication** - Sugar Milling Research Institute. (1989)