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Critical comparison of technologies for small-user water treatment

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THE IMPACT OF water-borne disease on rural communities in South Africa is significant, with diarrhoea alone being responsible for some 43 000 deaths per annum (Pegrum *et al*, 1998) and 20% of all deaths in the one to five age group (Bourne and Coetzee, 1996). These conditions have resulted in the South African Water Services Act of 1997 and the associated Regulations obliging water service authorities to progressively ensure "efficient, affordable, economical and sustainable access to water services" (WSA, Act 108 of 1997).

Considering the above, it is important to determine what type of water treatment processes are appropriate for small, rural communities in South Africa. In small towns and rural communities where surface waters with high colour readily occur, scaled down conventional colour removal water treatment plants are often utilized. However, continuous, successful operation of these conventional water treatment plants seldom occurs, resulting in the provision of drinking-water which sporadically exceeds the South African Maximum Allowable Limits (MALs) for drinking-water. In comparison, it is possible for a small community to run a semi-automated membrane based water treatment plant which prevents this sporadic failure with regard to MALs.

This paper describes the assessment of a membrane based plant at a small, rural town (approximately 250 km from Cape Town) in the Western Cape, South Africa. The raw water of the town is a highly coloured surface water (~200 mg Pt/l) with consistently very poor bacteriological quality. Current water treatment practices are wholly inadequate and, in general, the town is supplied with drinking-water of very poor quality that by far fails South African and international MALs for human consumption.

The assessment was to include comparison with a conventional water treatment plant with regard to plant performance, cost benefits (if any), and the ability of a local community member to operate the plant.

Rural drinking-water treatment considerations

Water treatment in small, rural communities needs to be carefully approached. It is generally found that scaled down versions of conventional city size water treatment plants do not perform well in rural South Africa. The reasons for this include inadequate operator attention, under-equipped operators, under-qualified operators, and increased difficulty of plant operation.

The principal advantages of a membrane-based process are threefold. Firstly, membranes generally act as a fail-safe filter ensuring that the chemical, physical and bacteriological quality of water is always good (i.e. considerably less vulnerable to variable operator attention). Secondly, membranes are able to neutralize pathogens that conventional treatment and chlorination are not able to achieve (e.g. parasites). Thirdly, the semi-automation or full-automation of membrane plants limits operator input requirements. Where pre-treatment is included, wear on the ultra-filtration membranes is significantly reduced. Furthermore, the use of ultra-filtration membranes also significantly reduces the requirement for chemical addition in the pre-treatment step.

Membrane based water treatment plant

The membrane based plant considered is an imported (German manufactured) mobile package water treatment plant designed to condition surface water so as to comply with international water quality standards. The unit incorporates flocculation and pre-filtration, membrane filtration, adsorption and chemical disinfection and treats approximately 2000 l/hr depending on the raw water characteristics. Chemicals used to treat the raw water included those required for aiding flocculation (polyaluminium chloride - PAC and polyelectrolyte), pH adjustment (soda ash) and disinfection (calcium hypochlorite - HTH). In addition, calcium hypochlorite and citric acid were used as cleaning chemicals for the membranes. The membrane based water treatment plant is shown in the following figure (Figure 1).

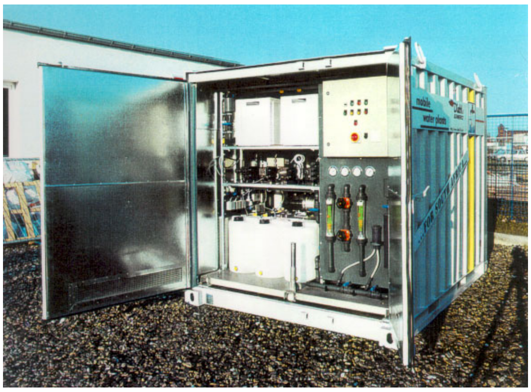

Figure 1. Membrane based water treatment plant

Membrane based plant: installation, monitoring and test results

The membrane based plant was installed at the rural town and a community member with no previous water treatment training or experience was trained within 2 weeks in all aspects of plant operation.

Microbiological and physico-chemical samples were collected by the project team for analysis at the CSIR's Analytical Laboratory. Sample analysis to evaluate plant performance was based on *SABS 241-1999: South African Standard for Drinking Water* (SABS, 1999), which is similar to international drinking-water quality standards.

Typical results obtained from the membrane based water treatment plant are shown in Table 1.

The results obtained during the trial period indicated that the plant performed well, consistently providing a high quality drinking-water that at all times satisfied MALs.

During the five-month assessment period at the rural town, the plant failed on two occasions. On the first occasion the problem was found to be a faulty relay, which was rapidly rectified with the assistance of a local electrician. In the second instance the plant malfunctioned as a result of the failure of an air valve, which was subsequently replaced under CSIR supervision. Hence, the only problems that occurred during the five-month period were trivial and easily rectified. However, in both cases plant downtime was approximately 1 week, which highlighted the requirement for adequate back-up service/support and increased use of local components.

Table 1. Membrane based water treatment plant: typical

Determinant	Raw	Final
Calcium as Ca (mg/l)	0.5	1.6
Alkalinity as $CaCO_3$ (mg/l)	0.0	4.0
Iron as Fe (mg/l)	0.5	0.05
Aluminium as Al (mg/l)	0.4	0.06
Electrical Conductivity (mS/m @ 25 C)	4.7	4.7
pH	4.6	7.2
Total Dissolved Solids (mg/l)	30	30
Turbidity (NTU)	0.44	0.28
Colour (Unfiltered) (mg Pt/l)	250	< 10
Colour (Filtered) (mg Pt/l)	250	< 10

SABS Class 0 (Ideal)	
SABS Class I (Acceptable)	
SABS Class II (Max. allowable)	
Failure SABS Class II	
No SABS guideline	

Determinant	Raw			Final		
Heterotrophic Plate Count (per 1 ml @ 35 oC)	291 ±10000	277 ±10000	291 ±10000	1	3	5
Total Coliform (per 100 ml)	1660	1613	1810	0	0	0
Faecal Coliform (per 100 ml)	193	177	162	0	0	0

Comparative assessment of conventional water treatment plant performance

In order to assess the performance of the membrane based plant it was compared to a nearby conventional plant, which essentially treats the same source as the membrane based plant. This existing water treatment system treats approximately 10 000 l/hr and employs conventional water treatment principles of coagulation, flocculation, sedimentation, sand filtration and disinfection. The performance of this conventional plant would therefore serve as a basis for comparison of the two technology approaches. The conventional water treatment plant is shown in Figure 2.

Typical results obtained from the conventional water treatment plant are shown in Table 2.

Figure 2. The conventional water treatment plant

Table 2. Conventional water treatment plant: typical physico-chemical and microbiological results

Determinant	Raw	Final
Calcium as Ca (mg/l)	1.6	1.5
Alkalinity as $CaCO_3$ (mg/l)	5.3	0.5
Iron as Fe (mg/l)	1.3	0.11
Aluminium as Al (mg/l)	0.62	0.57
Electrical Conductivity (mS/m @ 25 C)	8.0	9.8
pH	6.1	4.7
Total Dissolved Solids (mg/l)	51	63
Turbidity (NTU)	2.5	1.5
Colour (Unfiltered) (mg Pt/l)	300	20
Colour (Filtered) (mg Pt/l)	250	10

Determinant	Raw	Final
Heterotrophic Plate Count (per 1 ml @ 35EC)	3100	6550
Total Coliform (per 100 ml)	1575	90
Faecal Coliform (per 100 ml)	730	28

SABS Class 0 (Ideal)	
SABS Class I (Acceptable)	
SABS Class II (Max. allowable)	
Failure SABS Class II	
No SABS guideline	

The results obtained during the assessment period showed that the conventional plant is highly vulnerable to passing on contaminated treated water to the end-user if not operating optimally. Frequent episodes of treated water quality failing *SABS 241-1999* MALs (i.e. not fit for human consumption) occurred. Both the plant operator and the community confirmed that the plant did not continuously operate at an optimal level.

Cost comparison – membrane based vs. conventional water treatment plant

The cost comparison was based on a water treatment plant capacity of 10 000 l/hr operating for 20 hours/day (i.e. providing a community of 2000 people with 100 L/person/day). Water treatment plants compared included:

- A German manufactured, fully imported membrane based water treatment plant
- A South African manufactured membrane based water treatment plant
- A South African manufactured conventional water treatment plant

Total installed capital cost estimates were obtained from manufacturers of the different water treatment technologies. Operating costs included those related to chemicals, labour, electricity and maintenance and were based on required on-site inputs and information supplied by manufacturers (US\$ 1.00 = ZAR 8.00, April 2001).

The cost comparison revealed that the total installed **capital cost** of the German membrane based plant is significantly more expensive (~ 2.2 times) than a South African conventional water treatment plant. A cost estimate from a South African manufacturer of membrane based plants showed that a saving of at least 15 % over the German plant is envisaged. Furthermore, the cost comparison showed that the membrane based plant shows significant **operating cost** savings over the conventional plant. This can mostly be attributed to lower labour and chemical requirements.

The **Net Present Value** (NPV) based approach relates the cash flow projection of a project over a specific time period

Table 3. Cost comparison input variables

	Membrane	Conventional
PLANT CAPACITY	10 000 l/hr	10 000 l/hr
TOTAL INSTALLED CAPITAL COST	\$88 750 (German) \$75 000 (SA)	\$40 000 (SA)
OPERATING COSTS		
Chemicals		
Chemical Costs		
PAC	\$1.12/kg	\$1.12/kg
Polyelectrolyte	\$1.12/kg	-
HTH	\$1.75/kg	\$1.75/kg
Soda Ash	\$0.30/kg	\$0.30/kg
Citric acid (membrane cleaning)	\$3.75/kg	-
HTH (membrane cleaning)	\$1.75/kg	-
Chlorine gas	-	\$1.75/kg
Chemical Dose		
PAC	35 mg/l	77 mg/l
Polyelectrolyte	0.1 mg/l	-
HTH	0.5 mg/l	2 mg/l
Soda Ash	50 mg/l	50 mg/l
Citric acid (membrane cleaning)	0.1 mg/l	-
HTH (membrane cleaning)	0.1 mg/l	-
Chlorine gas	-	2 mg/l
Chemical Wastage		
% of chemical usage	5 %	5 %
Electricity		
Cost	\$0.025/kWh	\$0.025/kWh
Plant power consumption	8.5 kW	10 kW
Labour		
Rate	\$2.34/hr	\$2.34/hr
Plant operation, maintenance, etc	1 hr a day	2 hrs a day
Additional plant optimisation	-	2 hrs a day
Maintenance		
% of capital cost	5 %	5 %

(in this case 10 years). The NPV assessment captures both the capital and operating costs for the two alternative technologies and relates these as one financial sum in terms of today's money. This approach therefore clearly indicates which alternative is financially more viable.

The NPV costing assessment showed that due to the perceived higher risk of using the German membrane based plant (the manufacturers are located in Germany, with no formal back-up service/support at present in South Africa), there is no financial gain in using the German membrane based technology.

The NPV cost comparison, however, showed that the use of a locally manufactured South African membrane based plant (with lower capital costs and less risk), yields a nominally positive NPV of $2 700. This result indicates that it is financially advantageous to use a membrane based system. It is important to note that this observation is contrary to conventional thinking by funders and local government engineers, where the initial higher capital costs of membrane based plants results in a general opinion that membrane processes are simply too expensive.

Conclusions

From analysis of both plant performance and the cost comparison, the following points should be noted:

- The principal advantage of the membrane based treat ment process is that it provides consistently high quality drinking-water and it is not possible for the system to pass on partially treated water that fails bacteriological standards. It has the additional advantage of ensuring removal of difficult to remove pathogens such as *Giardia* and *Cryptosporidium* parasites that are likely to be present in poor quality surface waters. Furthermore, it has been shown that a local community member is able to operate the treatment process on an ongoing basis.
- An issue of primary importance with regard to membrane based plants in rural communities is the require ment of adequate back-up service should technical failures occur.
- The principle advantage of the conventional treatment process is that it is well understood and that local engineers and water treatment plant operators are comfortable with the process.
- The principal disadvantage of the conventional process is that it requires full time skilled operator attention, and that any lapse in such attention is likely to result in drinking-water "unfit for human consumption" being passed on to the consumer. A further disadvantage is that conventional treatment is not capable of removing parasites which are likely to occur in poor quality surface waters.
- Financial assessment shows that:
  - Where locally manufactured back-up service exists, the Net Present Value approach shows that the membrane based plant has financial advantages over the conventional water treatment plant.
  - Where no local back-up service is available (an imported unit with no local back-up service), the associated risk results in a financially non-competitive circumstance.
- Regardless of which water treatment system is used, a structured "drinking-water quality sampling programme" should be initiated at small water treatment works where raw water, treated water, and selected reticulation network sites are tested on at least a monthly basis for physico-chemical and bacteriological quality. Those data should be the basis of ongoing water treatment plant performance review.

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