BIOLOGICALLY ENHANCED PRIMARY SETTLEMENT:

A scoping study to determine bioflocculant opportunities for locally grown crops and their associated waste for COD, N and P removal in small rural WWTWs

Report to the
Water Research Commission

by

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WRC Report No. KV 248/10

ISBN 978-1-4312-0019-1

October 2010

The publication of this report emanates from a project entitled *Biologically enhanced primary settlement: a scoping study to determine bioflocculant opportunities for locally grown crops and their associated waste for COD, N and P removal in small rural WTWWs*
(WRC Project No. K8/886).

Executive Summary

In excess of R3 billion per annum is spent on treating wastewater in South Africa yet compliance by some parts of the sector is poor. This has a negative impact on the country's water resource quality. Furthermore, capacity of treatment works has not kept up with the growth in towns and the populations served by water-borne sewerage systems. It will cost tens of billions of Rands to address the capacity constraints of WWTWs in the next decade. Alternative solutions are available which, if successful, can reduce both the capital and operating treatment costs of waste water in the country.

Whereas the use of flocculants in the chemically enhanced primary treatment (CEPT) process has been shown to enhance plant capacity, the use of chemical products comes with many drawbacks. Recent work on the use of biological flocculants indicates that these products have advanced to a point where they can also be used in CEPT and may be able to avoid some of the shortcomings of chemical products.

A scoping study was thus undertaken into the roles that biological flocculants can play in municipal wastewater treatment. Extensive jar testing with different products and extraction methods showed that the products tested were capable of enhancing the reduction in the COD of the water from around 30% to over 60% when compared to conventional sedimentation.

Other benefits include the reduction in suspended solids and turbidity. No benefits could be gained from the biological products tested with respect to nitrogen and phosphate levels, with excessive dosing rates even leading to a build-up of these nutrients.

Whilst an enhancement in COD reduction by 30% will by itself not meet the discharge standards applicable for small to medium WWTWs, this may extend the capacity of the treatment works in certain cases.

Not all bioflocculants have could be tested. Other products which are available in the country, some as wastes (e.g. peach kernels), could not be tested within the time available for this initial scoping study. Five previously researched biological flocculants were compared to the most commonly used flocculant in CEPT, Ferric Chloride.

Although Ferric Chloride outperformed the biological products in terms of total nutrient removal capacity, Fenugreek and Opunita, due to their low dosing rates, seem the most economical. They are however limited in their nutrient and suspended solids removal capabilities and where high levels of COD need to be removed, may be more useful as a flocculant aid or in combination with other flocculants.

Tests confirmed that the improvements made in the extraction procedures for Moringa will benefit COD removal. Such improvements in extraction procedures should be tested on other biological flocculants to see if their performances can also be improved.

The tannin-based product tested in this study, TE169, and Chitosan have high COD removal capabilities but do not seem to be cost-effective.

The tests confirmed that Moringa flocculants also have anti-microbial activities. Its usefulness should be further examined as avoiding chlorination will avoid long-term chlorine build up in fertilised lands which would be detrimental to certain crops. Engagement with the regulator regarding the controlled use of such bioflocculants for treating water that can be used for irrigation purposes should be undertaken.

Opuntia may be an attractive product as it can be cultivated in most parts of the country and it may also yield a good source of ruminant feed. However, agronomic, laboratory and plant testwork should first be conducted to validate the potential roles it and other biological flocculants can play in waste water treatment in the country. The use of biological flocculants can stimulate an industry with an annual turnover of around R300 million. As most of this would be spent on labour intensive activities in rural areas, it will stimulate rural development. The benefits to the country in the long term would be even greater as the further financial benefits at municipal level could exceed this amount.

The mooted anaerobic secondary treatment options may assist in reducing the electricity consumption of the country by as much as 1%. Furthermore electricity production at WWTWs would be more attractive if this route is followed as it more of the energy value can be recovered.

Savings in electricity consumption would reduce the amount of greenhouse gasses emitted by the country, assisting it meeting its commitments under the Copenhagen Accord. In some cases the increased methane gas production potential from the envisaged treatment options could make methane use projects financially viable. Where projects qualify, carbon credits from optimised precipitation can yield around R0.2/kl of effluent treated based on prevailing carbon credit pricing.

Phosphate recovery and nitrogen precipitation may as Struvite be facilitated by some of the biological flocculants. Unfortunately, at the time of completing this study readily available low cost sources of magnesium could not be identified to make this financially attractive.

In undertaking this study, it was hoped that alternative uses for extractable wastewater components could be found, their extraction costs be lowered, energy usage reduced, energy production facilitated and carbon financing facilitated in a manner and to the extent that wastewater treatment is no longer a drain on the finances of municipalities and the country. It is unlikely that this vision can be completely realised at this point in time, but it would also seem that several opportunities exist that can take the sector several steps in that direction.

Waste beneficiation is already starting to be promoted in the country, and this study indicates that it can be further expanded. Of the R0.6/kl that currently goes into treating waste water at macro WWTWs, R0.15/kl may be saved in electricity consumption. As much as R0.15/kl in renewable energy may also be generated. R0.05 is available as phosphate, but it does not seem economically viable to recover it at this stage.

Carbon credits at R0.2/kl will assist to cover capital expenditure. In some cases the re-use value of the treated water and the fertiliser value of the sludge may enhance the cost recovery to a point where WWTWs are no longer expenditure departments for municipalities, but become positive social change agents and even revenue generators.

Further efforts will be required and stakeholders should be engaged at an early stage relating to discharge standards if these opportunities from nature are to be utilised.

Acknowledgements

This project would not have been possible without assistance from the Water Research Commission in the form of funding of the research efforts.

The following person/ parties also helped facilitate the completion of this project:-

- UGU District Municipality is acknowledged for permitting access to the Melville WWTW, operational insights and for conducting microbial analysis of water samples;
- Universal Water Solutions, for supplying the testing equipment and reagents;
- Microfiltration cc for supplying microfiltration discs;
- NCP Chlorchem, Tanac and Sud Chemie for supplying samples of their flocculants and for technical advice;
- Mr Micky Naidoo for his assistance in the building of the jar stirrer; and
- Hentiq 2383 (Pty) Ltd for the supply of the biological flocculants used in this study.

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Introduction

South Africa's municipalities treat approximately 7.5 million cubic meters of effluent on a daily basis (Botha *et al*., 2009). The operating costs to treat the effluent exceed R3 billion per annum and the capital replacement cost of the installed treatment capacity would be close to R40billion. The effluent treatment processes used are similar across the country, ranging from the more basic processes such as anaerobic ponds, trickling filters to aeration basins to highly developed enhanced biological nutrient removal (EBNR) systems (Nozaic *et al.*, 2008). Whereas all of these systems have proven abilities to treat wastewater, the efficacy of the treatments vary from municipality to municipality, from plant to plant and even within selected technologies.

There are many reasons for the variance in performance and non compliance with discharge standards at waste water treatment works WWTWs, these include:

- Resource allocation and prioritisation of the service by the responsible water service authorities (WSAs);
- In some cases inappropriate technology solutions;
- The lack of skills, motivation and incentivisation of staff;
- Plant capacity and upkeep;
- Challenges with respect to non-designed loading (oils, blood, chemicals, heavy metals, etc.);

Larger WWTWs (in general) have a better skills base, use advanced treatment processes and have access to the necessary resources to optimally operate their WWTWs. South Africa holds a leadership position with respect to certain wastewater treatment technologies and there are many works that perform to world class standards. Smaller works may not always have access to the same resources, yet some still manage their works well. Unfortunately many of the smaller works, (despite having less stringent discharge standards to meet, advanced treatment plant and the necessary operational resources) are still not complying with discharge standards. Thus even small rural WWTWs are having a negative impact on water resources (Igbinosa *et al*., 2009.)

Plant capacity is also a major factor of concern (Botha *et al.,* 2009.) Many works are receiving inflows that are at or exceed their rated capacities. Many works suffer from large changes in effluent flow rates and characteristics[6] on a seasonal basis, due to seasonal migrations of tourists and migrant workers. At many works, the flow is reduced because there are sewage leaks and blockages in the reticulation system. Stormwater ingress in some cases causes both hydraulic and nutrient overloading. The cost associated with increasing the treatment capacity at WWTWs is between R4 mn to R10 mn per mega (10^6) litres per day (MLD) of treatment capacity (Personal Communication, Golder Associates) and the operating costs are between R0.5 and R1.5/kl treated (Botha *et al.*, 2009). With estimates thus running into tens of billions of rands to address the capacity constraints, less capital intensive and more robust solutions are sought[9].

If carbon loading is the capacity constraint, it is possible to increase the total plant capacity by as much as 30% due to higher nutrient removal in the primary settlers. A treatment process similar to CEPT, may offer rural communities a simpler and more robust treatment alternative to BNR or EBNR systems. For CEPT to be viable, the additional operating costs (chemicals) would need to be offset by lower energy costs and lower capital costs. In South Africa low electricity costs have hindered the economic viability of CEPT. The cost of electricity is however set to double from 2008 levels over a short period of time. WWTWs are collectively estimated to use 1% of electricity in South Africa. The production of electricity by gas engines run off methane from sludge digestors has the demonstrated ability to supply around 30-40% of the electricity requirements at BNR WWTWs[11]. Thus employing sludge digestion and methane utilisation, in SA, could offset the need for as much as 200MW of the national coal fired baseload capacity. Not only would this make a contribution towards the countries energy efficiency drive, and commitments under the Copenhagen Accord, but in some cases the projects may qualify for CERs under the Kyoto Protocol.

There are technical limits on how much of the energy potential that can be economically recovered from wastewater. At existing BNR secondary treatment WWTWs that have primary settlers, it is mainly the sludge from the primary settlers that is digestible. This fraction only represents 30-40% of the energy value of the wastewater. As flocculants are effective in removing dissolved fractions of COD, which are the more readily digestible fractions of COD than the settlable fractions, electricity yields should therefore be higher and thus power generation projects may be viable at more WWTWs than is currently the case.

The product that is most widely used for CEPT is Ferric Chloride (Ferric) as it is also particularly effective in removing phosphates. There are however several drawbacks with the use of Ferric.

- It requires a pH >8 to perform well, which usually means that the influent has to be limed.
- It lowers the pH and alkalinity of the treated water. Low pH water is not suitable for discharge and may cause corrosion problems within the works. Also as a pH >6.8 is important for nitrogen (N) removal in biological nutrient removal (BNR) systems, aggressive (>100 mg/L) dosing of Ferric will necessitate pH and alkalinity re-adjustments of the treated water prior to secondary BNR treatment. This will add to the cost and efforts required at WWTWs.
- The flocs produced by Ferric flocculation are loose and result in higher sludge volumes compared to unassisted settlement. At locations where iron levels in soils are already high, the sludge may only be sent to landfill sites. Sludge disposal therefore becomes costly especially as the sludge produced is no longer fully biodegradable. This additional sludge disposal cost may make CEPT using Ferric uneconomical at some works.
- Ferric dosing results in iron residue in the treated water. This may give the water an unsightly red tint at times.
- Ferric dosing increases the electro conductivity of the treated water.
- When Ferric Chloride is used the chlorine fraction goes into solution placing a limit on the re-use ability of the treated water for irrigation purposes.

Despite these drawbacks which preclude high levels of Ferric dosing (>100 mg/L) it has been shown that when Ferric is dosed at approximately 50 mg/L, most of the above drawbacks are minimised and Ferric dosing in many cases is both practical and economical.

Both laboratory and plant scale testwork has shown that biological flocculants also have the potential to assist and in some cases simplify the CEPT processes. Where viable, the cultivation and processing of biological flocculants may also enable rural communities to retain scarce currency within their communities, create opportunities for rural development and help these communities become financially self sufficient with regard to their sanitation needs.

In recent years the research efforts into biological flocculants for potable water treatment has shown improving potential of these products. Work has also been expanded into the use of biological products for wastewater treatment. However the advancement in the extraction processes for some of the biological flocculants that are being tested for potable water has not been matched by the repeating of earlier promising testwork on wastewater, or the results thereof are not as yet published. The local extraction of biological flocculants will enable local stakeholders to determine whether the extracts can be recovered easily, and whether they are cost effective and capable of meeting the results published.

There are many biological products that have proven flocculation capabilities. These include Moringa seeds, Chitosan, Tannins, Fenugreek, Opuntia, Peach seed kernels, Beans, Rice and Maize. All of these products are cultivated (or available as waste products) in South Africa.

Whereas this project looks at whether some selected biological products can be used as a substitute for Ferric in CEPT, some biological flocculants products are also of interest as they have both anti-pathogen and flocculation capabilities. This is particularly interesting for rural works where land is available for the cultivation of low-risk crops using bioflocculated and biodisinfected wastewater.

In South Africa Enhanced Biological Nutrient Removal (EBNR) systems dominate plants treating more than 10MLD (Noziac *et al*, 2008.) Even smaller works have turned to EBNR systems to comply with discharge standards that require both N and P removal. Unfortunately many of these works still fail to deliver the required effluent qualities because they do not have the skills to operate and maintain these systems. A simpler solution for micro to small works through robust treatment technologies is sought and could be facilitated through the use of biological flocculants. Such technologies could include Upflow Anaerobic Sludge Blanket (UASB) reactors, Biological Filters (BFs,) Sand filtration systems, and wetland systems.

In order to validate the published test results and to test the effectiveness of improved extractions of certain bioflocculants, jar tests followed by physio-chemical and microbiological analysis was conducted on water extracted from the inlet to the Melville WWTW in the UGU District, on the South Coast of KZN.

A first order techno-economic evaluation was conducted, attempting to establish dosing costs of the biological flocculants. The cost effectiveness of municipal wastewater treatment using biological flocculants was studied, including incentives under the Clean Development Mechanism (CDM.)

Literature Survey

The nutrient removal capabilities of plant based flocculants has been advanced firstly by understanding the mechanisms through which they act and then by the progress made in isolating and extracting the flocculating agents. Some biological products are already being used commercially, whilst others have only been tested at laboratory scale.

Biological flocculants are advantageous over inorganic ones primarily because they produce biodegradable sludges. Other advantages that some biological flocculants have over commonly used inorganic products includes robustness with respect to pH, minimally affecting the alkalinity of the treated water, reducing the sludge volume produced in the primary settlers, and reducing bacterial loading of the treated water.

This section will mainly describe some of the work recently published on the treatment of municipal waste waters through the addition of biological flocculants.

Commonly researched Biological Flocculants

When biological flocculants are being considered for a WWTW, cognisance should be taken of products that can be cultivated or are waste products in that geographic area. For example peach kernels should be an abundant waste product in the Western Cape. It should be evaluated prior to other products being imported into the region. This will save on transportation costs for what will be a very low value commodity, and will keep currency within the region of use. It is beyond the scope of this work to consider all known biological flocculants, but rather an attempt is made at understanding how some of the better known ones may be used and what their current limitations are.

Moringa oleifera

Of all the plant materials that have been investigated over the years, the seeds from Moringa oleifera have been shown to be one of the most effective as a primary coagulant for potable water treatment (Jahn, 1988.) Moringa oleifera is a pan tropical, multipurpose tree, grown for its green – asparagus like fruit/ vegetable.

Figure 1. Drumsticks and other vegetables that have flocculation capabilities.

From left to right as seen in a KZN green grocer, Beans, Moringa, Guar beans and Okra are all biological flocculants. Even certain fungi have flocculating capabilities.

Moringa oleifera is a small, fast growing, hardy tree that ranges in height from 5-12 m with an open, umbrella shaped crown, straight trunk, 10-30 cm thick, with corky, whitish bark. The evergreen foliage, depending on the climate, has leaflets 1-2 cm in diameter; the flowers are white or cream coloured. The fruits or pods are initially light green, slim and tender, eventually becoming dark green, firm and up to 120 cm long. Fully mature dried seeds are round or triangular shaped, the kernel being surrounded by a lightly wooded shell with three papery wings. Plants can be easily established by cutting or by seed. The cuttings bear fruit within a year, but suffer from poor root development, whereas the saplings bear after approximately two years.

The fresh fruit represents a high value crop earning an estimated R11,000/ ha for farmers in India where it is currently cultivated in over 30,000 hectares. The mature seeds contained 332.5 g crude protein, 412.0 g crude fat, 211.2 g carbohydrate and 44.3 g ash per kg dry matter. The water soluble flocculants (mainly proteins) represent approximately 10% by mass of the crushed de-husked mature seeds.

Figure 2: Moringa Oleifera growing in KZN

Moringa is currently cultivated as a backyard crop in South Africa, as seen in the picture to the left. Mainly for its 'drumstick' vegetable. Cooked leaves are also consumed by the Asian populations and as marog in Mpumalanga, but mainly in times of drought. It may play an important role in enhancing food security. Trials are being undertaken in KZN with annual varieties that flower after just 8 months as shown in Figure 2 on the right. Despite the worst drought in 70 years in the region, newly planted seedlings established without irrigation. Moringa is tolerant of shallow and poor soils as can be seen on the left.

As a coagulant, *Moringa* is non-toxic and biodegradable. It is environmentally friendly, and unlike some chemical flocculants, it does not significantly affect the pH and alkalinity of the treated water.

The efficiency and properties of *Moringa oleifera* as a natural coagulant in water treatment were studied from the 1980s. (Jahn, 1988; Sutherland *et al.*, 1994; Ndabigengesere & Narasiah, 1998; Okuda *et al*., 2001a & b; Ghebremichael, 2004) using different extraction methods for the active coagulant from *M. oleifera.* Laboratory investigations have confirmed the seeds to be highly effective in the removal of suspended solids from waters containing medium to high initial turbidities.

The first advancement over traditional knowledge was establishing that the de-husking and the de-fatting the seeds improved the turbidity removal efficiency of Moringa (Ndabigengesere et al, 1998). Compared to alum, the optimal dosage of shelled and defatted *Moringa oleifera* seeds was almost the same (at 50 mg/L) for the treatment of medium turbidity waters, for potabilisation. In case of the non-shelled seeds, the dosage is greater (500 mg/L) for medium initial turbidity waters. Sludge produced by coagulation with *Moringa* was found not only to be innocuous but also four to six times less in volume than the chemical sludge produced by alum coagulation (for treatment of turbid waters.)

Treating water with crushed seeds or water extracts of *M.oleifera* seeds has one identified disadvantage. The coagulant-inactive seed material that is also water-soluble leads to elevated dissolved organic material in the treated water (nitrates, orthophosphates, etc.). Thus, results from early testwork indicated that water extracts were not capable of removing COD from municipal wastewaters through flocculation alone.

However Bhuptawat *et al*., (2006) showed that up to 50% of COD may be removed via coagulation-flocculation-sedimentation followed by rapid sand filtration at doses of 50 mg/L of Moringa water extracts.

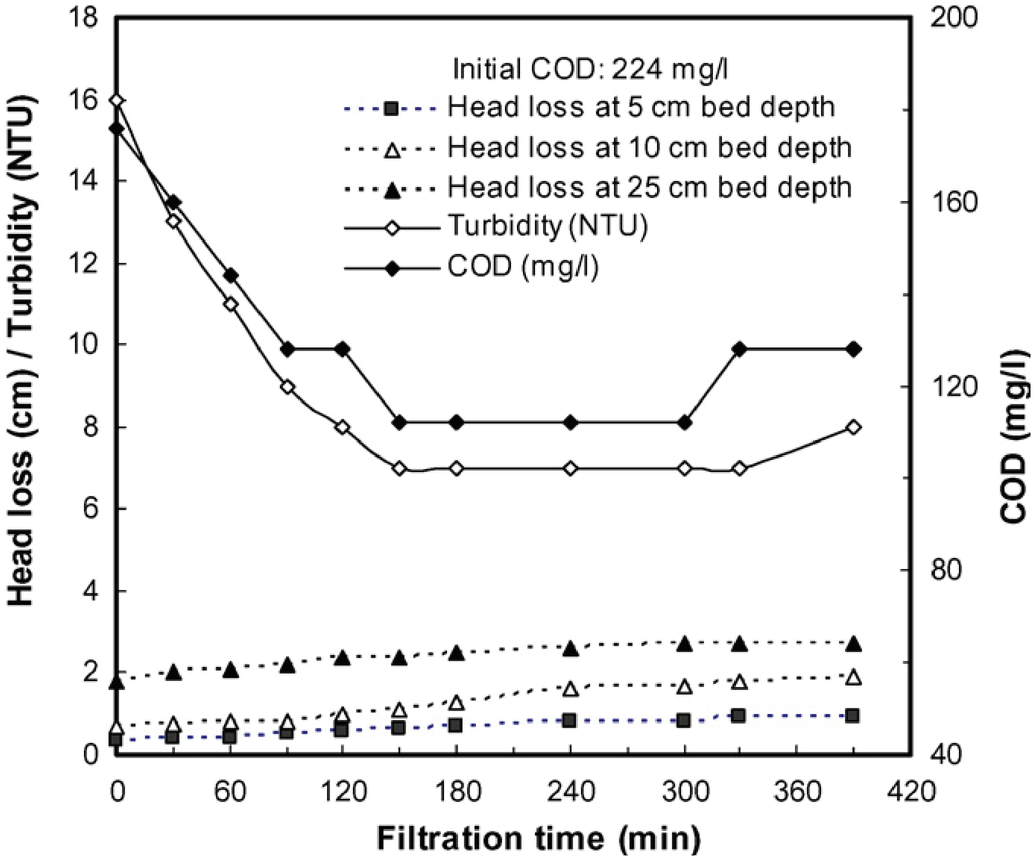

Figure 3: Removal of COD through Moringa water extract and filtration

Filter runs of 5 hours were achieved before breakthrough occurred. Follow up tests by the same authors showed much improved COD removal through the additional dosing of 10 mg/L of Alum.

The addition of Alum at a level of 10 mg/L increased the COD removal to 63% with Moringa water extract dosing at 50 mg/L. Filtration via filter paper showed a further improvement in COD removal, to levels of 50 mg/L. Although these tests meet the discharge limit of 75 mg/L COD that applies to small WWTWs, the tests were conducted on a low strength wastewater and the results may not be achieved with higher strength wastewater.

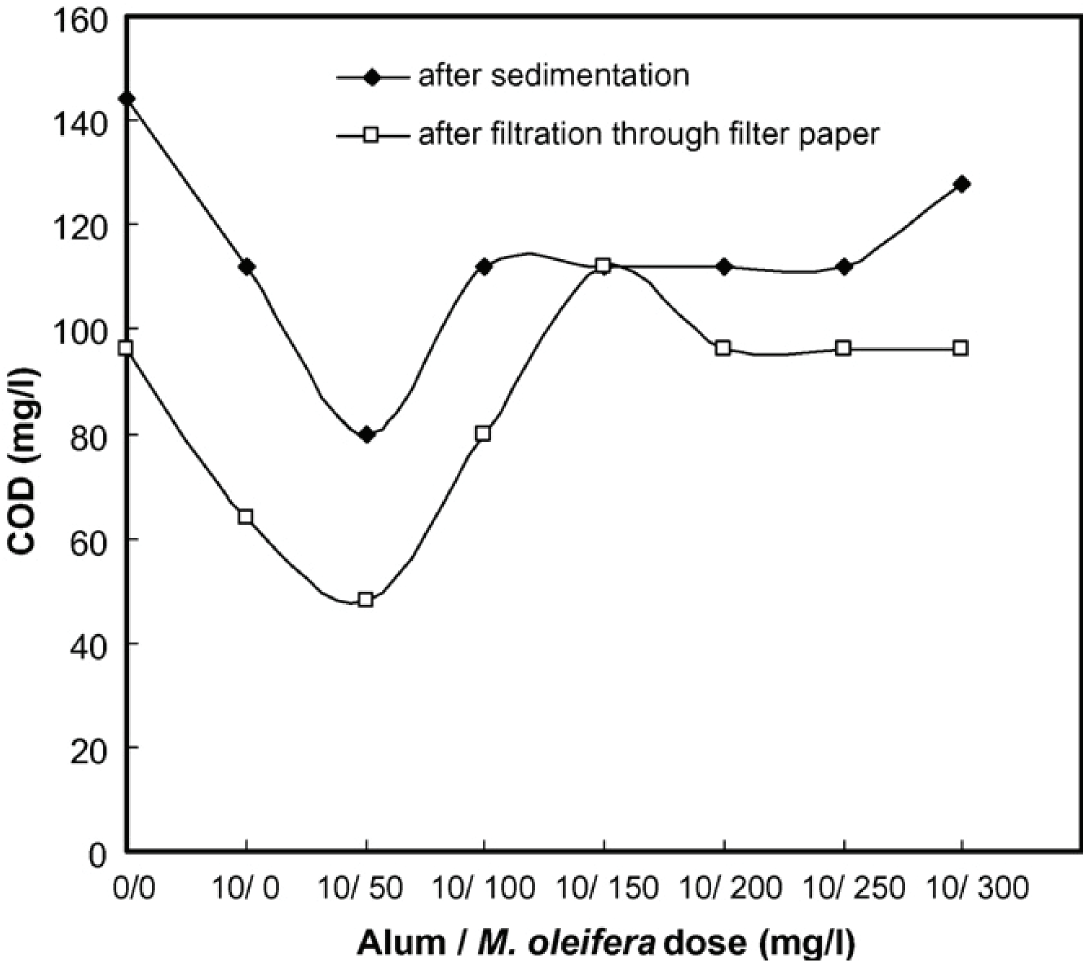

Figure 4: The dosing of Alum as a flocculation aid to Moringa.

Nonetheless, this could be a basic treatment process for micro/ small WWTWs that have space available for simple secondary treatment processes such as wetlands or irrigation land aimed at phosphate and nitrogen removal. The use of Alum will however increase sludge production. Combinations of Moringa and other biological flocculants could also yield synergistic results and avoid the challenges that would arise from additional and non-biodegradable sludge that would result from Alum dosing.

M.oleifera water extract dosed at 150 mg/L also gave additional removals compared to a plain sedimentation control of 40% for COD and in excess of 80% for suspended solids (Folkard *et al*, 1999.) These results are contrary to most studies that indicated that Moringa water extracts are not capable of enhancing COD removal. However, as these were tested on a mixed domestic and industrial wastewater, the results may suggest that Moringa is well suited for the treatment of certain industrial effluents. A shift in the BOD:COD ratio may occur after Moringa flocculation.

A breakthrough was achieved when extraction of the proteins using 1M sodium chloride solution gave enhanced coagulation at significantly reduced dosage compared to water extracted material – 95% turbidity reduction at 4 ml/L (of salt extracts) compared to 78% reduction at 32 ml/L (of water extracts) for a prepared test water comprising kaolin in water of initial turbidity 50 NTU (Okuda *et al*, 1999). The improvement in extraction is attributed to the 'salting-in' mechanism whereby increased ionic strength gives increased protein solubility. The study also found that extraction of seed proteins in other salts gave similar improvements.

A further enhancement was made when it was found that micro-filtered salt extracts of Moringa did not lead to a build-up of COD when used for the preparation of potable water (Suleyman *et al*, 2005). This extraction process is relatively easy to achieve.

Salt Extraction of Moringa flocculants:

Seeds of dry pods are to be used. The winged seed cover is removed just before the extraction. The kernel is ground to a fine powder using a "kitchen" blender. Oil is removed by mixing the powder in 95% ethanol/ acetone for 30 minutes. The solids are then be separated by filtration through a muslin cloth and dried at room temperature for a period of 24 hours. From the dried sample, 5.0 g of the seed powder is mixed with 500 ml of saturated NaCl solution for 30 minutes using a kitchen blender and filtered through a 0.45 µm filter. The filtrate should be stored at room temperature, preferably in a dark place and used within 3 months.

It would be interesting to see if microfiltered salt extracts of Moringa are able to enhance COD removal in domestic wastewaters.

There are other extraction processes which are also said to further improve the performance of Moringa extracts. These require dialyses of water extracts. They have only been tested at laboratory scale and their commercial scaling up is not proven as yet. These processes are also protected by international patents.

Moringa flocculants offers several advantages over conventional flocculants in WWTWs such as Ferric:

- Activity is maintained over a wide range of influent pH values – no pH correction is required;
- Natural alkalinity of the raw water changes only slightly following flocculation – no addition of alkalinity required; and
- Sludge production is greatly reduced and is essentially organic in nature with no iron residuals.

In addition to acting as a flocculent Moringa has been shown to reduce heterotrophic bacteria from (280-500) to (5-20) cru/ml, and faecal coliforms from (280-500) to (5-10) MPN 100/ml (Babu *et al., 2005)*. This characteristic is interesting as it may enable certain small WWTWs to remove a large amount of solids and pathogens from the water prior to discharging the water for irrigation purposes without having to use chlorine.

South African irrigation water standards for less than 500 m^3/day allow for waters with a COD<400 mg/L and a faecal coliform count of up to 100,000/100 ml to be used for irrigation purposes. Moringa should be able to achieve an order of magnitude improvement in on the faecal coliform count and the salt extracts may be able to simultaneously enhance COD reduction to these levels. Higher standards apply for larger irrigation schemes and even higher standards would apply for export markets (e.g. Canada allows 100 Faecal and 1000 total Coliforms per 100 ml in irrigation water.) So it would seem as though this option is only open to micro sized WWTWs <500 m^3/day. Whilst these works may only represent around 3% of the flow to the countries WWTWs, they represent about 60% of the facilities in South Africa.

If these results can be achieved they open an opportunity for the simplification of micro sized WWTWs and can overcome some of the regulatory and enforcement challenges, whilst creating opportunities for rural development.

Promising work with Moringa was also conducted at the University of Ghent. Kalogo *et al* (2000) coupled an UASB reactor to a CEPT pre-treatment. *M.oleifera* coagulant in the CEPT pre-treatment unit beneficially increased the ratio of soluble COD to volatile SS by a factor of 10 compared to plain sedimentation and 3 when dosing ferric chloride as coagulant. The UASB yielded more biogas and gave 71% removal of total COD at 2 hours hydraulic residence time. This compared with 54% removal of total COD at the same residence time when Ferric was used. The use of Moringa improved the start up time of the UASB reactor by 20%.

Other benefits included:

- Increased the acidogenic and methanogenic activity by factors of 2.4 and 2.2 respectively;
- Increased the specific biogas production by a factor of 1.6;
- Favoured fast growth of the sludge bed; and
- Allowed the aggregation of coccoid bacteria and growth of microbial nuclei – the precursors of anaerobic granulation.

It would seem that the technological pathways for Moringa Oleifera use in municipal wastewater treatment could include:-

- In combination with a high rate sand filter, for further COD, SS and turbidity removal, followed by algal ponds or wetland treatment or irrigation for phosphate and nitrogen removal;
- With simultaneous or sequential dosing of low doses of other biological flocculants for maximised COD and possibly phosphate removal;
- In CEPT followed by EBNR systems;
- Through CEPT, in combination with a UASB reactor.
- Through CEPT, in combination with a MBR.
- The fact that Moringa extracts are highly effective in the removal of SS, and does not affect the alkalinity of the supernatant indicates that it may create conditions suitable for the formation of Struvite crystals. Struvite is formed when magnesium is added to phosphate containing alkaline waters that also contain some nitrogen in solution and have low suspended solids (SS.) The crystals are a source of highly valued and increasingly scarce phosphate fertiliser.

The fraction of COD that remains in the water should be studied as if there is a shift in the ratio of BOD:COD, its use may still be of interesting to dose higher rates even in BNR WWTWs.

Opuntia Spp

Opuntia has been used for centuries in South America for the preparation of potable water (Diaz *et al*, 1999.) The mucilage from Opuntia fiscus indica has been shown to have similar turbidity removal capabilities as Moringa oleifera and also has anti-bacterial capabilities. Comparison of zeta potential measurements and transmission electron microscopy images of flocs formed by *Opuntia* spp. suggested that it operated through predominantly through a bridging coagulation mechanism, (Miller *et al.*, 2008)

Miller *et al*. showed that the following parts of the cactus pear have coagulation activities.

Table 1: Flocculation capabilities of various part of Opuntia

Part of Opuntia	**Coagulation activity**
Fresh whole pad bottom half	Present
Fresh whole pad top half	Present
Skin	Absent
Outer pad without skin	Present
Outer pad with skin	Present
Inner pad	Present
Whole pad: macerated	Absent
Dry whole pad: dried at 80^{o}C	Present
Dry whole pad: dried at 120^{o}C	Absent

Spineless varieties of Opuntia ficus indica are cultivated for its fruits – prickly pear, as a host for insects, and to a lesser extent as cattle fodder in South Africa. Several spined varieties have been declared weeds and cover parts of the Eastern Cape. These wild trees are harvested for their fruit by the local people. Opuntia can be seen growing almost all over South Africa from the Eastern Cape, North West, Gauteng, Limpopo, KZN and Mpumalanga. Growing this species, with effluent and sludge from the waste water treatment works in low rainfall areas may expand its suitability and growth rates. Such a program would produce locally sourced flocculants and a source of fodder for ruminants.

Biomass yields of 60 to 120 wet tons per annum from cultivated stands are possible. And mucilage yields are approximately 1.5% of wet mass.

Figure 5: Opuntia Fiscus Indica growing on the E-Cape, KZN border

Diaz *et al*, (1999) demonstrated that Cactus latifaria and the seeds of Prosopis juliflora were both effective in turbidity removal to below 5NTU for potable water treatment. Zhang *et al*, (2005) reported that the *cactus* coagulation attained comparatively high turbidity removal efficiency, and water with turbidity less than 5NTU could be obtained with initial turbidities of 20 to 200NTU. When used to treat the same water sample, the optimum dosage of cactus coagulant was found similar to that of Alum. Effects of factors such as pH, temperature, alkalinity on cactus coagulation were also studied. The study did not specify the type of cactus used in their experimental work.

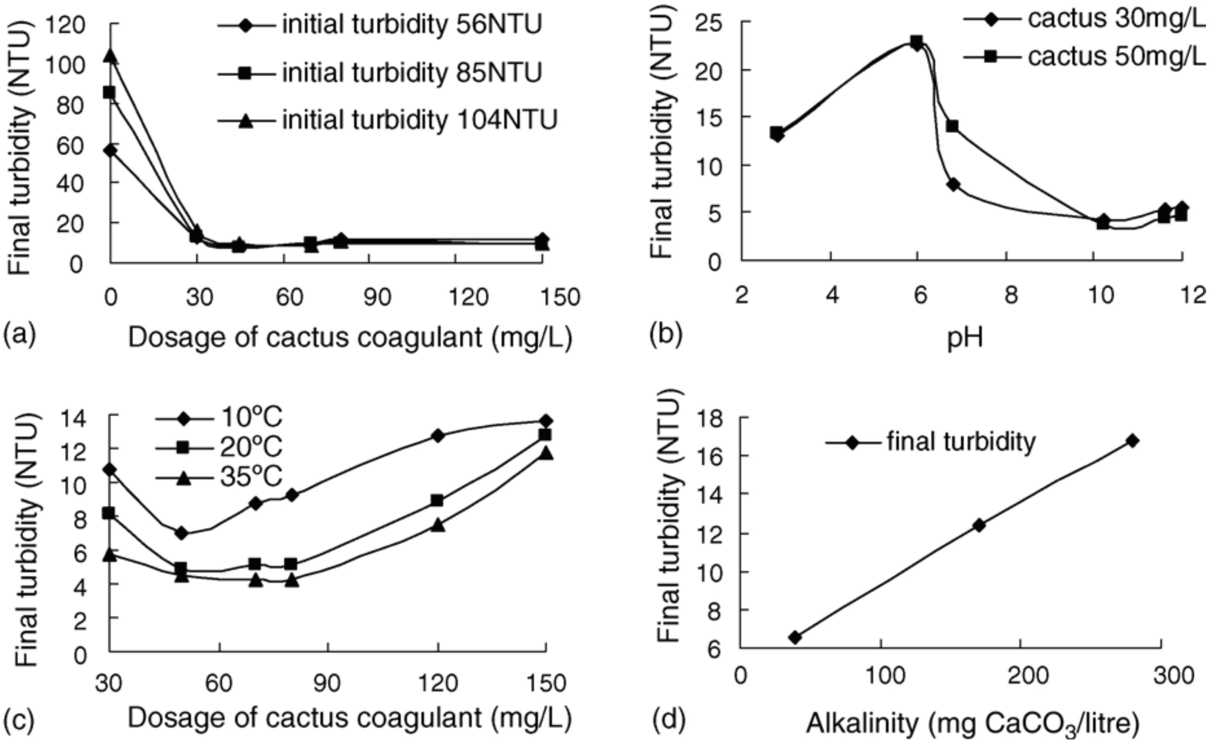

Figure 6: Cactus and turbidity reduction as functions of (a) dosage rate, (b) water pH, (c) water temperature and (d) alkalinity.

High removal efficiency of turbidity (85%) and COD (55%) were also obtained when cactus solids were used to treat sewage water. When cactus was used with Alum simultaneously the removal efficiency of turbidity and COD were higher than that of cactus or Alum when use independently.

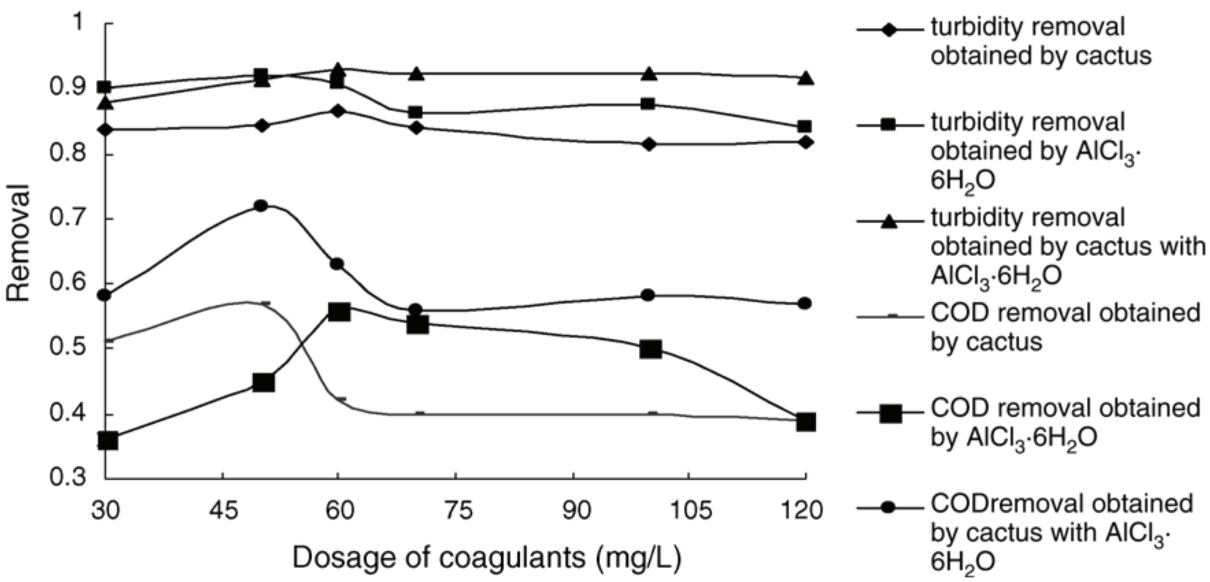

Figure 7: Use of cactus and alum COD removal from sewage.

Opuntia is potentially a very low cost bioflocculant that has been shown to remove up to 55% of COD at a doing rate of 50 mg/l or over 70% with Alum as a flocculant aid.

Technology pathways for Opuntia spp flocculating gels are similar to that of Moringa extracts but it requires pH adjustment of the incoming water to 7 or higher.

- It may be able to be used as a primary flocculent in the CEPT process pre EBNR with low dosing rates;
- With or as a flocculant aid to maximise COD removal;
- It may be used in CEPT followed by a UASB reactor;
- It may be used in CEPT followed by an MBR;
- In combination with ponds or wetlands; and
- Be used for pre-treating water prior to phosphate precipitation;

Opuntia gel has antimicrobial activities that should be quantified as they would have a positive effect on the treated water, this like with Moringa may condition water to an extent that it becomes suitable for re-use for irrigation purposes.

Tannins

Tannin based flocculants are derived from anionic tannins and converted to a desired ionic state in the processes outlined later herein. The use of tannin based flocculants presents several advantages versus chemical flocculant and coagulant agents:

- Using modified tannins in turbidity removal requires low dosages (between 1 and 10 ppm) so despite their higher cost, they may still be cost effective;
- pH adjustment is not needed;
- Tannins are available and easy to store. It can be a social-change factor, as it may be economical to process existing bark wastes with a relatively simple chemical modification to produce flocculants.

Tanfloc is a tannin-based product, which is modified by a patented physio-chemical process, and has a high flocculent power. It is the most commonly cited product with regards to waste water treatment research. It is obtained from *Acacia mearnsii* bark. This tree is very common in Brazil and also South Africa.

The scientific literature refers to a reaction mechanism that involves three reagents: a tannin mixture, mainly polyphenol tannins, an aldehyde such as formaldehyde and an amino compound, such as ammonia or a primary or secondary amine or amide compound. The three reagents, under certain conditions (of pH under 7 and temperature 80 ^{o}C), may produce the mentioned flocculant agents.

Tanac claim that the sludges produced are bio-degradable. Locally a company Sud Chemie also produces a range of tannin based flocculants. The use of TE169 for domestic wastewater treatment was suggested over other of Sud Chemise's products as it is approved for drinking water treatment by the Department of Health and has the highest tannin-aldehyde ratio of their products.

Caselles-Osorio and Garcia (2006,) found that adding Tanfloc to water did not change the alkalinity or pH. Urban wastewater after it had undergone a physio- chemical pre-treatment with 70 mg/L of Tanfloc), showed the following improvements.

Table 2: Tannin use to enhance nutrient removal

	COD (mg/l)	Ammonia (mg/l)	Turbidity (NTU)	SO_4 (mg/l)	Electroconductivity (uS/cm)
Inlet	354	32	118	164	457 (uS/cm)
Outlet	180	30	20	164	430
Removal	49%	5%	83%	0%	5%

The water was then treated through a wetland simulation and the results indicated that the life expectancy of the wetland can be increased by 10 years due to the reduced solids loading on the wetland reticulation system. Unfortunately no data was published on phosphate removal from this study.

Treatment options for Tannin flocculants could therefore include:-

- In combination with a high rate sand filter, for COD, SS and turbidity removal, followed by algal ponds or wetland treatment or irrigation for phosphate and nitrogen removal;
- With simultaneous or sequential dosing of low doses of other biological flocculants for maximised COD and possibly higher phosphate removal;
- In CEPT with BNR secondary treatment;
- Through CEPT, in combination with a UASB reactor;
- Through CEPT, in combination with a MBR and
- For struvite precipitation.

Chitosan

Chitosan is a partially deacetylated polymer obtained from shellfish skeleton. Chitosan exhibits a variety of physio-chemical and biological properties resulting in numerous applications in fields such as cosmetics, biomedical engineering, pharmaceuticals, ophthalmology, biotechnology, agriculture, textiles, oenology, food processing and nutrition. Chitosan has also received a great deal of attention in the last decades in water treatment processes for the removal of particulate and dissolved contaminants.

Zeng *et al.*, 2007, demonstrated that due to its lower dosing rates (1 to 10 mg/L) Chitosan's use as a flocculant can be justified on cost grounds when compared with PAC: sodium silicate in CEPT.

In particular, it has been shown to assist in the granulation process of UASB reactors, thereby reducing the start-up time. Chitosan has no harmful effect on human health, and the disposal of waste from seafood processing industry can also be solved. Chitosan is a natural material, the sludge cake from the coagulation after stabilisation and dehydration could be used directly on agricultural lands, therefore not only saving landfill space and the funds spent on waste disposal but also recycling useful material.

Chitosan efficacy is pH dependant and works best at a neutral to alkaline pH. When the flocculant solution is pH adjusted, Chitosan does not reduce pH or alkalinity. Secondary treatment options for Tannin flocculants could include:-

- In combination with a high rate sand filter, for COD, SS and turbidity removal, followed by algal ponds or wetland treatment or irrigation for phosphate and nitrogen removal;
- With simultaneous or sequential dosing of low doses of other biological flocculants for maximised COD and possibly phosphate removal;
- In CEPT with BNR;
- Through CEPT, in combination with a UASB reactor;
- Through CEPT, in combination with a MBR and
- To condition the water for Struvite precipitation.

Chitosan is also believed to have anti microbial activities, so like Moringa and Opuntia, it could be used to condition waste water to a point that enables it to be used for irrigation purposes. Chitosan is also claimed to be beneficial to plants.

Trigonella Fenugracum

Fenugreek is a hardy leguminous annual herb that has many nutritional benefits and is widely cultivated in South Africa.

Figure 8: Fenugreek crop residue growing in KZN

Fenugreek mucilage, a food grade natural polysaccharide, was reported as a flocculant for tannery effluent treatment by Mishra *et al.,* (2003). The effects of polysaccharide concentration, contact time and pH on percent solid removal were studied. The maximum suspended solid (SS) and dissolved solid (TDS) removal were nearly 85% and 40%, respectively using flocculent dose of just 0.08 mg/L. The suitable pH range was neutral for maximum efficiency of mucilage as flocculent. Time required for maximum TDS removal was 3 h whereas it was only 1 h for SS removal.

Polysaccharides are usually used as flocculant aids and it could help some of the biological products that are limited in removing dissolved solids.

Fenugreek efficacy is pH dependant and works best at a pH around 8. Fenugreek does not reduce pH or alkalinity of the treated water.

Secondary treatment options for Fenugreek flocculants could include:-

- In combination with a high rate sand filter, for COD, SS and turbidity removal, followed by algal ponds or wetland treatment or irrigation for phosphate and nitrogen removal;
- With simultaneous or sequential dosing of low doses of other biological flocculants for maximised COD and possibly phosphate removal;

As a legume it is expected to have a high phosphate demand, and may enhance P removal if it included in fertigation/ wetland treatment schemes.

Secondary treatment options

Cost-effective solutions are a must for a developing country such as South Africa. Not only regarding operating costs, but also in respect of capital investment. Depending on the dosing rates of flocculants the physiochemical and microbiological characteristics of the water produced will be altered to different degrees. These changes may improve or retard the secondary treatment process of choice. The second step to achieving a lower cost waste water treatment system is matching and optimising the primary settlement process objectives to the selected secondary and possibly tertiary treatment steps.

Wetland/ Fertigation

Constructed wetlands are promoted as a low-cost, low-tech process to treat wastewater. It is basically, substrate planted with mainly aquatic, and sometimes with terrestrial plants. Inflow wastewater slowly flows from one end to the other. Other major construction parameters are the type of substrate in which the plants grow or the container material. Both usually have some cleaning capacity by themselves. The roots of plants, especially aquatic macrophytes, work as biological filters that remove organic matter. At the same time, microorganisms residing in the submerged roots in the wastewater degrade other pollutants that are later absorbed by the plants.

Afterwards, the treated wastewater is commonly discarded to natural water bodies or used for irrigation of plants without any further treatment. Periodically, in some constructed wetlands, the plants need replacement. Usually wetlands are not designed to remove nutrients, such as phosphorus. They do so indirectly because the ions are nutrients for the plants (de-Bashana *et al*, 2005.)

The removal capacity of nitrogen and phosphorus by a wetland can be substantial and can overcome the shortcomings of some of the identified biological flocculants. Assessment of the contribution of duckweed Lemna gibba, a marcrophyte, and its associated microorganisms (algae and bacteria forming an attached biofilm) to remove nutrients showed that the biological floating mat complex (plants and microbes) is responsible for removing up to 75% of the nutrients in the wastewater. The macrophyte contributed up to 52% of phosphorus removal by its own growth; the associated organisms and microorganisms removed the rest.

The limitations to the use of wetlands are the availability of land, climatic factors such as extreme cold or heat, strong winds, predatory animals and disease. They may represent a good option for micro and small WWTWs.

Rapid sand filtration

Rapid sand filtration may also be used to further remove COD and suspended materials by removing coagulated but unsettled matter. This could be used as a single step when used for preparing irrigation/ industrial water or to further improve the performance of MBRs.

Biological Filters

Biological or trickling filters are principally used to reduce the COD and Nitrogen levels of wastewater. High nutrient levels lead to fouling and where CODs are greater than 800 mg/L, effluent reclcyling may be necessary. Enhanced primary settlement may reduce the nutrient levels to a degree that avoids this step. Lower suspended solids loading will also be beneficial as clogging rates will be reduced.

Biological nutrient removal

When the secondary treatment step is BNR, the carbon, nitrogen and phosphate levels will determine how much COD removal should be undertaken for optimal for N and P removal. At medium to macro sized works, unassisted primary settlement is used to remove around 30% of the COD. Some N and P removal also occurs in the primary settler.

Flocculants, individually or in combination with each other can double the amount of COD that can be removed in the primary settlement process. This may not be desirable for BNR treatment works as it could lead to nutrient starvation for the activated sludge. The inlet COD at WWTWs range between 300 mg/L to over 1000 mg/L. It is mainly in the latter parts of this range that flocculant use could be beneficial for BNR WWTWs.

For other secondary treatment processes, such as UASB reactors, MBRs, rapid sand filtration and wetlands/ fertigation systems low COD levels are not as problematic. For these secondary treatment options, having low suspended solids is more desirable. Suspended solids removal and COD removal are positively correlated for a substantial dosing range for all the products considered, so maximising COD removal could be used as the control parameter for these secondary treatment options.

Upflow Anaerobic Sludge Blanket Reactors

An integrated chemical-physical-biological treatment concept for the low-cost treatment of domestic wastewater was tested by Aiyuk *et al*, (2004). Although this was conducted with conventional flocculants, the results indicated that CEPT followed by UASB treatment could achieve high quality effluents.

The CEPT pre-treatment consisted of the addition of a Ferric and an anionic organic flocculant and removed on average 73% of the total chemical oxygen demand (COD(t)), 85% of the total suspended solids, and 80% of PO_4^{3-}. The UASB system, which consequently received a low COD input of approximately 140 mg/L, was operated using a volumetric loading rate of 0.4 g COD/L. d (hydraulic retention time [HRT]=10 h) and 0.7 g COD/L. d (HRT=5 h). For these conditions, the system removed about 55% of the COD in its influent, thus producing an effluent with a COD of approximately 50 mg/L. A zeolite, when applied in batch mode before the UASB reactor, removed approximately 45% of the NH^{4+}, whereas its application as a post-treatment cartridge resulted in almost 100% NH^{4+} removal. The simple design and relatively low operating costs (estimated at R0.7 to R1/kl), due to low costs of added chemicals and low energy input, combined with excellent treatment performance, showed that this system can be used for domestic wastewater treatment as it is cost effective when compared to the average operating cost range of R0.6 to R1.50/kl in SA.

The Chemically Enhanced Primary Treatment (CEPT) process and the Upflow Anaerobic Sludge Blanket (UASB) process, both followed by complementary secondary treatment has thus seen much attention in countries such as Brazil, where large plants have been designed and built. The applied technologies are cost-effective: they present low investment and efficiencies of COD removal of up to 70%. They allowed the plant construction in steps, an initial phase with efficiency over the usual primary treatment, followed by appropriate secondary treatment to achieve the effluent quality required by their water quality standards.

The higher initial reduction of COD and TSS also permits savings in construction and operational costs of secondary treatment, due to lower organic load and lower energy consumption (Jordao *et al*, 2008).

CEPT followed by UASB treatment would represent a simplification of the waste water treatment process when compared to EBNR systems and should be considered by as an option by new works of works that are expanding or need to be expanded.

The removal of 80% of the COD in low loaded wastewater (Agrawal, *et al*, 1996) will enhance the feasibility of energy production from digested sludge, as it has been shown that the soluble fractions of COD are more digestible than the settleable fractions. If these levels of COD removal can be achieved at a plant scale, then the above type of works could be self sufficient with respect to its energy needs with some works even able to supply neighbouring communities with a renewable source of electricity.

Materials and Methods

Materials

Source of testwater

The Melville Wastewater treatment works is located in Melville, on the KZN south coast. It is a 1MLD package plant that serves the Melville community via a piped feed for Melville and also neighbouring communities (up to 20km away) via trucked in septic tank waste.

Water was sampled at the inlets to the buffer tanks, which is just after the second screens which were also serving as a detriotor. Hydraulic loadings to the works peaked in the mornings between 8am and 12am. The nutrient loading was relatively stable though as the septic tanks from which sewage is drawn are serving as nutrient buffers. It was noted that more often than not, the inlet water was tending towards having been anaerobic in nature.

Figure 9: The Melville Wastewater Treatment Works

The Melville WWTW is a 1MLD ‘package plant.’ It cost R10 million to build. The works uses air injection as opposed to suspended aerators. The compressed air is supplied by a 15kW compressor. Gaseous chlorine is dosed for disinfection.

Figure 10: Sewage being trucked in to the Melville WWTWs

The anaerobic nature of the tested water was due to the frequent trucking in of sewage from anaerobic septic tanks as was seen during the sampling. The Melville works was selected over other works managed by the UGU District Municipality, due to its proximity to the testing laboratory and the fact that it treats mainly domestic sewage.

Sources of chemicals and consumables

The chemicals used in the preparation of the flocculants were acquired from Lab and Analytical Supplies in Durban and were used untested. The inorganic flocculants were obtained from NCP Chlorchem. Tannin flocculants were supplied by Tanac and Sud Chemie. Chitosan was purchased from Marine Chemicals, India.

Extraction procedures

Moringa

Moringa Oleifera seeds were imported from Mozambique. 100 g of seed was drawn and the winged seed cover was shelled and the kernel was ground to a fine powder by using a blender.

Figure 11: Moringa seed in husk and de-husked on the right.

Acetone was used as a solvent for extracting the Moringa oil. The solution was then filtered through a stainless steel strainer. The defatted cake was then left to dry overnight. 3 grams of seed powder was suspended in 300 ml of deionised water and stirred repeatedly for 30 minutes. The suspension was then filtered through a stainless steel strainer followed by microfiltration via a syringe filter fitted with a 0.45 micron filter to yield the flocculating protein.

Fenugreek

Fenugreek was obtained from a spice wholesaler in Durban. Tests revealed that 5L of deionised water was needed to dissolve the gel of 250 g of milled seeds. A thick mucilaginous solution resulted, from which the pure polysaccharide was obtained by precipitation with alcohol.

Tests on 100 ml gel samples indicated that precipitation was reduced after 300 ml of alcohol and no further precipitation occurred after adding 500 ml alcohol. It was therefore determined that alcohol dosing should be 5:1 for maximum polysaccharide yields.

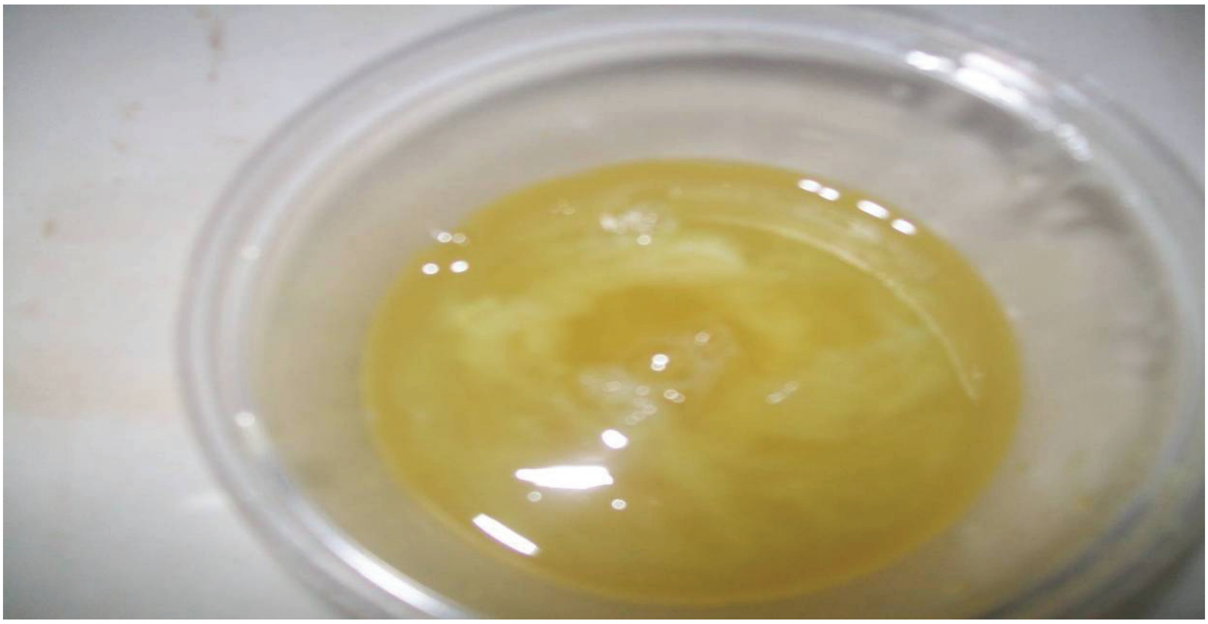

Figure 12: Fenugreek Polysaccharide precipitating in alcohol

The precipitated polysaccharide was then washed with acetone to remove impurities and finally dried at room temperature overnight. Thereafter it is dissolved at a concentration of 1.5% w/w in deionised water at room temperature. It was poorly soluble, as noted in the literature. The solution was then stored at 4^0C.

Opuntia

Cladodes were harvested from un-tended stands in Mnandi, Pretoria. A single mature cladode, weighing 2.592kg, was washed in tap water and left to dry. It was then sliced and 'juiced' using a domestic juicer (Sunbeam Model SJE 1800.)

Figure 13: Opuntia cathodes sliced just prior to juicing

Cacti react to physical injury by secreting a coagulating gel to seal its wounds. This gel has been found to an effective coagulant. Juicing resulted in 1344 g of juice and 1170 g of pulp. The addition of 200 ml acetone to 100 ml of the juice yielded 2 g of precipitate indicating the presence of the flocculating gel.

Jar tests using the extracted juice did not produce enhanced flocculation, so alternative extraction methods were attempted. The tests results cited in the literature review were conducted with cactus that was dried at 80°C. As the energy cost of drying the cactus would be very high, the following alternative method was attempted.

The Preparation of natural polyelectrolytes from Opuntia spp

The cactus is cut in small pieces (10 x 30 mm), and approximately 132 g of cactus pieces and 750 mL of tap water are transferred to a 2 L flask with gentle stirring for 10 min. The extraction of viscous natural polyelectrolytes from the diced cladode to the water must be monitored to avoid the build-up of organic matter as filtration of the mucilage is difficult. The solution is kept at 4°C until use.

Preparation of the Opuntia polyelctrolyte in this way would enable both the flocculant portion and the bulk energy rich fodder to be used, maximising the value extraction from the cactus.

Tannin

No attempt was made at producing tannin based flocculants are they currently being manufactured locally by Sud-Chemie. Two products were obtained from Sud-Chemie

- TE169; and
- TE 1480

In addition to this Tanfloc was obtained from Tanac in Brazil and pure tannin was obtained from Mimosa Central Co-Op Limited.

Chitosan

Chitosan is only soluble in dilute acids. Prior studies showed that HCl was a suitable solvent as it does not lead to a build-up of COD. 1 gram of Chitosan was dissolved in 100 ml of 32%HCl. The pH of the solution was then adjusted to 5 by adding it to 50 grams of NaOH solution that had been dissolved in 900 ml of distilled water.

Methods

A laboratory scale comparative study was undertaken using the standard jar testing procedure to determine the optimal dosing rates and cost-effectiveness of the five biological flocculants selected in this study. Simultaneous tests were also undertaken using Ferric Chloride as the primary flocculant as Ferric is widely used at WWTWs overseas and it would be a good benchmark for the capabilities of the biological products.

A 6 place jar-stirrer was built; paddle rotations were initially at 100rpm for 60 seconds and then reduced to 30 rpm for 30 minutes for all the tests. The speed control was achieved via a VSD controller drive on the drive motor.

Figure 14: A 6 Place Jar stirrer with VSD for speed control

A digester and colorimeter were purchased from Universal Water Solutions, the local agents of Hach Instrumentation. Tests for P, Total N, Fe, COD, TSS were conducted according to the Hach procedures manual. The above methods except for TSS, are USEPA approved for wastewaters. TSS results herein must therefore be taken as an indication only. Reagents supplied by Universal Water Solutions for the above tests were used untested.

pH and conductivity were tested with the use of a multi-parameter hand held tester. Alkalinity was tested for by the use of test strips. The initial jar tests were conducted to determine the optimal dosing rates for the various products. Turbidity reduction was used as the initial control.

Samples were drawn from the settled water and supplied to the UGU District Municipality for microbiological analysis. Samples were transported, chilled by ice and were tested on the same day as their production.

Preliminary testwork

Doses of Moringa extracts were limited to the range 2.5 ml to 40 ml/L after initial tests showed COD and conductivity worsening after 10 ml/L. Ferric was dosed between 40 mg/L and 240 mg/L. TE169 between 10 and 40 mg/L. Fenugreek polysaccharide dosing and opuntia extracts at varying rates did not induce precipitation. This was determined to be due to the low pH (6.2 to 6.5) of the incoming water as later tests at adjusted pH of 8.8 showed flocculation activities similar to that found in prior publications. Chitosan was dosed between 2 and 8 mg/L.

Figure 15: Settled water from Moringa flocculation (in the back) and Ferric (in the front).

Table 3: Initial Moringa Jar test results

	Untreated	2.5 ml/L	5 ml/L	10 ml/L	20 ml/L	30 ml/L	40 ml/L
pH	6.3	6.3	6.3	6.3	6.3	6.2	6.2
Conductivity (uS)	750	1073	1301	1836	2850	3690	4430
P (mg/L)	14.3	12.4	12.6	13	13.6	14.5	13.9
Total N (mg/L)	32	33.6	36.2	24.6	37.2	50.4	55
Suspended Solids (mg/L)	440	292	246	187	92	63	53
COD (mg/L)	923	515	475	414	589	805	998

It was noted that higher doses of Moringa salt extracts were having a negative impact on conductivity, phosphate levels, nitrogen and COD. Tests were then conducted on the flocculant itself and it was found that it had a phosphate content of 0.27 mg/L, a pH of 3.8, a conductivity of 1280 mS and COD of around 50 000 mg/L.

Tests were repeated at higher and lower dosages to determine if the increase in conductivity could be explained by over or even under dosing of the flocculant. The positive correlation between dosing rate and conductivity remained between the tested dosing rates of 1 ml/L to 60 ml/L. Turbidity was not the optimal control parameter as the correlation between CODs and turbidity only held in the lower test range. Higher Moringa extract dosing whilst improving turbidity and TSS of the water, increased the COD and N levels.

As per prior research it was found that the optimal dosing rate of Moringa salt extracts was at the very lower end of the test range. Hence the comparative tests that followed were conducted with low dosage rates.

Tests on Ferric were conducted with the pH of the influent adjusted to between 8.4 and 8.8 through the addition of NaOH. As with Moringa, the conductivity increased, but not nearly to the same extent. Fenugreek was not effective in flocculation until the pH of the water was adjusted to >8.5. This could limit its usefulness in waste water treatment. The tannin based product TE169, did not lead to a large increase in conductivity, or drop in pH.

High dosing of diced Opuntia (40 mg/L to 60 mg/L) increased the conductivity (1363 to1736 uS) and dropped the pH to (5.8-4.8) from 883 uS and 6.7, respectively. So it was decided to conduct further testing between 5 and 30 g/L which corresponded to the optimal rates when used for treating potable water.

Fenugreek dosing had no impact on the pH of the treated water or the conductivity, so it was decided to test it between 0.016 mg/L and 0.24 mg/L as suggested by the literature.

Comparative testwork

Figure 16: Turbidity reductions by the tested flocculants.

To compare the effectiveness of the various products, for each batch of tests, 100 L of raw sewage samples were collected from the Melville WWTW and decanted into a plastic holding container, from where it was agitated by a hand paddle and thirty eight 1 L samples were drawn to be jar tested.

The visual improvement in water quality results typical of the jar testing undertaken are shown above, with from left to right, Fenugreek polysaccharide, Ferric, Opuntia, TE169 and Moringa salt extracts. When analysed the supernatant following the flocculations yielded the following results.

Moringa salt extracts

Table 4: Moringa salt extracts, Jar testing results

	Settled	1 ml/L	2 ml/L	5 ml/L	10 ml/L	20 ml/L
pH	6.4	6.4	6.3	6.3	6.2	6.2
Conductivity (uS)	617	735	838	1140	1655	2610
P (mg/L)	5.6	6.8	9.7	-	15.2	15.7
Total N (mg/L)	34.8		33.8	31.8	35.4	45.2
Suspended Solids (mg/L)	110	108	91	61	41	48
COD (mg/L)	491	430	402	339	389	611
COD filtered (mg/L)			329	332	382	592

The optimal dosing was found to be 5 ml/L of the extract. It resulted in a COD reduction of 31% over unassisted settlement, without impacting too negatively on pH, alkalinity, or conductivity. The supernatant from the Moringa flocculation was filtered through a 6 micron filter and the results showed slightly improved COD reductions. Higher dosage rates resulted in a negative impact on both N and P levels, but improved the removal of suspended solids.

Tannin flocculant – TE169

Table 5: TE 169, tannin, Jar testing results

	Settled	40 mg/L	80 mg/L	100 mg/L	200 mg/L	300 mg/L
pH	6.4	6.7	6.7	6.6	6.6	6.6
Conductivity (uS)	617	586	590	593	596	599
P (mg/L)	5.6	12.7	10.3	6	15.2	12.5
Total N (mg/L)	34.8	34.8	32.2	31.2	28	30
Suspended Solids (mg/L)	110	103	127	77	33	20
COD (mg/L)	491	371	357	309	234	193

Tannin based flocculant TE169 performed very well on most parameters, achieving an enhanced COD reduction of 61% at a dosing rate of 300 mg/L. The low suspended corresponding suspended solids rate of 20 mg/L, indicates that the water may be easy to filter and this could be used as a simple means of further COD reduction. Of concern though was the increase in Phosphate levels. Even at the higher dosing rates Conductivity and pH of the water did not deteriorate.

Ferric Chloride

Table 6: Ferric Chloride, Jar testing results

	Settled	40 mg/L	80 mg/L	120 mg/L	160 ml/L	200 mg/L
pH	8.8 (adjusted)	7.3	7.1	6.8	6.5	5.9
Conductivity (uS)	617	760	805	836	856	878
P (mg/L)	5.6	3.5	0.38	0.19	0.22	0.19
Total N (mg/L)	34.8	26	25.2	25	23.4	23.6
Suspended Solids (mg/L)	110	46	29	19	12	1
COD (mg/L)	491	256	218	167	135	134

Ferric Chloride performed well in its strength areas, i.e. the removal of P, SS and COD. Dosing at rates over 120 mg/L were not seen to be beneficial as the P content did not decline further and the benefits in COD reduction thereafter were small in comparison the price paid in pH, conductivity and flocculant use. At a dosing rate of 120 mg/L the enhanced COD reduction achieved was 66%. To avoid having to re-lime the water, 120 mg/L was the limit for the tested water.

Opuntia

Despite its potential Opuntia proved to be a very difficult product to work with. Only certain parts of the cactus have flocculating capabilities and extraction via juicing rendered them inactive. Lengthy contact times >20 min resulted in an increase in turbidity due to what is believed to be chloroforms going into solution. Even avoiding stirring, could not avoid this result. The analysis of the treated water showed the following results.

Table 7: Opuntia, Jar testing results

	Settled	5 g/L	10 g/L	20 g/L	30 gl/L
pH	8.8	7.9	7.9	7.8	7.4
Conductivity (uS)	617	807	814	874	938
P (mg/L)	5.6	11.7	10.9	9.9	9.6
Suspended Solids (mg/L)	110	67	73	73	79
COD (mg/L)	491	365	404	350	410

The dosing levels at 5 and 20 g/L produced 26% and 29% enhancement in COD reduction respectively. Higher phosphate levels were noted throughout the dosage range.

When dosed at lower rates, via the mucilage extraction process described earlier, Opuntia was consistently able to reduce the COD of the treated water to below 370 mg/L.

Fenugreek

Table 8: Fenugreek Polysaccharide, Jar test results

	Settled	0.016 mg/L	0.032 mg/L	0.08 mg/L	0.16 ml/L	0.24 mg/L
pH	8.8	8.1	8.2	8.2	8.2	8.5
Conductivity (uS)	617	706	708	707	707	708
P (mg/L)	5.6	4.4	6.3	9.2	10.2	11.4
Total N (mg/L)						
Suspended Solids (mg/L)	110	97	98	94	100	90
COD (mg/L)	491	355	341	342	338	354

Fenugreek required a pH >8.5 before there was an improvement in nutrient removal. The low doing rates required of fenugreek polysaccharide to achieve to 30% enhancement in COD reduction could indicate that it may have a role to play as a flocculant aid as is the practice with other polysaccharides.

Chitosan

Table 9: Chitosan, Jar Test Results

	Raw Un-Settled	Settled	2 mg/L	4 g/L	8 mg/L
pH	6.8	6.8	6.8	6.8	6.7
Conductivity (uS)	698	667	922	1109	1545
P (mg/L)	29.5	19.8	22.0	16.4	16.3
Total N (mg/L)	19.4	16.9	16.5	16.6	23.4
Suspended Solids (mg/L)	226	139	120	110	79
COD (mg/L)	688	409	346	327	286

Chitosan dosing at 8 mg/L led to a 30% enhancement in COD reduction and a 43% reduction in suspended solids. The higher dosing rates seemed to assist with P removal, but had a negative impact of N levels.

Sludge production

The volume of sludge produced at WWTWs should be minimised to minimise sludge conditioning and disposal costs. Tests showed that Chitosan performed the best of all the flocculants with respect to sludge production, producing 18 ml/L. The untreated sludge volume was 16 ml/L. If one considers that primary sludge is usually around 60% of the total sludge produced, sludge production at a conventional BNR works extrapolates to around 27 ml/L.

The use of flocculants Fenugreek, Moringa, TE169 and Ferric Chloride led to 18 ml/L, 19 ml/L, 21 ml/L and 28 ml/L of sludge in the primary settlement process respectively.

Whilst it is expected that lower secondary sludge would result from BNR treatment after enhanced precipitation, the exact amount would need to be tested at plant scale to determine whether enhanced precipitation using biological flocculants increase or decrease the total sludge production rate. The biological flocculants performed better than Ferric Chloride in this regard. Moringa produced 32% less sludge and TE169 25% less than Ferric. However, the low sludge production of Fenugreek corresponded to its low removal of suspended solids.

Microbial Results

Moringa dosing has an effect on the treated water. Visually it seemed to suppress anaerobic digestion as seen from the three clearer jars below. Later COD tests showed that this was not the case but rather that Moringa remained effective in removing the digested matter that went into suspension with the other flocculants. This explains why it was found to assist the granulation and reduce the startup time of UASB reactors.

Figure 17: Apparent suppression of anaerobic digestion by Moringa

Water from the treated solutions was supplied to the UGU water laboratories for microbial analysis and the results follow.

Date of analysis	Sample Point	E.coli cfu/100 ml	Total Coliforms cfu/100 ml
23 March 2010	Raw Unsettled	>100 000	>100 000
23 March 2010	Raw Settled	>100 000	>100 000
23 March 2010	Moringa 2 ml	>100 000	>100 000
23 March 2010	Moringa 10 ml	15 200	>100 000
23 March 2010	TE169 100 mg/L	>100 000	>100 000
23 March 2010	TE169 150 mg/L	>100 000	>100 000
23 March 2010	Ferric 80 mg/L	>100 000	>100 000
23 March 2010	Ferric 120 mg/L	>100 000	>100 000
07 June 2007	Sample 7 026	>100 000	>100 000
07 June 2007	Sample 8 052	>100 000	>100 000
07 June 2007	Sample 9 080	>100 000	>100 000
07 June 2007	Sample 10 C2	>100 000	>100 000
07 June 2010	Sample 11 C5	>100 000	>100 000
07 June 2010	Sample 12 C10	>100 000	>100 000
07 June 2007	Sample 4 M20 F	8 200	11 900

Moringa reduced the E-Coli count by 85%, confirming its potential role as a combination sanitisation flocculation agent. However dosing rates higher than the optimal for COD removal would have to be used to de-sanitise the water to irrigation standards.

TE169, Ferric and unassisted settlement did not result in a measurable reduction in pathogen levels. Opuntia and Chitosan are also believed to have anti-microbial capabilities, indicating that these products could also be used to treat wastewater for fertigation purposes, but tests for the effect of these products on the microbiological characteristics of the treated water did not show any microbial activity.

Microfiltration of the flocculated water reduced the Ecoli and Total Coliform count by 92% and 89% respectively. It may be possible to obtain a suitably low COD and microbial count in the water if it is flocculated using Moringa and sand filtered.

Discussion, Recommendations and Conclusions

Table 10, Performance comparison of tested products

Flocculant	% COD removal enhancement	% SS removal enhancement	%P removal enhancement	% N removal enhancement	Sludge production ml/L	Microbiological improvement
Un assisted	40%	38%	32%	-	16	No
Ferric	48%	58%	38%	25%	28	No
Moringa	31%	45%	-	-	19	Yes
Chitosan	30%	43%	18%	-	18	Expected, but not observed
TE169	37%	30%	-	-	21	No
Opuntia	29%	34%	-	-	19	Expected, but not observed
Fenugreek	28%	12%	-	-	18	No

Ferric has a far greater COD and P removal capability than the biological products tested. Some N removal was also measured. The tests showed that both TE169 and Chitosan are also able to achieve very high COD removal rates, but these dosing rates may not be economical.

When dosed at economical dosing rates, the following results were achieved.

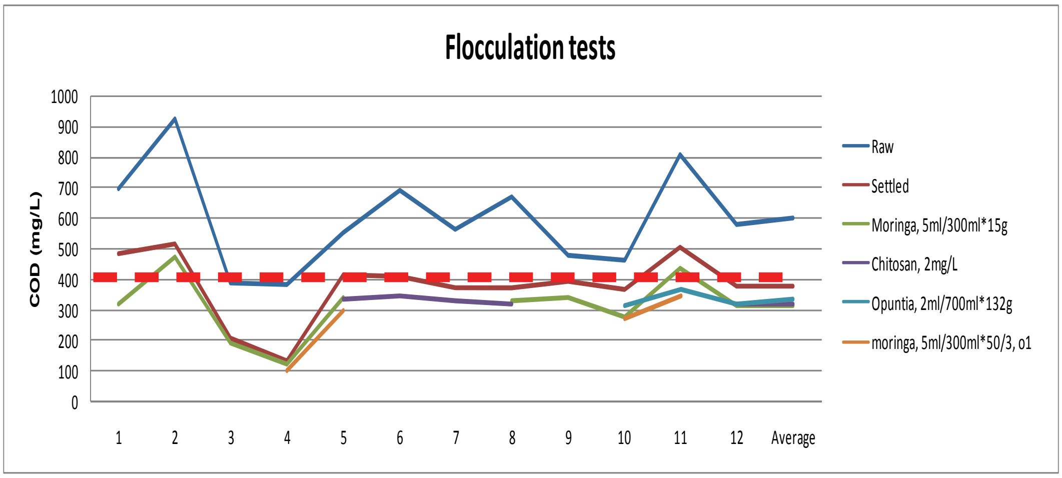

Figure 18: Results of optimal dosing of various biological flocculants at various incoming CODs

As a minimum, it indicates that biological flocculants can be used in certain situations prior to a BNR system with low dosing rates. For micro and small WWTWs, where irrigation with the treated water is an option, the biological flocculants were able to reduce the COD to below the maximum permissible level of 400 mg/L.

Opuntia, as it can be grown in most parts of the country can play an important role here as it can be combined integrated into the water treatment process as a 'constructed wetland.' When dosed simultaneously Moringa and Opuntia were able to produce a water with an average COD of 303 mg/L. Which represents a 20% enhancement in COD removal over un assisted settlement or a 50% total COD removal.

The removal of suspended solids by most of the tested products indicates that the treated water could then be suitable for various types of filtration from sand filtration to microfiltration. Confirmation is required on the degradability of the sludges produced by the biological flocculants as some of them are formulated using chemical compounds.

Nitrogen and Phosphate removal was minimal for all of the tested bioflocculants. South African discharge standards have limits on both N and P. For small treatment works Nitrate levels of 10 mg/L, ammonia of 6 mg/L and phosphate levels of 6 mg/L are permitted. Only Chitosan showed some P removal ability.

The use of some of the biological products (Moringa and Opuntia) led to rises in conductivity of the treated water. The standard allows for an increase of 150 mS during the treatment process. This does not occur at the optimal dosing rates, but may occur if bioflocculants are used to disinfect the water.

Low dosing rates did not result in the pH dropping significantly for any of the products tested, although the inlet pH was already close to the lower limit of the discharge standard on most occasions. Fenugreek requires a high pH to be effective, but does not reduce the pH of the treated water significantly. This would be a disadvantage should a plant be subject to an upper limit on pH of 7.5.

Treatment options of waste waters post bio-flocculation

There are many treatment options that can be employed after biologically enhanced primary settlement. The dosing rates will have to be adjusted to match the secondary treatment process.

Constructed wetlands

Given that wetland management/ construction would be the major cost in this type of treatment, maximising wetland life expectancy would be a priority. Wetland life expectancy is limited by the amount of solids that will enter the system. The use of biological flocculants could be used to enhance the elimination of suspended solids by 40%, thereby extending the life expectancy of the wetland system. Certain bioflocculants, such as Opuntia, Fenugreek and Moringa may be suitable inclusions in constructed wetland systems. It must be cautioned though that both Opuntia and Moringa will require some moisture stress to produce their respective flocculating agents. Wetland systems must have sufficient capacity buffering to enable them to still perform adequately during cold months or to recover from unplanned plant mortality.

Filtration for reuse

South Africa is an arid country and water re-use may be necessary to sustain its growing water usage. Water treated this way may be suitable for certain applications such as cooling water in the mines and power stations, for irrigation schemes or for other industrial applications.

Katayon *et al*., (2006) tested whether the addition of Moringa would assist microfiltration performance in treatment of secondary oxidation pond effluent using hollow-fibre crossflow microfiltration and coagulation process. Optimum dosage of Moringa water extract was recorded as 100 mg/L for turbidity reduction of secondary oxidation pond effluents ranging between 30 and 100 NTU. Filtrate quality of about 50 mg/L COD, 25 mg/L BOD_5, 2 mg $CaCO_3$/L alkalinity, 1 NTU turbidity, 1 mg/L TSS and VSS respectively was produced when using microfiltration with and without coagulation.

Turbidity removal achieved ranged between 50 and 57%. Better flux performance and lower rate of fouling were achieved when combining microfiltration with coagulation. The benefits of higher suspended solid removal are higher filter runs and thus possibly lower operating costs.

CEPT and Biological Filters

Biological filters are still widely in the country, but many are overloaded. A combination of CEPT and BFs could be suitable for small to medium sized WWTWs due to lower solids and nutrient loading. Biological filters are not used for high phosphate removal rates, so this option would only suite works that have a phosphate limit > 7 mg/L.

Phosphate recovery

Currently, phosphorus is regarded more as a contaminant than a resource. Mined rock phosphate is an abundant and relatively cheap source of phosphate for fertilizer production. This perspective has started to change in recent years as at the current rate of exploitation, the high quality portion of the resource will be largely depleted in less than 100 years, if another source of high-quality phosphate is not identified (Isherwood, 2000). This will place a burden on agriculture production, because lower-grade phosphates will have to be used, significantly increasing production costs. Phosphates recovered from wastewater plants might be a viable source of industrial raw material for manufacture of phosphate fertilizers.

The most common approach for removing phosphate from wastewater is Ferric precipitation, which makes the precipitate unrecoverable for possible industrial processing into fertilizer (Donnert and Salecker, 1999; Donnert and Salecker, 1999). Phosphate recovery from municipal wastewater is possible without Ferric precipitation as it is also possible to recover about 80% of the phosphorus flowing into wastewater treatment facilities as Struvite (magnesium ammonium phosphate hexahydrate ($MgNH_4PO^{4-}$ $6H_2O$.)) (Booker *et al*., 1999; Stratful *et al*., 2001; Williams, 1999).

Struvite precipitates spontaneously in wastewater treatment environments where high concentrations of soluble phosphorus and ammonium are present. Additional essential conditions are low concentration of suspended solids and a pH above 7.5. Precipitation of struvite requires that its components are available simultaneously in the wastewater in the molecular ratio 1(Mg^{2+}):1(NH_4^+):1(PO_4^{3-}). Normally, municipal wastewater tends to be rich in ammonium, but deficient in magnesium, so supplementation of magnesium is required, and this helps to increase solution pH (Lee *et al*., 2003a; Chimenos *et al*., 2003; Munch and Barr, 2001; Nelson *et al*., 2003; Van Rensburg *et al*., 2003).

One of the limitations of struvite precipitation is the cost of Magnesium oxide. An alternative source of magnesium could be “bittern” (a by-product of the desalination process.) Due to water scarcity, desalination may become widespread in certain parts of the country in the coming years and the re-use of bittern should be a consideration when desalination plants are designed.

CEPT and UASB treatment

Both Chitosan and Moringa have been shown to be beneficial to the granulation in, and performance of UASB reactors. Other biological flocculants may have similar benefits. CEPT and UASB treatment represents a lower capital and a lower treatment option for WWTWs than BNR. This treatment process is not widely used in South Africa, but should be investigated when new works are being considered.

Biological Nutrient Removal

Whereas, South Africa has invested heavily in this type of treatment process, CEPT with Ferric in combination with BNR (and EBNR for both N and P removal) poses two major challenges. Firstly the reduction in pH and alkalinity levels may lead to ammonia breakthrough. Although bacteria can adapt to consistently low pH levels over a period, there may be challenges in the colder months. The biological products tested did not negatively affect pH to a great extent, so this concern is overcome.

For the tested waters the total Nitrogen levels were around 30 mg/L. This will require analkalinity in excess of 210 mg/L for de-nitrification. The incoming water had an alkalinity around or greater than 240 mg/L. Moringa did reduce the alkalinity to around 180 mg/L at dosings higher than the optimal dosing for COD removal. Fenugreek required the testwater’s pH to be adjusted upwards, so there was no shortage of alkalinity. TE169 and Chitosan did not reduce the alkalinity of the incoming water even at higher doses than is optimal.

The second concern is on nutrient starvation of the activated sludge. There are already seasonal challenges with low nutrient levels at some WWTWs even without enhanced precipitation. If enhanced precipitation is to be employed to the full individual (and possibly higher synergistic) capabilities of the tested flocculants, then it is likely that supernatant from the sludge digestors would have to be returned to the aeration basin to provide the necessary nutrients to sustain the BNR process. It is not know whether this would be sufficient. If this has to be undertaken the desired energy savings may not be realised, as it would compromise the capacity enhancement and energy savings assumptions.

Techno-economic analysis

Flocculant production costs

This study was undertaken to make a first order estimate of the cost of producing biological flocculants. To complete this first assessment, many assumptions had to be made. Studies from abroad also had to be used with the assumption that local costs would be the same . A comprehensive review of the costs based on local dynamics extraction efficiencies and agronomic potential will be required prior to a full feasibility study. Fortunately some biological products are available commercially and their pricing can also be used to make a direct estimate of their dosing costs.

Tannin based flocculants

South Africa produces 60% of the world's biological tannins. A local company Sud Chemie markets a few tannin based flocculants. TE169, the tested product sells (in bulk) for around R6/kg, ex Pietermaritzburg. Another product is often cited in research papers, Tanfloc. Its cost is US$ 1,850/ton CFR, South Africa and is not competitive from a pricing perspective when compared to TE169.

Opuntia Spp

Studies in Northern Brazil showed that the cost of producing Opuntia biomass to be approximately R0.6 per kg of dry matter (Dos Santos *et al.*, 2002) The flocculating gel represents only 1.5% of the wet biomass and much of the value can be recovered as an energy supplement for cattle feed (R0.39/kg) and the flocculant would have to be priced based on the balance of the production and processing costs.

Opuntia mucilage dosing at 2 ml/L was found to be optimal, and after adjusting for its feed value and 90% water content, the dosing cost of Opuntia is just R0.01/kl treated. Higher land and production costs in South Africa may however mean that Opuntia dosing costs may be around R0.1/kl. Opuntia cost drivers are planting and harvesting which are labour intensive exercises. The costs can be lowered by about 15% if wastewater is found to be suitable for fertigation purposes. Fertigation inturn may assist with N&P removal.

Moringa oleifera

Moringa has as many applications. The tree produces edible leaves, fruit, pulp, oil, presscake and flocculants. The valorisations of all of the extracts need to be determined independently, by competitors in their respective categories. The cost estimates for producing a kilogram of Moringa seed vary from $1.00/kg to $2.00/kg. It is a high oleic oil, is similar in characteristics to olive oil. It is highly valued in the cosmetics industry due to its low oxidative nature. Moringa's multiplicity of uses and extracts makes it difficult to predict the long run cost of the flocculating proteins. Currently the high value placed on its oil by the cosmetics industry means that the presscake after oil extraction is currently 'free.'

Even if the cosmetics market gets oversupplied, the health oil market is still an interesting market for Moringa producers. Due to the over recovery of value from its oil, dosing costs of Moringa would be as low as the lowest alternative, i.e. R0.2/kl. It does not represent a high proportion of the value in the seed and will be managed as a waste product by oil producers.

The widespread commercialisation of Moringa flocculants will require greater oil seed production rates which will erode the value of the oil as its use would have to cover the health food and mass edible oil markets. Competitors in these segments are priced at R20/kg and R3-7/kg respectively. It should be noted however that these are producer prices and that rural consumers pay already between R14 toR17/kg of edible oil. Similarly, the health segment pays around R70/kg at the consumer level for high oleic oils.

Moringa oil may find its rightful place into the food industry, but this will take several years. Rapid adoption in the health-oil segment is more likely than it displacing conventional cooking oils in the short term. But this is also a low volume segment.

If this low value, as opposed to the value of cosmetic market, is to be used then to make Moringa flocculent viable, all the potential value products from the Moringa tree have to be used economically.

The other products that may be harvested without a radical shift in cultural practices are:

- 5-20 tons of leaf meal per hectare, the cost of which, will probably just cover the harvesting costs if used as cattle feed or could exceed the seed value if processed for human consumption.
- 2 tons of oil cake post flocculent extraction. The valorisation of the presscake would also result in value destruction over the seed costs as it will probably only fetch R2500/ ton as animal feed.
- Activated carbon may be produced from the seed husks. If it can penetrate the competitive activated carbon market, it may help bring down the costs of Moringa flocculent extracts, but only marginally.

The cost recovery from the other products may still permit Moringa to be an economical flocculant. It must be cautioned that its dosing costs could be as low as R0.20/ kl or could need to be R2.00/kl for Moringa production to be viable if oil should move from its current price levels.

There is a need to conduct agronomic trials to determine whether new varieties and alternative cultural practices such as annual rationing, leaf and pulp harvesting can change the production rate, quality and costs of Moringa seed production. Like with Opuntia the costs of producing the primary product is largely driven by labour costs in planting and harvesting.

Chitosan

Chitosan is marketed at $14-$18/kg, not due to the cost of manufacturing, but because of its other competing high value uses, e.g. cosmetics, medical. Whilst it is envisaged that in the short term local shell fish wastes can be processed to Chitosan at much lower costs than the imported products, the alternative markets for Chitosan could push the value towards $10/kg in the medium term.

Fenugreek

The cost of fenugreek polysaccharide production is driven by four costs.

- The cost of the seed, R15/kg;
- The cost of the precipitate –alcohol;
- The cost of the cleaner – acetone; and
- Capital and processing costs.

From the laboratory extractions undertaken it does not seem likely that alcohol recovery will be possible. Analytical grade ethanol would cost around R125/l and 350 ml was used for the processing of the mucilage gel produced by 150 g of seed. Industrial scale processing would most likely incorporate acetone recovery, but this was not assumed for now. 150 ml of acetone was used in the extraction. The cost of acetone was R28/l. The costs were escalated by 40% to include the capital and processing costs.

It will cost around R3000/kg to produce the polysaccharide. Fortunately, it is used at extremely low dosage rates (0.016 mg/L) so dosing costs are not high.

Carbon credits

The Kyoto protocol and Clean Development Mechanism allows sewerage treatment works that remove COD in a manner that reduces greenhouse gas emissions to register Certified Emission Reductions(CERs.) These reductions – commonly referred to as carbon credits can be quite substantial; 60,000 tons per annum at a 36MLD WWTW. Flocculation processes have been shown to enhance COD removal to 70% of the initial COD and between 50% and 60% of the balance can be removed anaerobically through a UASB reactor. If the primary sludge from such a process is digested with gas recovery and the gas from the UASB reactor is also collected, this treatment process will reduce greenhouse gasses emitted in several ways:

- By reducing the amount of electricity used at the works;
- By reducing the amount of CO_2 emitted by activated sludge;
- If methane gas from the digestors is used for electricity production ‘dirty’ grid electricity would be partly or totally avoided. Alternatively even by capturing and flaring methane gas there will be a reduction is green house gas emissions; and
- By facilitating higher methane recovery rates at WWTWs, bioflocculants can make such systems viable at smaller WWTWs than is currently the case.

Even existing BNR WWTWs could qualify for CERs if they employ sludge digestion with gas flaring/ utilisation. But enhancing the anaerobic COD reduction over aerobic (activated sludge) will increase the amount of CERs that could be claimed. Again this will make the feasibility of CDM projects more viable, especially for smaller treatment works.

Currently there is a simplified methodology that can be used. The drawbacks are that it puts a cap on the amounts of credits that a project can claim to 60,000 tons per year (approximately translating to a 36MLD treatment capacity) and does not take all the emission into account. Where micro plants are in operation, it is possible to bundle projects together to make them financially viable. To avoid the long lead-time and CDM methodology development costs, it may still be the best option for smaller works.

Since the establishment of the CDM mechanism, CERs prices have stabilised around EUR12/t, peaking at close to EUR 30/ton and falling as low as EUR2/t when problems relating to carbon carryover emerged on its inception. Bolstered by continued growth in volume, the global carbon market value is projected to grow by 68% per year from under $84 billion in 2009 to $669 billion in 2013. This remains a vastly untapped source of funding for development projects in South Africa. Most CDM projects registered to date are in China and India. Under the simplified methodology, a project can qualify for R5.2 million worth of CERs per annum for 7 years, renewable 3 times or as a once of 10 year CDM project. Discounted at 15% pa the CDM could raise R21 million for upgrades that may be required to the sludge handling process. This will help with the feasibility of methane production, capture and destruction systems.

The United States may also establish a carbon emissions cap and trade program. The system may be operational by 2012; immediately establishing the second largest carbon market in the world. The system will allow for cross-border carbon trading, with a preference given to developing countries in Africa and South America. Although the indicated floor pricing under the proposed mechanism of $10/t of CO2 is some 33% lower than the CERs trading under the existing CDM mechanism, its establishment of a floor pricing mechanism will enable this revenue stream for the first time to be included in project financing cashflow projections without project developers having to sell forward their credits at vastly discounted rates.

With the recession, the value of the global carbon markets is expected to decrease by 29% to under $84 billion in 2009. Prices in the carbon markets are expected to rebound significantly post-2012.

It is estimated that R0.3/kl could be recovered from carbon credits under a CEPT-UASB system. However not all credits for available under the existing simplified methodology will qualify for credits because the process could be more economical than conventional treatment and would therefore not be deemed '*additiona*l.' For a project to qualify for credits it must not be the most cost effective solution, not meet an investment IRR hurdle criteria or suffer from technical uncertainty.

However, the addition of sludge digestion with methane capture for destruction or re-use would in most cases qualify for CERs. Even if CERs for the other potential sources would not qualify, the value of the credits would still be substantial at R0.2/kl of effluent treated.

To claim incentives under the CDM mechanism WWTWs would have to make sure that they receive and manage the wastewater treatment process as per the prescribed methods. This creates a positive financial incentive for the proper management of WWTWs.

Total treatment costs

The following data was obtained from several large WWTs (>30MLD.) The treatment costs at Sunderland ridge are probably understated by around R0.15/kl due to internal electricity cost allocation errors at Tshwane.

Table 11: Treatment costs at large WWTWs.

	Northern Works	Rooiwal	Sunderland Ridge	Dasport
Total costs R/kl	0.52	0.96	0.64	0.84
Salaries	0.15	0.24	0.23	0.44
Electricity	0.11	0.13	0.01	0.15
Chemicals	0.08	0.19	0.16	0.05
Maintenance	0.08	0.17	0.24	0.20

The actual cost of electricity at these works is much lower than that used in the cost-benefit analysis. This is because the unit cost of electricity for the smaller works was much higher than that at Tshwane and Johannesburg. This should be taken up by the Municipalities or by SALGA as it prejudices the ability of small municipalities to competitively sustain service delivery. The treatment of municipal wastewater through the addition of biological flocculants will involve additional chemical costs, but lower electricity, capital and ultimately maintenance costs. Benefits from electricity savings, assuming that COD reductions have a linear relationship to aeration requirements range between R0.05 and R0.11/kl treated. If nutrient levels after flocculation are too low and nutrient has to be re-introduced to sustain the BNR process, then the benefits will conversely reduce.

Capital installation costs for BNR WWTWs capacity are between R4 to R10 million per MLD. When apportioned as a cost per kl treated, this is around R2.00/kl treated. If CEPT can increase the capacity of BNR systems, then substantial capital savings can be made. For a capacity enhancement of 30%, R0.51/kl is saved. It must be noted that in South Africa, many WWTW projects are financed through Municipal Infrastructure Grants (MIG) and a perverse situation thus arises whereby capital costs would be favoured over operating costs by municipalities as lower operating costs would afford them more discretionary spending opportunities. This may lead to the country as a whole paying for inappropriate capital investment choices.

Sludge thickening may be facilitated by bioflocculants, thereby enabling WWTWs to save on polyelectrolyte dosing (which accounts for about R0.1kl of effluent treated) and electricity consumption by sludge thickening activities.

For smaller treatment works (<10MLD), disproportionate salary costs push up the unit costs to over R1.20/kl. The benefit of lower staffing requirements form CEPT-UASB/ CEPT MBR may not materialise into savings due to social considerations, but some of the staff could be absorbed into bioflocculant production and waste beneficiation opportunities.

Cost benefit analysis of flocculants

Based on the dosing rates and production costs of the various products, the following cost-benefit analysis was produced.

Table 12: Cost-benefit analysis of tested flocculants

Product	Dosing rate (mg/L)	COD removal	Chemical costs (R/kl)	Electricity savings	Capital savings	Benefit/ (shortfall)
Ferric	40	61%	0.20	0.05	0.51	R0.36/kl
Chitosan	2	48%	0.21	0.09	0.40	R0.28/kl
TE169	100	52%	0.60	0.04	0.47	-R0.09/kl
Moringa seed	250	49%	0.20	0.07	0.41	R0.27/kl
Opuntia pads	380	45%	0.01	0.07	0.38	R0.44/kl
Fenugreek mucilage	0.016	49%	0.05	0.07	0.44	R0.46/kl

Only Fenugreek and Opuntia under the above assumptions can reduce the operating costs at BNR WWTWs, but when capacity is a constraint, and if they can actually bring about capacity improvements, Moringa, Chitosan and Ferric are also competitive solutions.

It must be noted that this analysis was for a mainly domestic wastewater with some unique characteristics. Tests should be undertaken at the works being targeted to see which product is the most cost effective solution. Where plant influents have higher COD concentrations than the norm CEPT may be more beneficial. The inverse would apply to when CODs in the influent is lower. Some works that treat both domestic and industrial waste have very high COD levels.

TE169 is not seen to be cost effective options at this point in time, but may be beneficial to certain problematic effluents, for example oil bearing ones. Also it may be possible to reduce the dosing rates by optimising the influent parameters such as pH or by synergistic dosing of flocculant aids. Moringa flocculant in the short term is viable. But it is cautioned that once the cosmetic oil market for Moringa is saturated, the true cost of the flocculant would have to be recovered for Moringa production to continue being viable. This could equate to a dosing cost of as much as R2.00/kl.

Chitosan, Fenugreek and Opuntia are interesting products as they seem to offer long run cost effectiveness.

CEPT in combination with MBRs, wetlands or UASB reactors could be much more competitive from both a capital and operating perspective than CEPT and BNR. Electricity costs may be largely avoided.

The following schematic indicate how biological flocculants can be put to use to maximise the nutrient removal, whilst maximising energy recovery, value recovery and minimising operating costs at WWTWs.

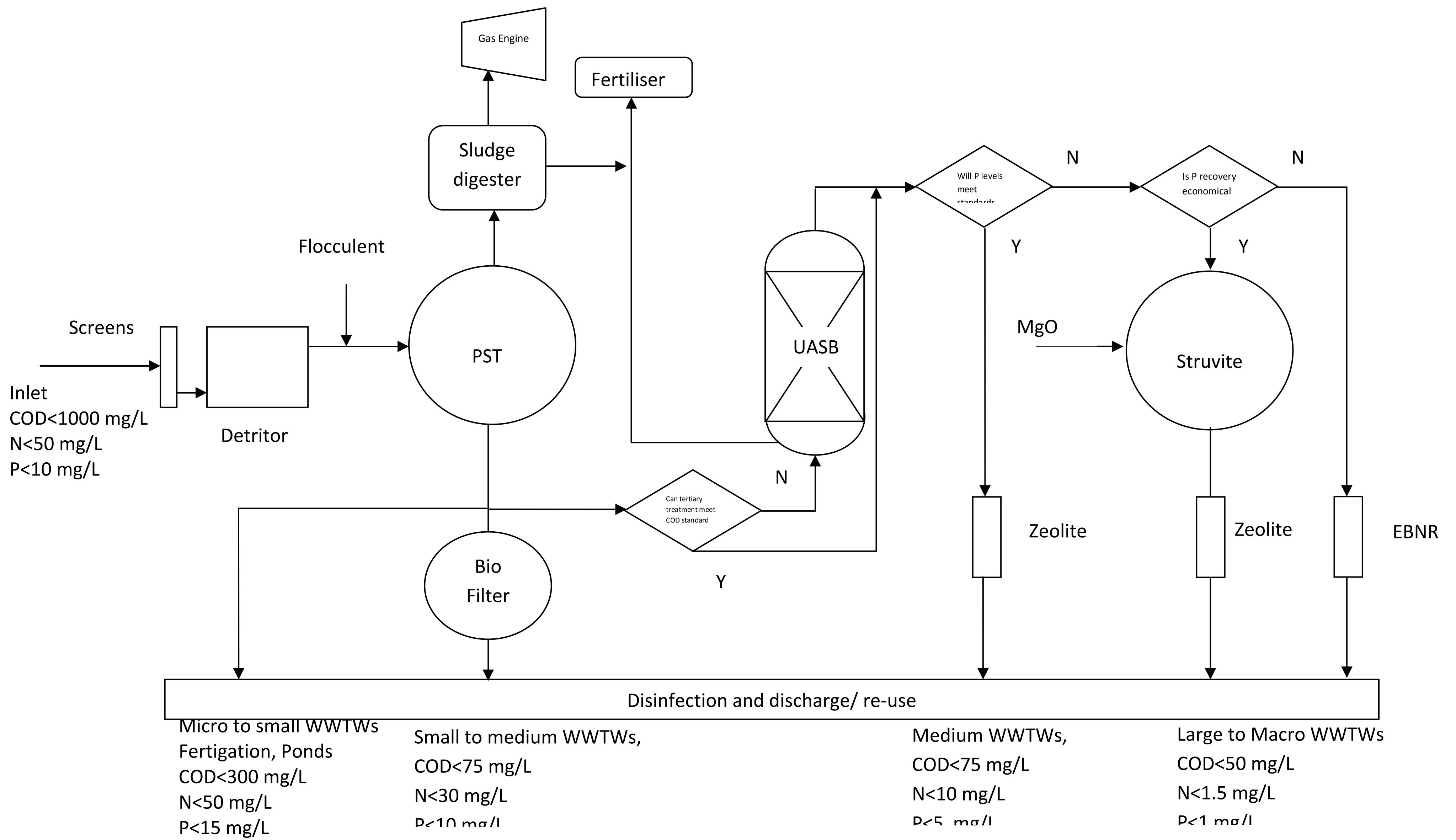

Figure 19: Mooted use of biological flocculants for, micro, small, medium and large to macro WWTWs

Although small and micro sized WWTWs only collectively consitiute 3% of the daily flow to WWTWs in the country they represent 62% of WWTWs and are contributing to the contamination of water resources (Igbinosa *et al.,* 2009). Unfortunately, many of these works are in poor rural areas where communities rely on the very same water sources for drinking purposes. These works can not afford the necessary skills to operate advanced waste water treatment processes. If water treated by bioflocculants can be used for irrigation purposes, a lot of the non-compliance can be eradicted, allowing stakeholders to focus their attention on medium to large WWTWs. Over 30,000 ha of land can be irrigated this way, further stimulating the rural economy.

Table 13: Size distribution of WWTWs in South Africa

The capacity of WWTP in South Africa is shown below:

Plant size category (Mℓ/day)	Estimated number of plants (#)[1]	Median wastewater flow treated (Mℓ/day)[2]	Total volume of wastewater treated (Mℓ/day)
< 0.5	488	0.25	122
0.5 – 2	108	1.25	134
2 – 10	208	6	1248
10-25	93	17.5	1625
25-100	71	62.5	4460
Estimated total volume of wastewater treated in South Africa			**7589**

[1] Estimated number of plants obtained from the DWAF data base corrected for the plant category sizes used in this report (Figure 1).
[2] The actual plant sizes in each plant size category was available.
Data: Golder and Associates study of WWTP.

Enhanced flocculation alone will not be able to meet the higher standards required for larger irrigation schemes or discharges to water bodies. Most works treating 2-10MLD and several treating between 10-25MLD are regulated by the general standard. Low cost secondary treatment process such as UASB reactors or MBRs may be able to meet this standard at competitive capital and operating costs when compared to BNR treatment. High nutrient levels corresponding to a COD of around 1000 mg/L may result in the combined BEPT-UASB/ BEPT-MBR works not meeting the discharge standard of 75 mg/L wrt COD but producing an effluent between 60 and 100 mg/L.

Tests were conducted on water 5 days after it had been through the CEPT process and those teated by Moringa had a COD < 100 mg/L, the water treated by the Moringa-Opuntia combination had a COD of 79 mg/L. UASB treatment may result in a reduction in N and P levels by around 20%. This will not enable the works to achive the general discharge specifications on these nutrients, but the use of adsorbants such as rechargable zeolites have been shown to facilitate ammonia-nitrogen removal.

The regulator should be engaged on this as the cost and complexity of achieving a higher quality effluent will not always warrant it. Rechargeable zeolites are known for their nitrogen removal capabilities but (Xiao Ming Li et al, 2007) noted that there was also a physical absorption, entrapment of PO_4 by the zeolite which resulted in up to 100% P removal, but this reduced after 2 to three days of operation.

For Macro sized works, treating >25MLD, as they are governed by standards that are very onerous with respect to all nutrient removal. Tertiary steps such as using rechargeable zeolites, struvite precipitation and possibly the combination of UASB and MBR may be required to meet this standard. Even the combination of these processes may not be able to achieve a median P output at 1 mg/L. It is expected that the envisaged combination of processes could produce an effluent with a mean P level of 2 mg/L. If the physical entrapment of PO4 is achieved in the MBR by the zeolite, the P standard can be met. This is a highly speculative series of assumptions, thus it is not suggested that works of greater than 25MLD be targeted for plant scale research in the coming years.

Hence only around 3000MLD of the 7500MLD of wastewater that is treated in the country is projected to benefit from the use of bioflocculants. But lessons learned at the smaller works and further research efforts may enable these mooted solutions to become viable for macro WWTWs also in coming years.

Further research areas

As with any process change, a full scale feasibility study should be undertaken to determine whether the promise that they hold can be realised at plant scale. Cognisance should also be taken of the effects of temperature and the local influences on influent quality as these may impact on the effectiveness of the biological flocculants. Test should be undertaken in combination with the envisaged secondary and tertiary treatment steps.

Other areas that could hold much promise is the synergistic combination of biological flocculants. Prior research has shown that Moringa and Opuntia combine well with Alum, improving COD removal rates to over 60%. Tests combining Moringa and Opuntia showed enhanced COD removal. It may be possible with the concurrent or sequential dosing of other biological flocculants, to further enhance nutrient removal.

The most promising secondary treatment technologies include the combination of CEPT with engineered wetlands, biological filters and UASB reactors. These combinations of processes should be tested at pilot sites. This will build the local knowledge pool that will be required for the implementation of such processes.

The cultivation of biological flocculants will create many work and local economic development (LED) opportunities in the country and region. These will require full agronomic evaluation prior to community scale roll-out.

The extracts of Moringa and solutions of Chitosan led to increases in conductivity. Tests should be undertaken to see if the conductivity of the treated water reduces as the flocculant residuals degrade or whether they arise from the chemical salts used in the extraction/ dilution processes.

Other biological flocculants should be evaluated in regions where they are abundant. If found to be effective, they would eliminate the need for transporting low value products over vast distances. Extraction processes for biological flocculants should be further improved on to maximise yields and qualities. Also the extractions undertaken should be scaled up to determine whether the costs match that which was extrapolated from the testwork.

Phosphate precipitation through the use lower cost magnesium sources should be investigated. If viable, it can be used to assist emerging farmers. Struvite precipitation will also reduce nitrogen levels of the wastewater. The Department of Water Affairs and other stakeholders should be engaged relating to the irrigation with wastewater standards. In the view of the Author, the permissible pathogen levels are too high and the permissible nutrient levels are too low.

Conclusions

The testwork confirmed that the biological flocculants are capable of enhancing the primary settlement process to varying degrees. This may be desirable for existing works that are constrained by capacity or have higher COD levels in their influents than is needed by the secondary treatment steps. The use of the biological flocculants did not significantly reduce pH or alkalinity.

When the dosing costs are compared to an idealised savings in electricity, only Opuntia and Fenugreek may be economical to dose. When capacity constraints also exist, and if the biological flocculants can actually increase plant capacity, then Moringa and Chitosan are also cost effective. TE169, despite having high COD removal capabilities, does not seem to be a cost effective option at this point in time. Additional optimisation of its formulation and dosing may correct this.

As Chitosan is already commercially available, it should be considered to meet any short term, pressing situations such as poorly managed WWTWs or problematic influents.

The problem of the voluminous sludge production is overcome to different degrees by the products tested. The best performing product was Chitosan, followed by Moringa. Opuntia and Fenugreek also showed improvements over Ferric. TE169, like Ferric led to a lot of sludge forming.

All the potential benefits of enhanced nutrient removal may not be gained at BNR treatment works. From previous research it would seem that other secondary treatment options such as rapid sand filtration, BFs, wetlands and UASB reactors seem to be better matched to the full potential offered by biological flocculants.

Of the five identified products, Opuntia and Fenugreek seemingly have the greatest potential for social change in South Africa by creating opportunities for rural employment. They lag the other products in terms of its advancement through research though. Chitosan and Tannin flocculants are already commercially available. WWTWs considering BEPT should engage with suppliers of these products to make them more financially feasible. Moringa is limited in that the other commercial valorisation of the other components of the seed first needs to be proven, before large quantities of flocculant become available.

Considerable energy savings can be realised at WWTWs if the envisaged anaerobic treatment processes are viable. This could reduce the electricity consumption in the country by as much as 1%.

Biological flocculants seemingly have the ability to bridge the gap between rural communities sanitation needs, its food and water requirements and help it meet its basic energy needs. Given its potential to stimulate rural development through the advancement of agri-processing businesses, and that the research that was conducted over many years is now mature enough for plant applications, this work should be advanced through further research larger scale efforts in the country.

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Annexure: 1 Basis of Estimates

1. WWTW Existing Flowrates, References (1)

The capacity of WWTP in South Africa is shown below:

Plant size category (Mℓ/day)	Estimated number of plants (#)[1]	Median wastewater flow treated (Mℓ/day)[2]	Total volume of wastewater treated (Mℓ/day)
< 0.5	488	0.25	122
0.5 – 2	108	1.25	134
2 – 10	208	6	1248
10-25	93	17.5	1625
25-100	71	62.5	4460
Estimated total volume of wastewater treated in South Africa			**7589**

[1] Estimated number of plants obtained from the DWAF data base corrected for the plant category sizes used in this report (Figure 1).
[2] The actual plant sizes in each plant size category was available.
Data: Golder and Associates study of WWTP.

2. Energy consumption at WWTWs in South Africa

Expected domestic influent characteristics		
COD	600	mg/L
SS	400	mg/L
TKN	50	mg/L
P	15	mg/L
COD received at WWTWS	4 560	tons
% COD removal via primary settlement	38%	
% of flow treated by primary settlement	80%	
COD removal via primary settlement	1 389	tons
Ammonia loading	380 000	kg/day
Oxygen requirements		
Oxygen required for 15 day sludge age	1.1315	
COD	132 109	kg/hour
Oxygen required for COD removal	149 481	kg/hour
Oxygen required for ammonia oxidation	71 250	kg/hour
Total oxygen required per hour	220 731	kg/hour
Power consumption		
kg/ O2 per kW transmitted	1.3	
Transmission losses	15%	
Power requirements for aeration	200	MW
Aeration % of total power consumption	60%	
Total power capacity requirements	333	MW
Power consumption	7 990	MWh per day
Size of SA generation capacity	38000	MW
% of generation capacity	0.88%	
Electricity costs		
kWh used	7 990 263	kW/ day
Effluent treated	7 600 000	kl/day
Electricity variable costs	0.5	R/kWh
Electricity costs per kl treated	0.53	R/ kl

Expected post Ferric effluent characteristics		
COD	236	mg/L
SS	50	mg/L
TKN	50	mg/L
P	4	mg/L
COD received at Aeration basin	1 793	tons
% COD removal enhanced settlement	61%	
% of flow treated by primary settlement	100%	
COD removal via primary settlement	2 767	tons
Ammonia loading	380 000	kg/day
Oxygen requirements		
Oxygen required for 15 day sludge age	1.1315	
COD	74 708	kg/hour
Oxygen required for COD removal	84 532	kg/hour
Oxygen required for ammonia oxidation	71 250	kg/hour
Total oxygen required per hour	155 782	kg/hour
Power consumption		
kg/ O2 per kW transmitted	1.3	
Transmission losses	15%	
Power requirements for aeration	141	MW
Secondary power requirements	170	MW
Power capacity requirements	311	MW
Power consumption	7 458	MWh per day
Size of SA generation capacity	38000	MW
% of generation capacity	0.82%	
Electricity costs with Ferric CEPT		
kWh used	7 458 443	kW/ day
Effluent treated	7 600 000	kl/day
Electricity costs	0.5	R/kWh
Electricity costs per kl treated	0.49	R/ kl

Electricity costs are expected to be lower in the aeration basin, but higher for sludge handling.

Expected post Chitosan effluent characteristics

COD	249	mg/L
SS	50	mg/L
TKN	50	mg/L
P	10	mg/L
COD received at Aeration basin	1 896	tons
% COD removal enhanced settlement	48%	
% of flow treated by primary settlement	100%	
COD removal via primary settlement	2 664	tons
Ammonia loading	380 000	kg/day

Oxygen requirements

Oxygen required for 15 day sludge age	1.1315	
COD	78 983	kg/hour
Oxygen required for COD removal	89 369	kg/hour
Oxygen required for ammonia oxidation	71 250	kg/hour
Total oxygen required per hour	160 619	kg/hour

Power consumption

kg/ O2 per kW transmitted	1.3	
Transmission losses	15%	
Power requirements for aeration	145	MW
Secondary power requirements	133	MW
Power capacity requirements	279	MW
Power consumption	6 685	MWh per d
Size of SA generation capacity	38000	MW
% of generation capacity	0.73%	

Electricity costs with Chitosan CEPT

kWh used	6 684 657	kW/ day
Effluent treated	7 600 000	kl/day
Electricity costs	0.5	R/kWh
Electricity costs per kl treated	0.44	R/ kl

Expected post TE169 effluent characteristics		
COD	263	mg/L
SS	50	mg/L
TKN	50	mg/L
P	10	mg/L
COD received at Aeration basin	1 999	tons
% COD removal enhanced settlement	56%	
% of flow treated by primary settlement	100%	
COD removal via primary settlement	2 561	tons
Ammonia loading	380 000	kg/day

Oxygen requirements		
Oxygen required for 15 day sludge age	1.1315	
COD	83 277	kg/hour
Oxygen required for COD removal	94 228	kg/hour
Oxygen required for ammonia oxidation	71 250	kg/hour
Total oxygen required per hour	165 478	kg/hour

Power consumption		
kg/ O2 per kW transmitted	1.3	
Transmission losses	15%	
Power requirements for aeration	150	MW
Secondary power requirements	160	MW
Power capacity requirements	310	MW
Power consumption	7 429	MWh per d
Size of SA generation capacity	38000	MW
% of generation capacity	0.81%	

Electricity costs with TE169 CEPT		
kWh used	7 429 417	kW/ day
Effluent treated	7 600 000	kl/day
Electricity costs	0.5	R/kWh
Electricity costs per kl treated	0.49	R/ kl

TE 169 also produced a high volume of sludge so electricity usage was adjusted upwards for sludge handling for this product too.

Expected post Moringa effluent characteristics

COD	275	mg/L
SS	50	mg/L
TKN	50	mg/L
P	10	mg/L
COD received at Aeration basin	2 092	tons
% COD removal enhanced settlement	49%	
% of flow treated by primary settlement	100%	
COD removal via primary settlement	2 468	tons
Ammonia loading	380 000	kg/day

Oxygen requirements

Oxygen required for 15 day sludge age	1.1315	
COD	87 172	kg/hour
Oxygen required for COD removal	98 635	kg/hour
Oxygen required for ammonia oxidation	71 250	kg/hour
Total oxygen required per hour	169 885	kg/hour

Power consumption

kg/ O2 per kW transmitted	1.3	
Transmission losses	15%	
Power requirements for aeration	154	MW
Secondary power requirements	133	MW
Power capacity requirements	287	MW
Power consumption	6 886	MWh per d
Size of SA generation capacity	38000	MW
% of generation capacity	0.76%	

Electricity costs with Moringa CEPT

kWh used	6 885 918	kW/ day
Effluent treated	7 600 000	kl/day
Electricity costs	0.5	R/kWh
Electricity costs per kl treated	0.45	R/ kl

Expected post Fenugreek effluent characteristics

COD	285	mg/L
SS	50	mg/L
TKN	50	mg/L
P	10	mg/L
COD received at Aeration basin	2 167	tons
% COD removal enhanced settlement	52%	
% of flow treated by primary settlement	100%	
COD removal via primary settlement	2 393	tons
Ammonia loading	380 000	kg/day

Oxygen requirements

Oxygen required for 15 day sludge age	1.1315	
COD	90 288	kg/hour
Oxygen required for COD removal	102 161	kg/hour
Oxygen required for ammonia oxidation	71 250	kg/hour
Total oxygen required per hour	173 411	kg/hour

Power consumption

kg/ O2 per kW transmitted	1.3	
Transmission losses	15%	
Power requirements for aeration	157	MW
Secondary power requirements	133	MW
Power capacity requirements	290	MW
Power consumption	6 962	MWh per d
Size of SA generation capacity	38000	MW
% of generation capacity	0.76%	

Electricity costs with Fenugreek CEPT

kWh used	6 962 495	kW/ day
Effluent treated	7 600 000	kl/day
Electricity costs	0.5	R/kWh
Electricity costs per kl treated	0.46	R/ kl

Expected post Opuntia effluent characteristics

COD	283	mg/L
SS	50	mg/L
TKN	50	mg/L
P	10	mg/L
COD received at Aeration basin	2 148	tons
% COD removal enhanced settlement	45%	
% of flow treated by primary settlement	100%	
COD removal via primary settlement	2 412	tons
Ammonia loading	380 000	kg/day

Oxygen requirements

Oxygen required for 15 day sludge age	1.1315	
COD	89 509	kg/hour
Oxygen required for COD removal	101 279	kg/hour
Oxygen required for ammonia oxidation	71 250	kg/hour
Total oxygen required per hour	172 529	kg/hour

Power consumption

kg/ O2 per kW transmitted	1.3	
Transmission losses	15%	
Power requirements for aeration	156	MW
Secondary power requirements	133	MW
Power capacity requirements	289	MW
Power consumption	6 943	MWh per d
Size of SA generation capacity	38000	MW
% of generation capacity	0.76%	

Electricity costs with Opuntia CEPT

kWh used	6 943 351	kW/ day
Effluent treated	7 600 000	kl/day
Electricity costs	0.5	R/kWh
Electricity costs per kl treated	0.46	R/ kl

3. Flocculant costs

3.1 Moringa

	Edible oil value	Health oil low value	Health oil high value	Cosmetic oil value	
Moringa seed costs	7.5	11.25	11.25	50	R/kg
Oil yield	34%	20%	20%	20%	
Oil value	15.00	20.00	50.00	289.06	R/kg
Presscake value	2.5	2.5	2.5	2.5	R/kg
Total derived values	6.59	5.80	11.80	59.61	R/kg
Flocculant cost	14	68	-7	-120	R/kg
In husk seeds	200	200	200	200	g
Post milling	145	145	145	145	g
Post oil extraction	124	124	124	124	g
Number of samples prepared	4	4	4	4	
Oil cake used per sample	31	31	31	31	g
NaCl solution	500	500	500	500	ml
Prepared flocculant solution	380	380	380	380	ml
Dosing rate	5	5	5	5	ml/L
Equivalent seed use	0.66	0.66	0.66	0.66	g/L
Seed cost	4.93	7.40	7.40	32.89	R/kl
Oil value recovered	3.36	2.63	6.58	38.03	R/kl
Oil cake value recovered	1.02	1.02	1.02	1.02	R/kl
Net cost of Moringa flocculating materials	0.56	3.75	-0.20	-6.16	R/kl

Moringa oil yields of 50% are possible with cold pressing. Higher yields can be obtained by using solvents, but oil extracted this way will not be acceptable to the cosmetics industry.

3.2. Opuntia

Cost of establishment of 1 ha of opuntia at four spacings

Parameter	Cost (US$/ha)			
	2 × 1 m	1 × 0.50 m	1 × 0.25 m	3 × 1 × 0.50 m
Soil preparation	26.32	26.32	31.58	31.58
Opuntia cuttings + transportation	36.84	131.58	263.16	63.16
Organic fertilization	131.58	131.58	131.58	131.58
Phosphorus fertilization	52.63	52.63	52.63	52.63
Weed control (herbicides)	84.21	84.21	84.21	84.21
Planting	47.37	89.47	136.84	52.63
Total	**378.95**	**515.79**	**700**	**415.79**

Production cost of 1 ha of opuntia during the first two years, at four spacings

Parameter	Estimated cost (US$/ha)			
	2 × 1 m	1 × 0.5m	1 × 0.25 m	3 × 1 × 0.5 m
50% of establishment cost	189.48	257.90	350.00	207.90
Interest @11%	45.26	76.32	104.21	50
Subtotal	**234.74**	**334.21**	**454.21**	**257.89**
Weed control	337.37	373.16	568.95	262.11
Harvest	263.16	394.74	526.32	236.84
Total cost	**835.27**	**1102.11**	**1549.48**	**756.84**

Estimated dry matter (DM) production cost during the first two years, at four spacings

Parameter	Estimated cost (US$/ha)			
	2 × 1 m	1 × 0.5 m	1 × 0.25 m	3 × 1 × 0.5 m
Total cost (US$/ha)	835.27	1102.11	1549.48	756.84
Production (t DM/ha)	10	15	20	9
Production cost (US$/kg DM)	**0.084**	**0.073**	**0.077**	**0.084**

Estimated cost of maintenance of 1 ha of opuntia in the 3rd and 4th years, at four spacings

Parameter	Estimated Cost (US$/ha)			
	2 × 1 m	1 × 0.5 m	1 × 0.25 m	3 × 1 ×
Planting (including interest)	279.995	410.535	558.42	307.895
Fertilizer - acquisition	78.95	78.95	78.95	78.95
Fertilizer-spreading	6.32	9.47	12.63	6.32
Weed control	94.74	102.63	126.32	94.74
Harvest	263.16	394.74	526.32	236.84
Total	**560.53**	**745.79**	**961.05**	**545.79**
Production t DM/ha	10	15	20	9
Production cost (US$/kg DM)	**0.056**	**0.050**	**0.048**	**0.061**

Average production cost (US$/kg DM)	0.070	0.062	0.063	0.072
Production cost (R/kg DM)	0.64	0.56	0.57	0.66
Recovered value -Fodder (R/ dry kg @R400/ dry ton)	0.39	0.39	0.39	0.39
Flocculant cost (R/ dry kg)	0.24	0.17	0.18	0.27
Dosing rate (g_{wet}/L)	0.38	0.38	0.38	0.38
Opuntia dosing costs (R/kl)	**0.01**	**0.01**	**0.01**	**0.01**

This analysis does not consider land costs which are much higher in South Africa than Brazil.

3.2 Fenugreek

Seed cost	15	R/kg
Seed used	150	g
Seed cost	2.25	R
Ethanol cost	126	R/l
Ethanol usage	350	ml
Ethanol cost	44.1	R
Acetone use	150	ml
Acetone cost	28	R/l
Acetone cost	4.2	R
Polysaccharide yield	23	g
Flocculant cost	3077	R/kg
Dosing rate	0.016	mg/L
Fenugreek dosing costs (R/kl)	**0.049**	**R/kl**

3.3 Tannin

TE169 cost	6	R/kg
Dosing rate	100	mg/L
TE169 dosing cost	**0.6**	**R/kl**

3.4 Chitosan

Chitosan costs	105	R/kg
Dosing rate	2	mg/L
Chitosan dosing costs (R/kl)	**0.21**	**R/kl**

3.5 Ferric

Ferric costs	1.6	R/kg
Concentration	40%	
Dosing rate	50	mg/L
Ferric dosing costs (R/kl)	**0.2**	**R/kl**

4. Capital cost at WWTWs

Capital costs of WWTWs		
Capacity costs	6 000 000	R/MLD
Finance costs (15 years @ 8.5%)	R 722 523	p/a
Annual throughput	365 000	kl per year
Cost/ kl	R 1.98	R/kl
Less cost of PST	250000	R/MLD
Finance costs (15 years @ 8.5%)	R 30 105	
PST capital cost/ kl	0.08	R/kl

5. Cost benefit analysis

5.1 Ferric

Cost and benefit analysis of CEPT with Ferric dosing		
Chemical cost	R 0.20	R/kl treated
Electricity savings	R 0.05	R/kl treated
Capital cost savings	R 0.51	R/kl treated
Total expected benefit (shortfall)	**R 0.36**	R/kl treated

5.2 Chitosan

Cost and benefit analysis of CEPT with Chitosan dosing		
Chemical cost	R 0.21	R/kl treated
Electricity savings	0.09	R/kl treated
Capital cost savings	R 0.40	R/kl treated
Total expected benefit (shortfall)	**R 0.28**	R/kl treated

5.3 TE169, Tannin

Cost and benefit analysis of CEPT with TE169 dosing		
Chemical cost	R 0.60	R/kl treated
Electricity savings	0.04	R/kl treated
Capital cost savings	R 0.47	R/kl treated
Total expected benefit (shortfall)	**R -0.09**	R/kl treated

5.4 Moringa

Cost and benefit analysis of CEPT with Moringa dosing		
Chemical cost	R 0.20	R/kl treated
Electricity savings	0.07	R/kl treated
Capital cost savings	R 0.41	R/kl treated
Total expected benefit (shortfall)	**R 0.29**	R/kl treated

5.5 Fenugreek

Cost and benefit analysis of CEPT with Fenugreek dosing		
Chemical cost	R 0.05	R/kl treated
Electricity savings	0.07	R/kl treated
Capital cost savings	R 0.44	R/kl treated
Total expected benefit (shortfall)	**R 0.46**	R/kl treated

5.6 Opuntia

Cost and benefit analysis of CEPT with Opuntia dosing		
Chemical cost	R 0.01	R/kl treated
Electricity savings	0.07	R/kl treated
Capital cost savings	R 0.38	R/kl treated
Total expected benefit (shortfall)	**R 0.44**	R/kl treated

6. Carbon Finance

CERs and Carbon Credits

Electricity usage reduction	1 031 016	kWh/ day
50% electricity self sufficiency	3 729 222	kWh/ day
CEF_{grid}	0.85	kgCO2e/kWh
BE_{grid}	1 476 864	tons/year
BE_{ww} (Poorly managed aerobic systems (0.3))	1 897 391	tons/year
BE $_{\text{Sludge methane potential, 0.5g solids/ L}}$	4 605 820	tons/year
CER price	R 120	
CER potential CER values	R 957 609 000	
CER value/ kl treated	**R 0.29**	

CDM valuation

CERs produced	60 000	
CER price	120	per t CO_2
Year 1	-	
Year 2	3 200 000	
Year 3	5 200 000	
Year 4	5 200 000	
Year 5	5 200 000	
Year 6	5 200 000	
Year 7	5 200 000	
Year 8	5 200 000	
Year 8	5 200 000	
Year 10	5 200 000	
Year 11	5 200 000	
	R 21 181 275	

Annexure: 2 Wastewater discharge standards

SUBSTANCE/PARAMETER	GENERAL LIMIT	SPECIAL LIMIT
Faecal Coliforms (per 100 ml)	1 000	0
Chemical Oxygen Demand (mg/l)	75 (i)*	30(i)*
pH	5,5-9,5	5,5-7,5
Ammonia (ionised and un-ionised) as Nitrogen (mg/l)	36	2
Nitrate/Nitrite as Nitrogen (mg/l)	15	1,5
Chlorine as Free Chlorine (mg/l)	0,25	0
Suspended Solids (mg/l)	25	10
Electrical Conductivity (mS/m)	70 mS/m above intake to a maximum of 150 mS/m	50 mS/m above background receiving water, to a maximum of 100 mS/m
Ortho-Phosphate as phosphorus (mg/l)	10	1 (median) and 2,5 (maximum)
Fluoride (mg/l)	1	1
Soap, oil or grease (mg/l)	2,5	0
Dissolved Arsenic (mg/l)	0,02	0,01
Dissolved Cadmium (mg/l)	0,005	0,001
Dissolved Chromium (VI) (mg/l)	0,05	0,02
Dissolved Copper (mg/l)	0,01	0,002
Dissolved Cyanide (mg/l)	0,02	0,01
Dissolved Iron (mg/l)	0,3	0,3
Dissolved Lead (mg/l)	0,01	0,006
Dissolved Manganese (mg/l)	0,1	0,1
Mercury and its compounds (mg/l)	0,005	0,001
Dissolved Selenium (mg/l)	0,02	0,02
Dissolved Zinc (mg/l)	0,1	0,04
Boron (mg/l)	1	0,5

* (i) After removal of algae

Many biological flocculants have the ability to remove heavy metals such as cyanide, chromium, arsenic from solution, so their use can assist with problematic effluents.

IRRIGATION WITH WASTEWATER

2.7. A person who-

(a) owns or lawfully occupies property registered in the Deeds Office as at the date of this notice;

(b) lawfully occupies or uses land that is not registered or surveyed; or

(c) lawfully has access to land on which the use of water takes place, may on that property or land:

(i) irrigate up to 2000 cubic metres of domestic and biodegradable industrial waste water on any given day provided the-

Faecal coliforms do not exceed 1000 per 100 ml;

Chemical Oxygen Demand (COD) does not exceed 75 mg/l;

pH is not less than 5,5 or more than 9,5 pH units;

Ammonia (ionised and un-ionised) as Nitrogen does not exceed 3 mg/l;

Nitrate/Nitrite as Nitrogen does not exceed 15 mg/l;

Chlorine as Free Chlorine does not exceed 0,25 mg/l;

Suspended Solids does not exceed 25 mg/l;

Electrical Conductivity does not exceed 70 milliSiemens above intake to a maximum of 150 milliSiemens per metre (mS/m);

Ortho-Phosphate as phosphorus does not exceed 10 mg/l

Fluoride does not exceed 1 mg/l; and

Soap, oil or grease does not exceed 2,5 mg/l.

(ii) irrigate up to 500 cubic metres of domestic or biodegradable industrial wastewater on any given day, provided the-

(a) electrical conductivity does not exceed 200 milliSiemens per metre (mS/m);

(b) pH is not less than 6 or more than 9 pH units;

(c) Chemical Oxygen Demand (COD) does not exceed 400 mg/l after removal of algae;

(d) faecal coliforms do not exceed 100 000 per 100 ml; and

(e) Sodium Adsorption Ratio (SAR) does not exceed 5 for biodegradable industrial wastewater.

(ii) irrigate up to 50 cubic metres of biodegradable industrial wastewater on any given day, provided the-

(a) electrical conductivity does not exceed 200 milliSiemens per metre (mS/m);

(b) pH is not less than 6 or more than 9 pH units;

(c) Chemical Oxygen Demand (COD) does not exceed 5 000 mg/l after removal of algae;

(d) faecal coliforms do not exceed 100 000 per 100 ml; and

(e) Sodium Adsorption Ratio (SAR) does not exceed 5 for biodegradable industrial wastewater,

if the irrigation of wastewater-

(a) does not impact on a water resource or any other person's water use, property or land; and

(b) is not detrimental to the health and safety of the public in the vicinity of the activity.