PERFORMANCE TESTING OF OPERATIONAL BASIN SOLAR STILLS

I Goldie · A Theunissen · J Bonthuys · V Cloete

WRC Report No. 1392/1/04

Water Research Commission

PERFORMANCE TESTING OF OPERATIONAL BASIN SOLAR STILLS

Report to the
WATER RESEARCH COMMISSION

by

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EXECUTIVE SUMMARY

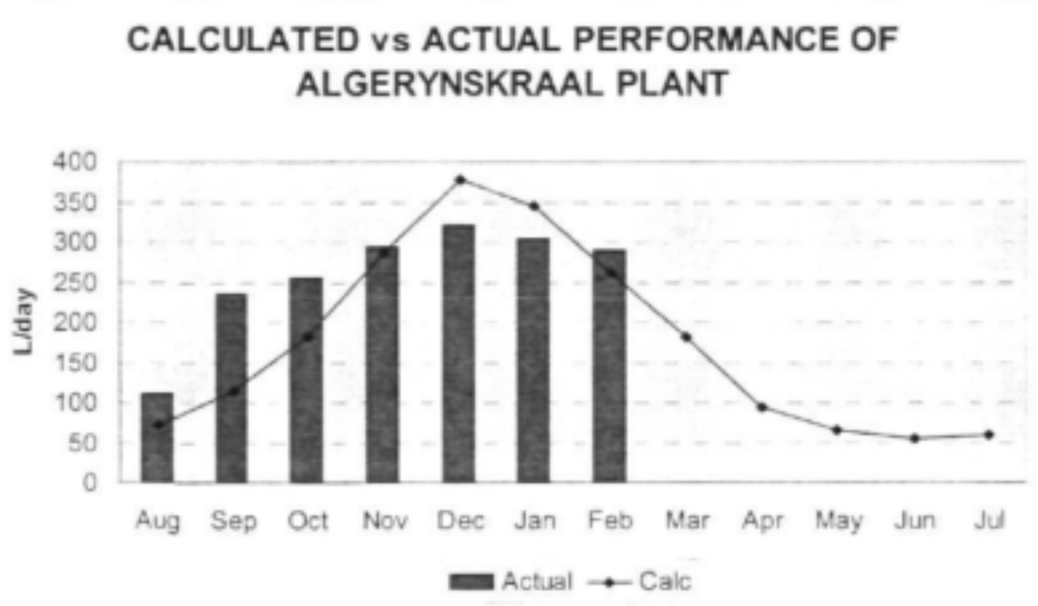
INTRODUCTION AND OBJECTIVES

The effective use of solar still plants for the production of potable water for small, rural communities in arid regions in Southern Africa has been demonstrated in an earlier WRC project. It has been shown that this small-scale desalination technology offers an economic alternative to fresh water especially where it is not used for agriculture and gardening purposes. Three aspects of the technology requiring further investigation have however been identified by interested parties. These are the expected life cycle (durability) of equipment, the bacteriological quality of the product water, and performance improvement to increase wintertime water supply without increasing water production costs. The project objectives were formulated from the above, namely to (i) determine the field durability of basin solar still plants in terms of critical components, (ii) quantify the bacteriological quality of solar distilled water produced under different environmental and seasonal conditions, and (iii) reduce the unit cost of potable water through improvement of winter productivity. In addition, a socio-economic study on a target community's perception of the suitability of the technology was included.

DURABILITY OF BASIN SOLAR STILLS

Solar still units from an experimental solar still plant at Kerkplaas in the Klein Karoo were used for the durability study. Units were disassembled and inspected at the University of Stellenbosch after two years of operational use in order to perform a thorough assessment of their structural condition. It was found that nearly all defects could be related to the solar still liner.

The rigid polypropylene liners (rPP) of some solar stills showed clear signs of degradation, and a number of solar still units leaked, generally due to ruptured heat-welded joints of the liner. The rPP liners were replaced with flexible polypropylene (fPP) liners, which cost less per unit area and did not exhibit visible degradation during operation after a period of two years. fPP was subjected to accelerated weathering investigations and its suitability as a stable and inert liner, capable of lasting for a minimum operational life of ten years, was confirmed. A further solar still design modification was also made, whereby the liner was not cut and then heat welded, but instead, tightly folded and fixed to the solar still frame, thus improving ease of construction and waterproofing. The commercial manufacture of solar stills based on the above new method was subsequently transferred to a commercial company (Solardome SA in Stellenbosch), which manufactured the solar still units for a new solar still plant in the Klein Karoo. No negative performance impact was seen when comparing the productivity of this plant to calculated values based on the productivity of earlier solar still designs (see Figure below).



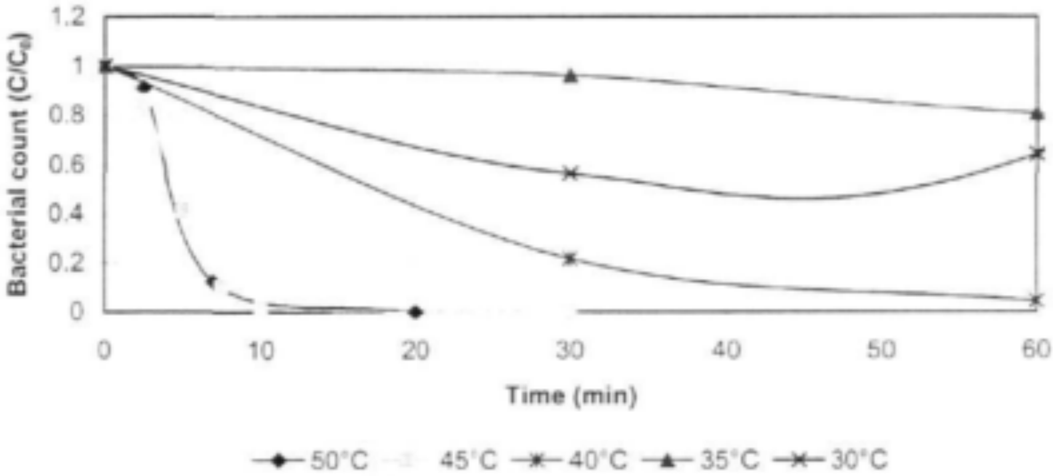
All the stills had calcium carbonate scale deposits on the liner. Although the presence of scale can negatively influence the productivity of a solar still, the more serious problem experienced was the tendency of the scale to block the overflow outlets of the stills, which caused the brackish feed water to overflow into the product water pipe system instead of into the waste system during flushing. Literature studies further indicated that exposure of the feed water to specific metals or metal alloys can potentially alter the scaling characteristics of hard water. This option was further investigated by placing zinc metal rods inside the basins of operational solar stills. A distinct visual difference in scale was noted between rows with and without the zinc rods – the former had a finely divided white powdery appearance (referred to as 'softer' scale), while the latter looked like hard, large flakes. The resulting 'softer' scale could be flushed out of the stills more easily, and a design modification was successfully implemented to eliminate scale-related feed water distribution problems.

MICROBIOLOGICAL WATER QUALITY OF BASIN SOLAR STILLS

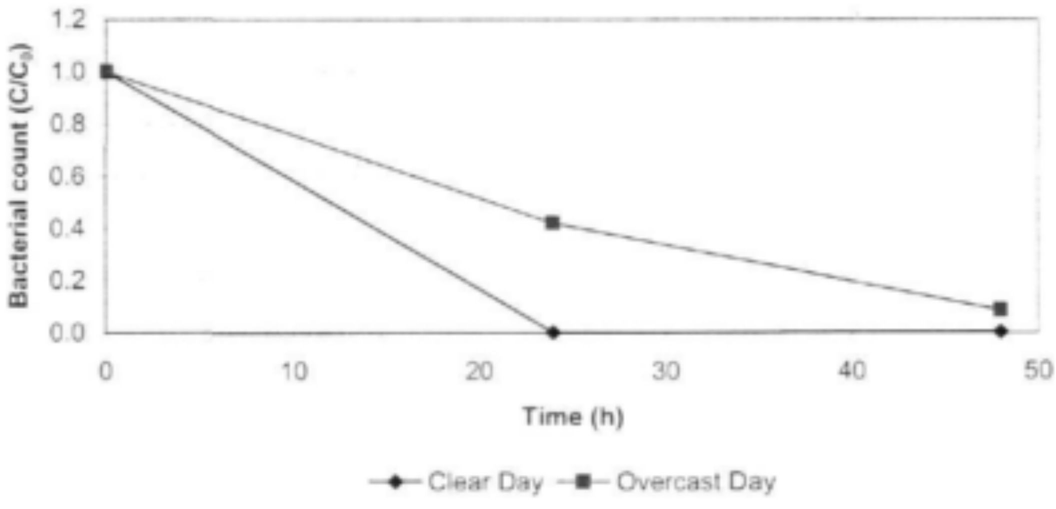
This part of the study aimed to determine the effectiveness of solar basin stills as a means of pasteurising microbiologically contaminated groundwater, simulated on laboratory scale by a microbiological indicator (an *E.coli* strain). The effectiveness was determined experimentally by measuring (i) the transfer of microbial contamination to the distillate and (ii) the microbiological activity inside the basin of an operational solar still. Experimental results were verified via a field test.

During the laboratory investigation it was found that the microbial count in the distilled water was zero in all cases, i.e. at all temperature settings investigated and for all sampling intervals. No transfer of microbial contamination therefore occurred from the basin of the solar still to the distillate or product water.

The microbial activity in the feed water inside the still basin is temperature dependent, and where inactivation occurs above a specific threshold temperature. This threshold temperature correlates well with the cardinal temperature profile of the specific microbe. Above the threshold temperature, effective thermal inactivation of the microbiological indicator takes place. At lower temperatures, the temperature obtained inside the solar still is not sufficient to inactivate the pollutant (Figure below).



The laboratory results were confirmed in a field test. Temperature profiles show that on clear days maximum temperatures of 40°C was reached, which is in sharp contrast to the overcast days when maximum temperatures between 25 and 30 °C were reached. The impact of the difference in temperature is reflected in the decay curves, where the microbiological indicator could not be completely inactivated after 48 hours (Figure below). As the water temperatures fall well within the cardinal temperature range of the bacterium, it can be concluded that the natural die-off rate of the microbiological indicator, together with its exposure to UV-A, could have contributed to the reduction in the bacterial count.

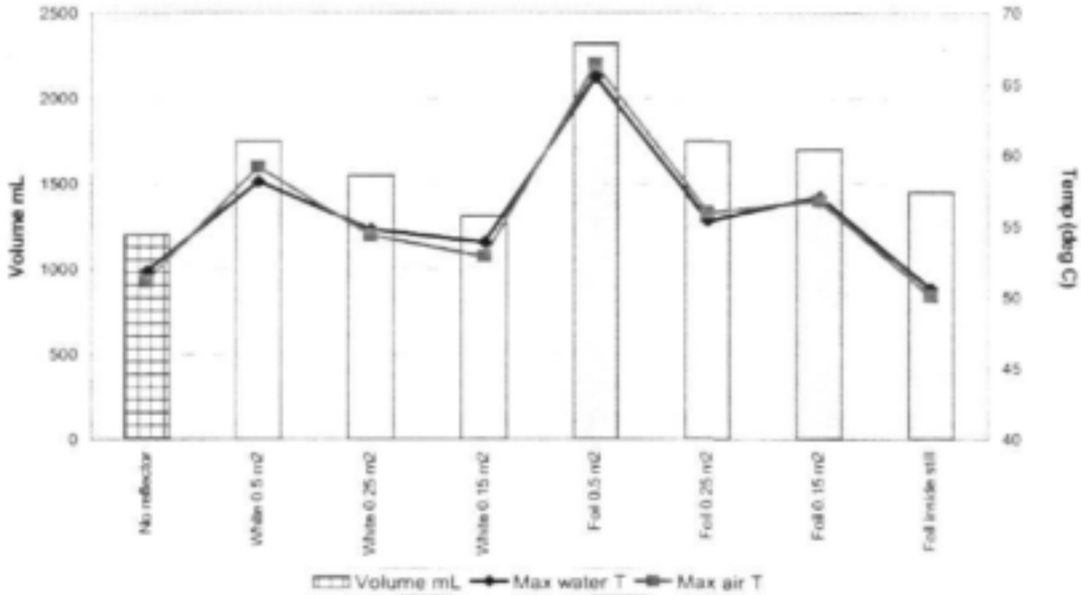


The major advantage of the basin solar still, therefore, lies in its design, as *E.coli* contamination present in the basin of the solar still cannot be transferred to the product water through the vapour phase. It can therefore be said that, although inactivation in the basin is via thermal inactivation or solar irradiation, the principal mechanism for cleaning the water is distillation. Successful inactivation of *E.coli* does however not necessarily imply inactivation of more resistant microbes such as the protozoa *Giardia* and *Cryptosporidium*, and spore-forming bacteria, as the latter require higher temperatures than are reached during winter in solar stills for thermal inactivation. As a result, these more resistant microbes may still be present in the solar basin after complete inactivation of *E.coli*.

IMPROVEMENT OF WINTER PRODUCTIVITY

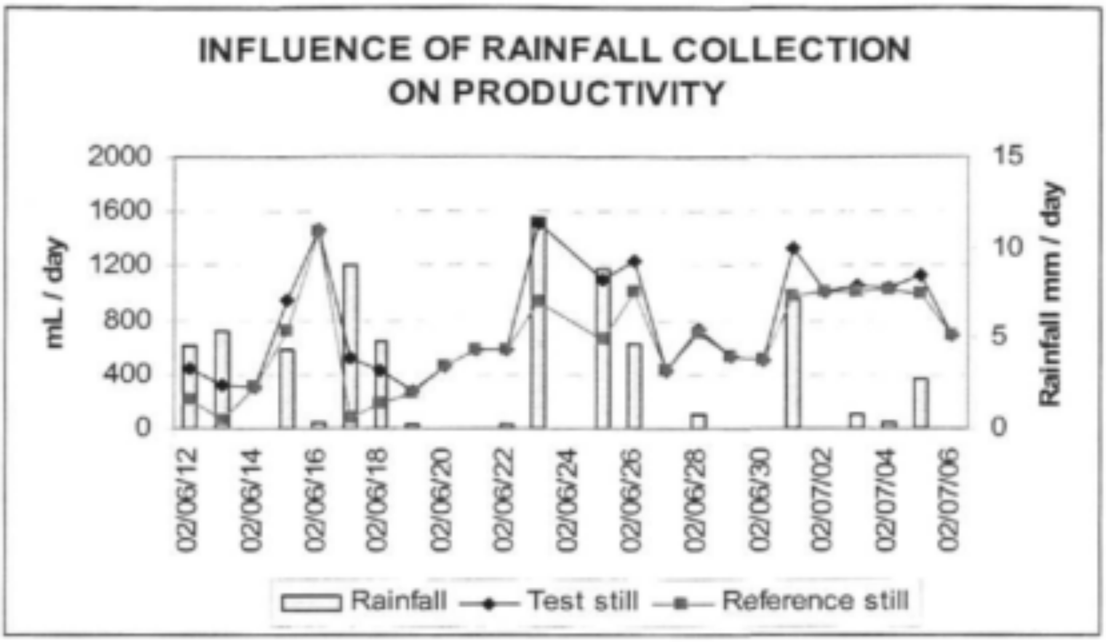
Two performance enhancement techniques were investigated to improve winter productivity, namely (i) the addition of reflecting materials to the still to increase the amount of incident radiation, and (ii) the integration of rainfall harvesting, especially for potential use in winter rainfall regions.

A productivity increase of up to 100% was recorded in the laboratory with a large, aluminium foil-coated reflector placed vertically behind an experimental solar still (see Figure below).



Unfortunately the productivity increase measured in the laboratory did not translate into significant productivity gain in the field, where an average increase of only about 5% in distilled water volume was recorded. This was far less than what was anticipated, and only slight temperature increases in basin water temperatures were noted. Further work on reflectors was consequently abandoned because the expected productivity increase of about 5% during the winter months only did not translate into a cost reduction of the product water. Further capital cost increases in terms of larger sized stands in solar still plants are also foreseen. These factors make the use of reflectors in the current configuration economically unattractive.

Experiments to determine the efficiency of rainfall collection from solar still covers were conducted by addition of an aluminium gutter to the front of a test solar still. Distilled water was collected in a separate container. Rainfall over specific test periods was recorded at the test site, while another adjacent solar still with similar productivity was used as control. Results showed that rainwater collection on the solar still cover could be used to increase the output from a solar still (see Figure below).



The most important practical problem at the community plant was the rapid collection of windblown dust and sand in the gutter, and consequent transfer thereof into the blending and pumping infrastructure of the plant, which caused product water contamination and pipe blockages and required constant monitoring. At the specific plant it was more cost-effective and practical to upgrade and integrate the existing rainfall harvesting infrastructure from rooftops with the solar still collection tanks.

SOCIO-ECONOMIC ASPECTS

As the technology demonstration phase of the Kerkplaas solar still project reached its conclusion, with the end of this WRC project, an additional aim was added to the project, namely to study the socio-economic impact of such a project on a typical target community. Such a study was conducted, independent from the technical project, by the Health Sciences Department of the Peninsula Technikon. From their findings it was concluded that, from the local community's point of view, the project at Kerkplaas had been successful as that they are reaping the results of the project. The community was however clearly not empowered on how to absorb and execute activities and responsibilities that had to date been executed by the project team. This shortcoming has to be addressed as part of the plant transfer process.

CONCLUSIONS

From the results of accelerated ageing and weathering tests it is shown that flexible polypropylene (fPP) is best suited for use as a liner material for operational basin solar stills. It exhibits better resistance to degradation and its is more chemical inert than the previously used rPP. It has the further practical advantage of allowing easier and improved incorporation into the still during construction, which can limit or, in cases, eliminate basin leaks during operational use. It has further been shown with a newly constructed solar still plant that the performance of solar stills is not negatively affected by the use of such flexible polypropylene liners.

Scaling will occur inside the solar still basin in cases where it is used to desalinate hard water. It was determined that a combination of plant layout design and exposure of the feed water to specific types of metal or metal alloys can substantially change the physical characteristics of the scale and so reduce the amount of scale present in the solar still during operational use.

Experimentally it was shown that, due to the mechanism of distillation, microbial contamination in feed water cannot be transferred to the product water of the solar still. Therefore, even if inactivation of microbial contamination in the basin of the solar still is ineffective, the pathogens will not be transferred to the product water. If a microbial contamination (e.g. faecal contamination) is introduced into the water system at a later stage, such contamination will however be blended back into the final water that is stored in the storage tank.

The microbial activity in the feed water <u>inside</u> the still basin is temperature dependent. Inactivation occurs above a specific threshold temperature. This threshold temperature correlates well with the cardinal temperature profile of a specific microbe. Above the threshold temperature, effective thermal inactivation of the pollutant takes place. At lower temperatures, the temperature needed inside the solar still is not sufficient to inactivate the pollutant. On the contrary, the temperatures can be conducive its growth.

Laboratory testing showed that solar still productivity may be increased by 100% or more, depending on the type and area of a reflector used. It was found that a reflector of approximately equal area to that of the solar still cover, and covered with aluminium foil, yielded the best results. In field testing under typical winter conditions of low solar radiation, the highest productivity gain achieved was however only 5%, which did not allow for an economically viable design change to be implemented.

A simple design modification, whereby rainfall collection on the solar still cover could be carried out, was demonstrated at a field test site. The lack of sufficient meteorological data, which takes into account all variables associated with rainfall, made it impossible at this stage to express the productivity gain in terms of mm precipitation. The design change was nonetheless implemented at a community plant, but it affected the product water quality negatively in that bird droppings, dust and physical particles, that inevitably collect on the solar still covers, were now washed into the plant and caused the product water to become turbid and contaminated. This modification was therefore also not completed, although the combination of the storage tanks for solar still product water and rainwater (collected on nearby roofs) was successfully implemented.

RECOMMENDATIONS

Flexible polypropylene is a most suitable liner material for basin solar stills due to its chemical and physical stability as well as its relative ease of processability during construction, and is therefore recommended as a standard liner for basin solar stills.

The hardness of the feed water plays a role in the design of a solar still plant, as it will determine the need for water softening devices. It is recommended that the cascade-type plant layout not be used with feed waters with high scaling potential. In such cases the overflow from each still should be taken directly to waste to minimise the risk of scale blockages.

Appropriate operation of solar stills is necessary to prevent accidental transfer of microbial contamination from the basin to the distillate, or to the end-user. During operation the following should be heeded: (i) avoiding a spray or mist inside the still whereby the microbes can be transported from the bulk water to the collector duct, (ii) draining the basin regularly to prevent concentration effects and (iii) preventing the re-use of the basin water for other household purposes. Preventative disinfection measures should always be taken in cases where solar distilled water is blended with raw feed water to ensure that any microbiological contamination found in the community storage tank is eliminated.

Due to the dependence of the pasteurization effectiveness of the open basin solar system on minimum weather specifications, the basin solar still should not be promoted in the market as a vehicle for the pasteurization of faecal contaminated water.

The use of reflectors with the current basin solar still design is not recommended, as no economic advantage in terms of product water costs can be expected. Integration of product water from a solar still plant with the rainfall collection infrastructure can be considered in winter rainfall areas, but this will first require that disinfection procedures for the water in the storage tanks be put in place.

With the implementation of new solar still projects, as with all such types of projects, it is essential to involve the community from project onset to completion. It is therefore recommended that community members be present at all decision making meetings that will determine the current and future operation of the particular plant, thereby ensuring their continued commitment to the general good maintenance and operation of the plant.

ACKNOWLEDGEMENTS

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"DURABILITY AND PERFORMANCE TESTING OF OPERATIONAL BASIN SOLAR STILLS, INCLUDING MICROBIOLOGICAL WATER QUALITY CHARACTERISATION"

The Steering Committee responsible for this project consisted of the following persons:

Dr G Offringa	Water Research Commission (Chairman)
Mr M Marler	Development Bank of Southern Africa
Mr CS Crawford	Department of Water Affairs and Forestry
The late Prof W Engelbrecht	University of Stellenbosch
Prof RD Sanderson	University of Stellenbosch
Mr ML Kovensky	McCracken Solar Stills (Pty) Ltd
Mr JA du Plessis	University of Stellenbosch
Mr SG van der Merwe	Eden District Municipality
Mr Jacob Seconna and his team	Health Sciences Department, Peninsula Technikon
Dr P Engelbrecht	Council for Scientific & Industrial Research (CSIR)

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This project was only possible with the co-operation of several individuals and institutions. The authors therefore wish to record their sincere thanks to the following persons:

The late Prof WJ Engelbrecht	University of Stellenbosch
Prof RD Sanderson	University of Stellenbosch
Prof GM Wolfaardt	University of Stellenbosch
Mr SG van der Merwe	Eden District Municipality
Mr ML Kovensky	McCracken Solar Stills (Pty) Ltd
Mr R Heneke	University of Stellenbosch
Mr C Maart	University of Stellenbosch
Solardome SA	
The Kerkplaas Community	Kerkplaas, Ladismith

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CHAPTER 1

INTRODUCTION AND OBJECTIVES

1.1 INTRODUCTION

The effective use of solar still plants for the production of potable water for small, rural communities in arid regions in Southern Africa has been demonstrated in an earlier WRC project. [It is strongly recommended that this report be read in conjunction with the WRC report 1032/1/03 entitled *Cost effective solar still units for drinking water provision in remote, rural areas of South Africa*]. It has been shown that this small-scale desalination technology offers an economic alternative to fresh water especially where it is not used for agriculture and gardening purposes. In many of the target communities other desalination techniques cannot be considered due to either the small size of the community, the lack of electricity supply, or the incapability of the community to manage/maintain sophisticated purification equipment. As a consequence of this research, many local water provision authorities in the Western and Northern Cape Provinces, as well as the Development Bank of South Africa, have expressed keen investment interest in the implementation of this technology. The Department of Water Affairs and Forestry (DWAF) also recently funded another solar distillation demonstration plant for the community of Algerynskraal in the Klein Karoo.

Three common factors requiring further investigation have however been identified by the interested parties. These are:

(i) the expected life cycle (durability) of equipment,
(ii) the bacteriological quality of the product water, and
(iii) improvement of winter productivity, to increase water supply without increasing water production costs.

Although thorough material characterisation (including accelerated ageing tests) has preceded field testing of solar stills, data based on operational observations is required to determine actual component degradation. This data will also benefit maintenance management, e.g. accurate determination of component stock levels of components.

Microbiological quality of the product water from small water treatment plants is normally monitored by sampling and analysis by the responsible local water supply authority. Because solar distillation technology can be regarded as a relatively new technology in the South African context, a more thorough and scientific investigation into the presence of harmful microbiological contaminants in the product water is required to identify potential application limitations of the technology.

Winter productivity of a solar still unit in the Southern African context can decrease by about 90% from high summer to mid-winter. It has been shown both in literature and experimentally that the seasonal use of removable reflectors attached to the solar still frame can limit the impact of this problem. Additionally, winter rainfall harvesting, in combination with a solar still plant, can also increase the community water supply capacity. These two aspects thus required further investigation.

1.2 OBJECTIVES

The project objectives are formulated from the identified areas that require further investigation, as mentioned in the preceding paragraphs:

(i) Determine the field durability of basin solar still plants,

(ii) Quantify the microbiological quality of solar distilled water produced under different environmental and seasonal conditions, and

(iii) Reduce the unit cost of potable water through improvement of winter productivity.

CHAPTER 2

DURABILITY OF BASIN SOLAR STILLS

2.1 BACKGROUND

Solar still units from an experimental solar still plant at Kerkplaas in the Klein Karoo were used for the durability study because their design in terms of performance had already been optimised in an earlier project (Goldie et al, WRC project K5/1032). These units had been exposed to operational conditions for at least two years, with some in use for more than four years. All units were taken to the University of Stellenbosch for disassembly and inspection in order to perform a thorough assessment of their structural condition. In order not to disrupt fresh water provision to the community, these actions were staggered over a period of two months during the winter of 2002, when rainwater was available as alternative drinking water supply. The following observations were made during the above inspection:

2.1.1 Structural integrity

The hollow, rigid polypropylene liners of four-year old solar stills showed clear signs of degradation above the basin water line (see Figure 1). This was a confirmation of the unsuitability of this type of liner for solar still application, and an important additional motivation for its replacement with flexible liners in newer solar stills.

A number of solar still units leaked, generally due to ruptured heat welded joints of the polypropylene liner. It was noted that these leaks appeared after cleaning and other inspection operations that involved transport and handling of the stills (cleaning on-site is ideal, but often impractical).

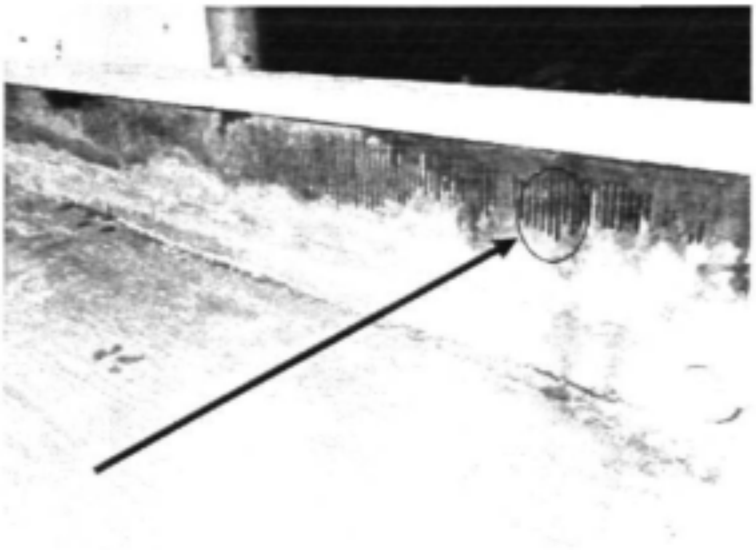

Figure 1: Degradation of the rigid polypropylene liner above the basin water line.

Leaks caused some of the wooden still frames to rot, which in turn caused them to disintegrate when moved off their stands (see Figure 2). In many cases the frames had to be replaced.

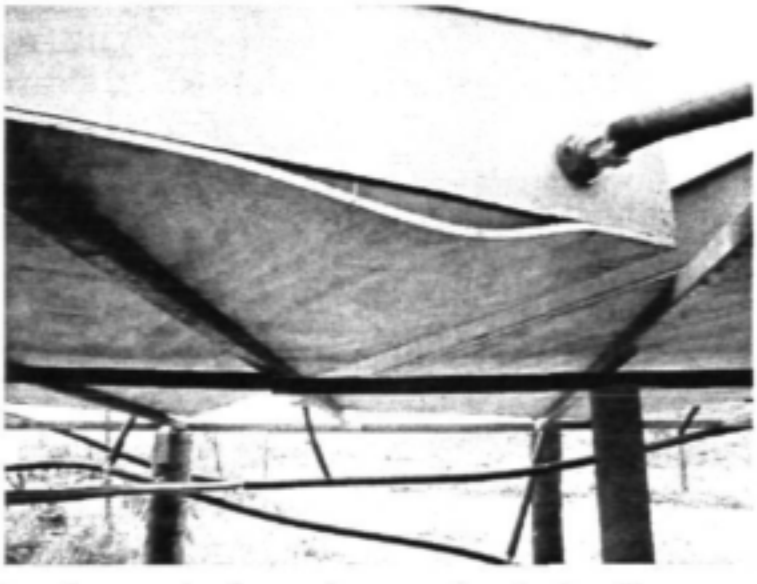

Figure 2: Disintegrating wooden frame of an operational solar still.

2.1.2 Scale formation

The presence of scale can negatively influence the productivity of a solar still by up to about 30% (Goldie) because of the lesser degree of 'blackness' of the liner, causing less efficient heat transfer from the liner into the saline water. A more serious problem experienced with scale was however its tendency to block the overflow outlets of the stills, which caused the brackish feed water to overflow into the product water pipe system instead of into the waste system during flushing (see effect on TDS of product water in Figure 3).

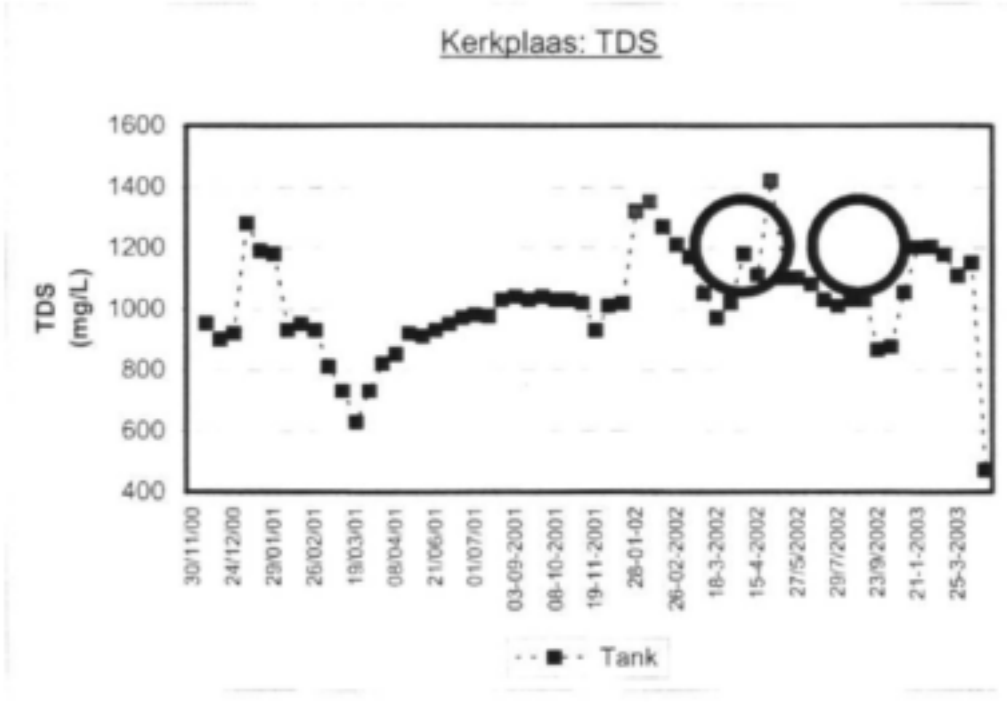

Figure 3: Effect on TDS after scale blockage of overflow feed piping.

All the stills had scale deposits on the liner. These deposits were identified by X-ray diffraction spectroscopy as mainly the aragonite form of calcium carbonate. The extent and appearance thereof varied, depending on whether there was metal in contact with the saline water and algae present in the basin, as well as the specific still position in the plant.

Stills with aluminium as internal support for the liner and with contact between the metal and the saline feed water had coarse, flaky scale deposits (Figure 4), which was easy to remove from the liner surface.

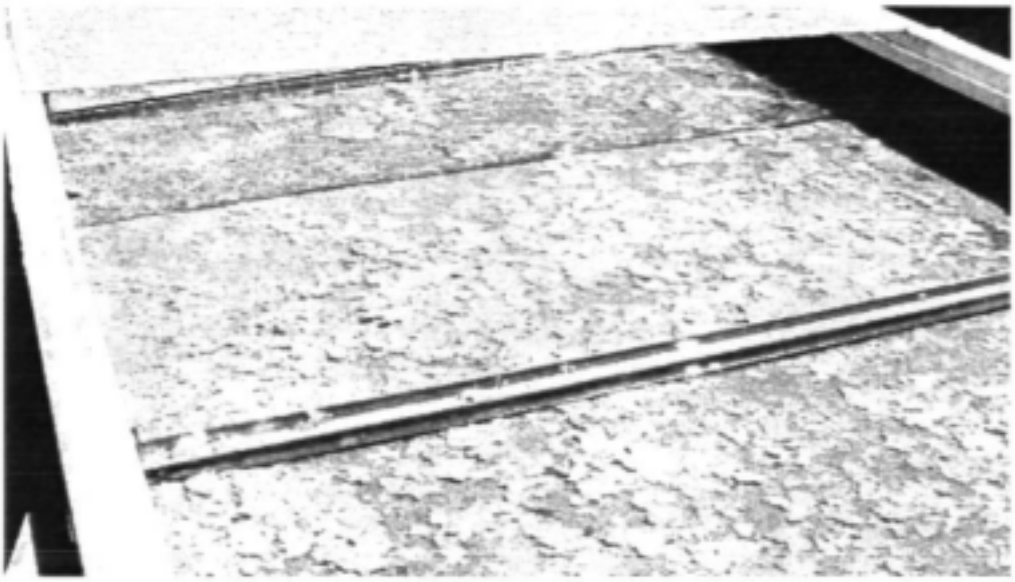

Figure 4: Scale deposit inside solar still with aluminium liner support rods.

Stills without aluminium support beams inside the basin generally had fine, sticky scale, which was difficult to remove and had to be scrubbed off manually. The tendency for scale formation on the water surface of these stills was also noted.

Algae growth was observed in the first of the cascading rows of solar stills, which receive feed water after the two inline filters. This was attributed to poor filter management, which allowed algae from the feed dam to slip past the filter (possibly during cleaning). The inline cartridge filter was also not protected against direct sunlight, which stimulated algae growth in the filter itself.

2.2 CORRECTIVE ACTIONS

Specific corrective actions were taken after the observations mentioned in the preceding paragraphs.

2.2.1 Polypropylene liner

The solar still liner is a critical component of the solar still, both in terms of performance (its degree of blackness influences productivity) as well as functionality (it contains the saline water inside the basin). Polypropylene had earlier been identified as a suitable liner (Goldie et al, WRC project K5/1032) because:

- It is commercially available in a black colour (necessary for good heat absorbance);
- Its unit cost is relatively lower than other liner options such as silicone and fibreglass (less than R40/m^2 in 2001);
- It is thermally stable over the application temperature range of ambient to a maximum of 130 °C (no degradation when analysed by DSC and TGA);
- Screening tests indicated that is possesses good chemical stability (no corrosion in boiling saline water);
- It exhibited chemical inertness during screening tests (no volatile components when analysed by GCMS and HPLC) and
- It could be shaped into the liner configuration.

Two important aspects of the liner can however be identified from par. 2.1.1 as requiring further investigation, namely durability under operational conditions (i.e. its resistance to the type of degradation as shown in Figure 1) and robustness (so that it does not start to leak during O & M operations). Being the only component of the still that may not be freely available for replacement in stills in rural areas highlighted the need to address these two factors.

The first step was to discard the rigid polypropylene (rPP) sheets as a liner option because of their irreparable degradation during operational use. This type of liner was also difficult to heat weld at the joints being flat, hollow sheets. This also contributed to problems with leaks at the joints. Instead, flexible polypropylene (fPP) liners, which cost less per unit area and did not exhibit visible degradation during operation were phased in as the standard liner material. fPP was therefore subjected to analytical investigation at the Institute for Polymer Science, University of Stellenbosch to confirm its suitability as a liner material, capable of lasting for a minimum operational life of ten years.

It was found that fPP contains four non-volatile additives, namely Tinuvin 327 (0.083%), Irganox 1010 (stabilizer - 0.169%), Irgafos (0.049%) and Irgafos 168 (0.499%). Analytical methods were developed to accurately quantify the presence of these additives in a 5% saline solution in the solar still basin (detection limit 0.5 mg/L additive *relative to the fPP). None of the above additives could however be detected by HPLC in* the brackish water after the liner was exposed to 50 °C in a 5%-saline solution for a one-month period. After six months at 50 °C, however, Tinuvin (0.0006%) leached out into the saline solutions. No other additives were detected in the saline water. As Tinuvin is a non-volatile stabiliser, it cannot contaminate the distilled water as it will not evaporate with the water. Furthermore, it carries FDA approval for use in food packaging, thus further lessening risks if consumed by humans.

After subjecting the liner to accelerated QUV and Xenon arc weathering testing simulating a ten-year operational period, no traces of cracking, crocodile skin or chalking could be found. The gloss on the fPP test samples had however deteriorated by about 50%, but this is a non-functional property for the liner application.

From the above it was concluded that, in terms of stability and ageing properties over a ten-year period, the fPP liner was acceptable for use as liner in solar stills.

After fPP had been identified, the construction methodology of a solar still unit was addressed to improve its waterproofing properties. Thus far heat welding was used to seal fPP liners (which worked better because of the thicker liner sheet), but it still proved difficult to make an all-round watertight seal. A design modification was then made, whereby the liner was not cut and then heat welded but instead, tightly folded and fixed to the solar still frame. To achieve this, the cover panel had to be changed to allow the fPP liner to be tightly fixed underneath its aluminium frame. This modification had the additional benefit that on-site in-place removal of the glass cover and / or liner was significantly simplified (see Figure 5 below). It also meant that the liner was kept intact, with no heat welded joints or cuts, apart from the water inlet / outlet holes.

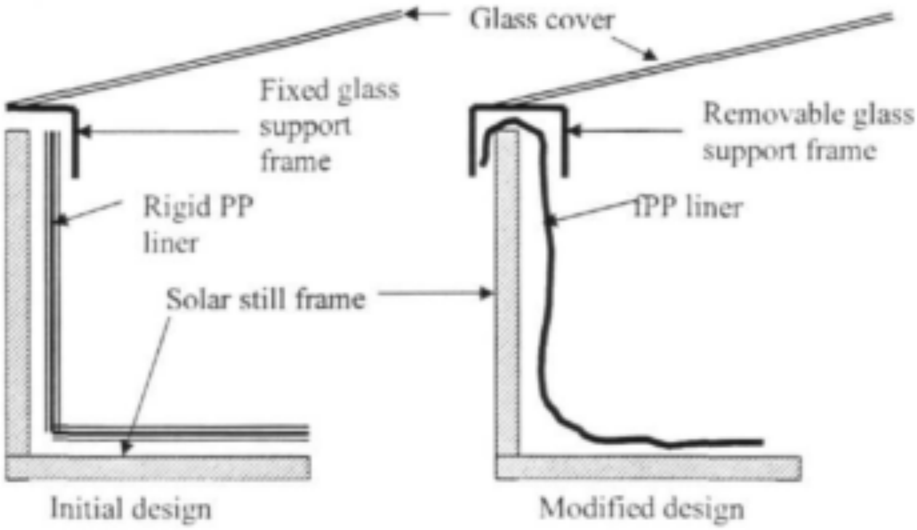

Figure 5: Modification of solar still design to eliminate liner leaks (cut-through side view).

The commercial manufacture of solar stills based on the above method was subsequently transferred to Solardome SA in Stellenbosch, a local commercial company well-experienced in the manufacture of solar powered equipment. Simultaneously, another solar distillation demonstration plant was commissioned during May 2003 for the DWAF at Algerynskraal near Ladismith in the Klein Karoo (Figures 6 and 7). The solar stills in this plant all incorporated the modified design discussed above and were manufactured by Solardome. No negative performance impact was seen when the productivity of this plant was compared with calculated values based on the productivity of earlier solar still designs (Figure 8).

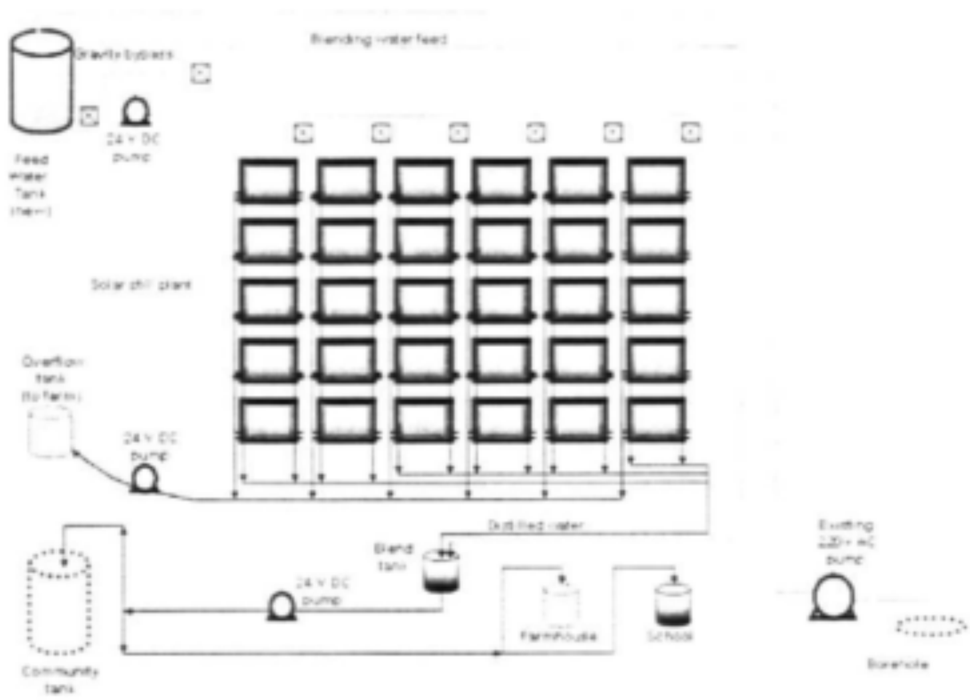

Figure 6: Schematic layout of DWAF solar still plant at Algerynskraal.

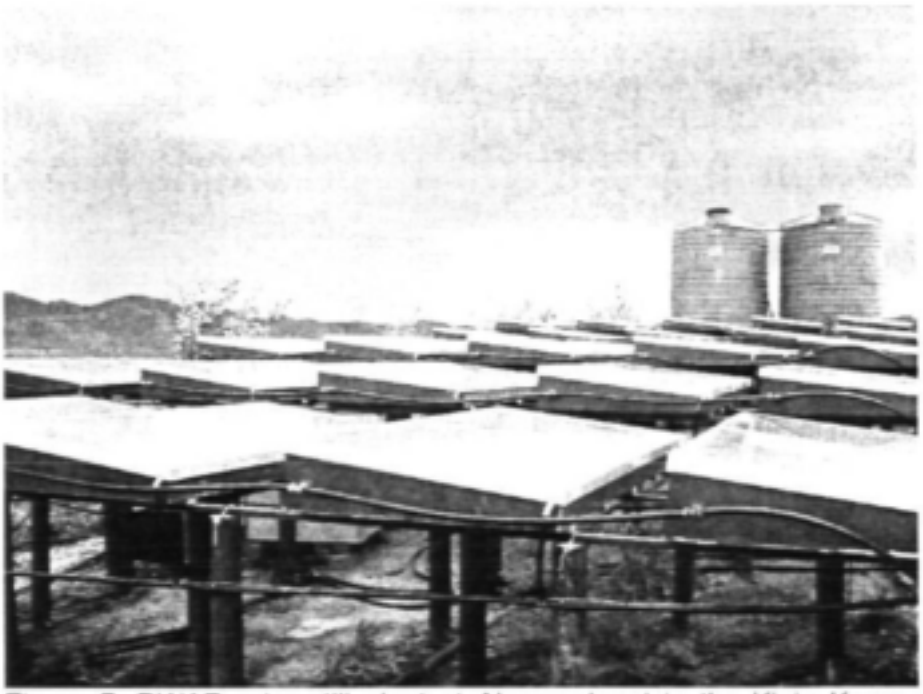

Figure 7: DWAF solar still plant at Algerynskraal in the Klein Karoo with Solardome-manufactured solar stills.

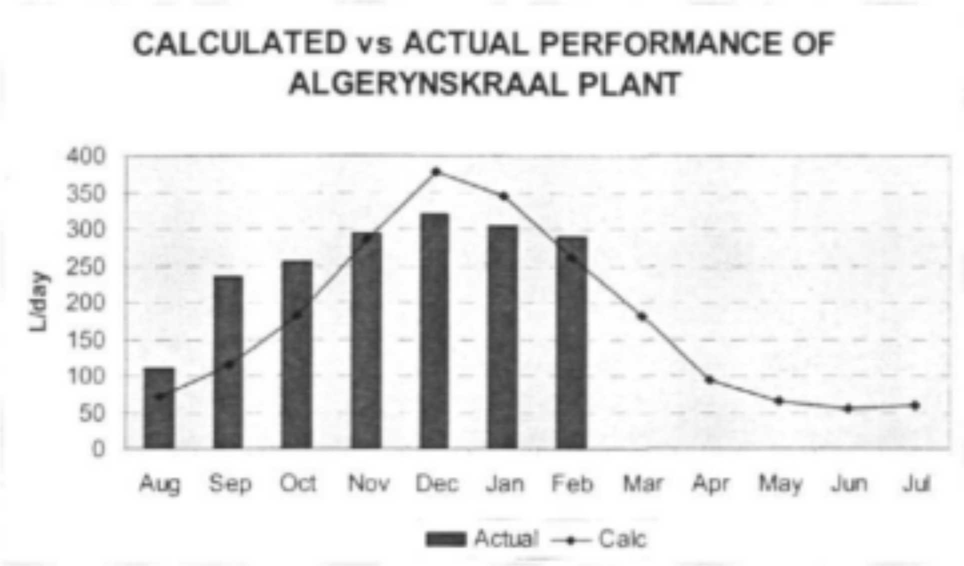

Figure 8: Performance data for Algerynskraal solar distillation plant (Actual: recorded productivity with modified solar stills, Calc: calculated productivity based on previous solar still design).

2.2.2 Scaling

The extent of scale formation together with the associated performance problems of solar stills were discussed in par. 2.2.1. It was highlighted that the main problem was that of scale on the surface of the water, which accumulated and gradually started to block the overflow pipes of the basins. Due to the cascade design of the plant, flush water started to enter the product water supply system, causing the TDS to rise (Figure 3). The following investigations and corrective actions were taken:

- An investigation into appropriate water softening devices were undertaken, and a number of commercial zeolite-devices were identified. It was however decided to look for other alternatives and not to integrate such sophisticated devices that would complicate plant O & M.
- Further literature studies indicated that exposure of the feed water to specific metals or metal alloys can potentially alter the scaling characteristics of hard water (Coetzee et al), so that removal of the scale can be removed (flushed out) more easily. This option looked promising and was further investigated by placing zinc metal rods inside the cleaned basins of two rows of solar stills at the Kerkplaas plant. A distinct

visual difference in scale was noted between rows with and without the zinc rods – the former had a finely divided white powdery appearance (referred to as 'softer' scale), while the latter looked like hard, large flakes.

- The resulting 'softer' scale could be flushed out of the stills more easily, which confirmed that it had different crystalline properties than before zinc treatment. Because of the cascading design, the scale that was flushed out of the first still into the following (second) started to accumulate on the basin floor. Flushing of the scale into the last (third) still and into the waste pipeline did not occur due to the low water flow rate from the second to the third still (see Figure 9).

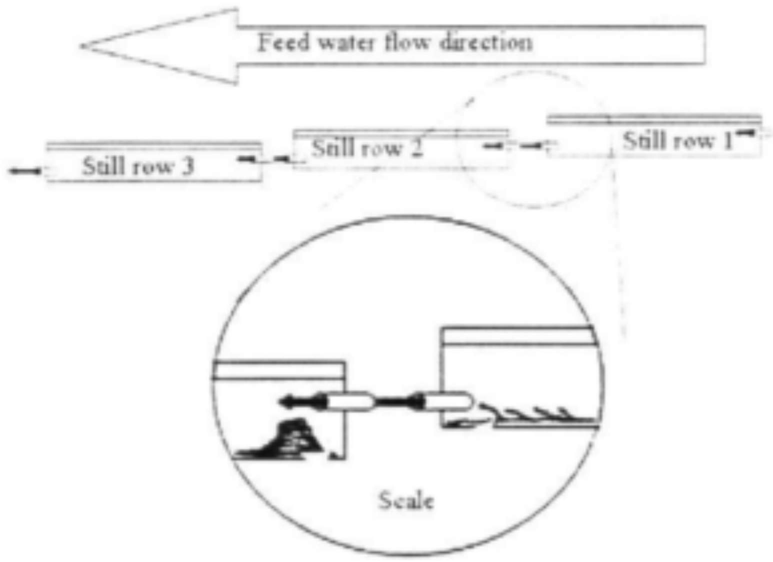

Figure 9: Ineffective scale removal by flushing of cascading solar stills.

- The cascade design was discarded in the DWAF project at Algerynskraal in favour of individually flushed units. In this design all 30 solar still units were fed individually through an automated solar powered control valve system, and the overflow of each still was connected to the central waste pipeline (see Figure 6). (The waste water at Algerynskraal is suitable for sanitation purposes). This modification was successfully implemented and no scale-related feed water distribution problems have been encountered to date, although the feed water was significantly harder than at Kerkplaas.

- Algae growth in the solar stills was prevented by covering inline filters with black bags and placing cartridge filters inside dark boxes.

During the four-year test period of the Kerkplaas plant, only two maintenance actions required the solar stills to be removed from their stands, namely the fixing of leaks and scale removal. This was usually difficult due to the compact plant design. Although both these problems were solved in the second solar still plant at Algerynskraal, another design change to the stand layout was made to simplify access and solar still removal without influencing the operation of the rest of the plant.

CHAPTER 3

MICROBIOLOGICAL WATER QUALITY OF BASIN SOLAR STILLS

3.1 INTRODUCTION

This part of the study aimed to determine the effectiveness of solar basin stills as a means of pasteurising microbiologically contaminated groundwater. This was simulated on laboratory scale by a microbiological indicator. The effectiveness was determined experimentally by measuring (i) the transfer of microbial contamination to the distillate and (ii) the microbiological activity inside the basin of an operational solar still. Experimental results were consequently verified via a field test.

3.2 DISINFECTION MECHANISM

The basin solar still lends itself to two disinfection modes, namely:

- Thermal pasteurisation via elevated temperatures due to the heating profiles inside the solar still (see Figure 11), and
- UV disinfection via solar UV-A irradiation, transmitted through the glass pane on top of the still (see Figure 10).

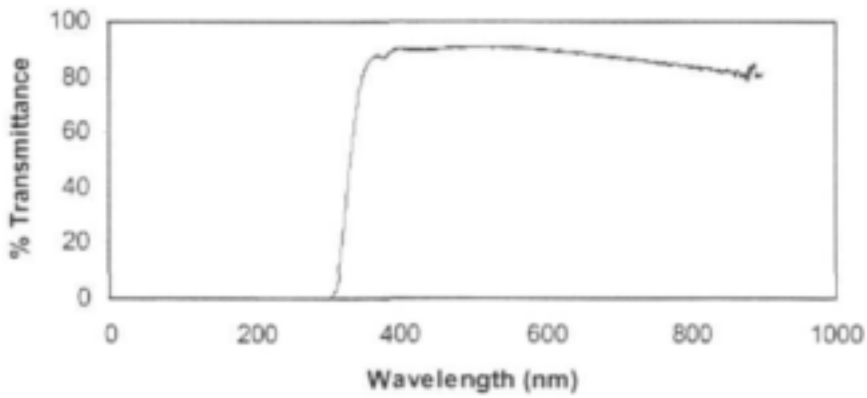

Figure 10: Transmittance of UV-A through the glass cover of a solar still.

The effectiveness of both these pasteurisation mechanisms in solar stills is influenced by seasonal effects. Both the temperature and intensity of UV irradiation are reduced considerably during the winter period. It was therefore important to keep this in mind when simulating actual conditions in the laboratory and drawing conclusions regarding the effectiveness of the pasteurisation. For the purpose of these experiments, only temperature variations were taken into account as UV irradiation generally does not impact on the specific microbiological indicator used.

All microbial organisms have a cardinal temperature profile, which indicates the temperature range in which the specific organism will grow and thrive. The growth rate indicated by this profile has a typical normal distribution, with a minimum and maximum temperature limit within which microbial growth can take place, as well as an optimum temperature where maximum growth can be expected.

Due to the extreme temperatures experienced in typical solar still application areas, it was important that the cardinal temperature profiles of the organisms under investigation were compared to the winter and summer temperature profiles of the specific region where the still would be used, in order to determine the pasteurisation effectiveness of the basin solar still at different times of the year.

Figure 11 illustrates typical winter and summer temperature profiles as measured at Kerkplaas in the Little Karoo. The cardinal temperature profile of typical *E.coli* is bound by a temperature range of 10°C - 45°C with an optimum temperature at 37°C. When these temperatures are superimposed on the seasonal temperature profiles in Figure 11, it is evident that thermal pasteurisation would be ineffective during the winter period, as the maximum temperature for microbial growth (45°C) is not exceeded. Instead, the temperature falls well within the temperature range where microbial growth can be expected. The only mechanism for inactivation of microbial contamination under such conditions would therefore be through the natural die-off rate of the specific microbe.

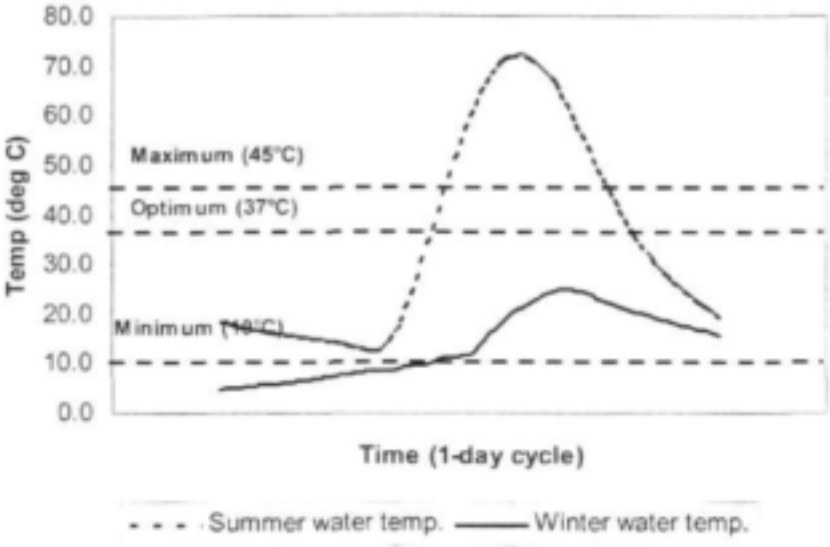

Figure 11: Generic cardinal temperature profile of microbes superimposed on daily temperature profiles.

Due to this tendency, it was considered important to investigate the actual pasteurisation effectiveness, both in the product water and the basin water itself.

3.3 EXPERIMENTAL

3.3.1 Laboratory solar still setup

Due to practical constraints such as ease of cleaning and disinfection, full-sized commercially available solar stills were deemed unsuitable for the experimental investigations to determine microbiological water quality. Therefore two similar solar still units, each about 1/40th of actual size (1500 ml capacity), were built using the following materials: polyurethane foam for the frame and insulation, black flexible polypropylene for the interior lining, aluminium for the gutter and window glass for the removable cover.

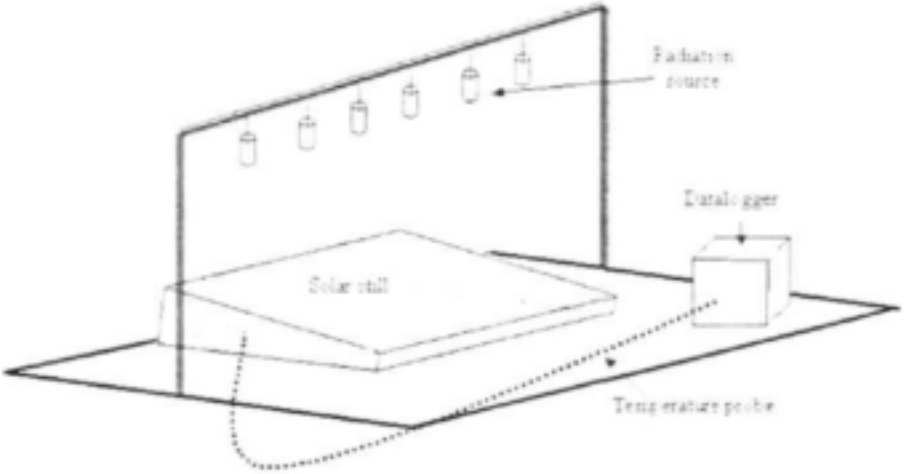

Figure 12: Experimental set-up used for studying the microbiological water quality.

The experimental unit consisted of one of the above stills (the other being used as control) positioned under an adjustable frame with six clear Osram ® SICCATHERM radiation bulbs (see Figure 12), while an identical control unit was operated without radiation. The radiation intensity between experiments was changed by making use of a calibrated commercial light dimmer. The temperature profiles inside the stills were recorded with temperature probes (± 0.15°C accuracy) connected to a four-channel Pace Scientific XR440 pocket data logger. Figure 13 shows a typical water heating profile inside a solar still, while Figure 14 shows the maximum temperatures for different dimmer settings, as well as the temperature at which distillation commences.

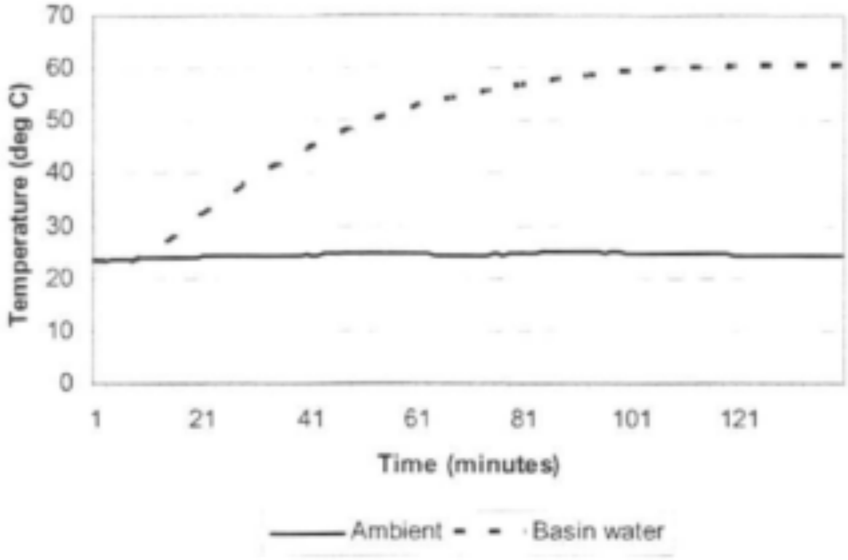

Figure 13: Typical basin water heating pattern inside an experimental solar still.

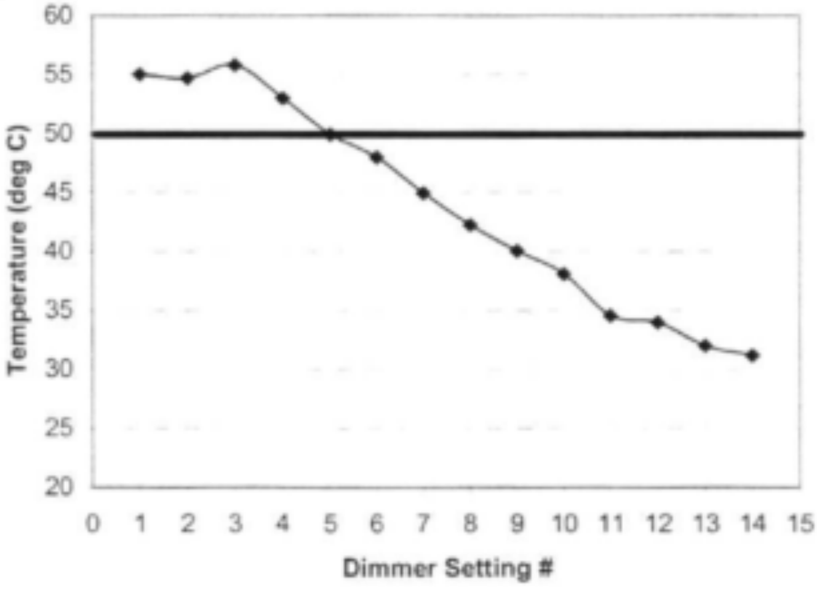

Figure 14: Maximum water temperatures measured inside a solar still at different settings (black horizontal line indicates distillation temperature).

3.3.2 Microbiological indicator

A wide of pathogenic viruses, protozoa and bacteria may be transmitted by water and may cause diseases such as gastroenteritis, fever, infections and cholera. Assessment of the safety of water by tests for all the pathogens which may be present would be impractical for technical and economical reasons (see South African Water Quality Guidelines Vol. 1, Domestic Use p68). Indicator organisms are therefore generally used for monitoring of the potential pathogens in drinking water. Since the waterborne diseases of prime importance are those caused by eneteric pathogens transmitted by the faecal-oral route, indicators of faecal pollution are generally included in drinking water quality monitoring programmes.

For the purpose of this evaluation, it was therefore necessary to determine the disinfection effectiveness of the basin solar still in terms of faecal contamination. As a result, it was decided to design the evaluation around a strain of *Escherichia coli* (*E.coli* ATCC 11229) as a microbiological indicator, as it is a highly specific indicator of faecal pollution which originates from humans and warm-blooded animals (South African Water Quality Guidelines Vol. 1, Domestic Use p69). This bacterium was labelled with a green fluorescent protein (GFP-labelled), ensuring easy enumeration of the test organism among other bacterial contamination in the solar still. The isolate was grown overnight, in 5 mL sterile Luria Bertani broth at a temperature of 30°C on a shaker, to a concentration of $\pm 10^{8}$ cells per mL.

Disinfection experiments were conducted with distilled water spiked with a standard mixture of sea salt, to result in a 5000 mg/l saline concentration, to simulate actual conditions in brackish surface water. The test organism was added to the saline water to a final cell load of approximately $6.67.10^{+6}$ cells per liter of saline water.

3.3.3 Microbiological testing procedure

Microbiological testing of the polluted water was done by sampling and testing of sample waters from the solar still at regular intervals (see Table 1). These samples were stored in sterile sample bottles and analysed for surviving cells of the microbiological indicator within a time period of 6 hours from sampling. A dilution series was prepared from each sample (in a saline solution prepared from Ringer's solution) from which 100 μL of diluted sample water was introduced onto Luria Bertani (LB) broth plates prepared from 30 g of LB media and 12 g of bacteriological agar per liter of distilled water. The plates were inoculated for 24 hours at 37°C, after which time colony forming units were counted (CFU/mL). A epifluorescent microscope, equipped with the appropriate filters, was used to distinguish between the GFP-labelled *E.coli* and other micro-organisms.

3.3.4 Experimental

The purpose of this experiment was to evaluate two different aspects of the performance of the solar still (see Table 1). The two areas of focus were:

- pasteurisation of the product water in terms of the microbial transfer of the microbiological indicator from the still basin to the distillate; and
- pasteurisation of the basin water in terms of (i) the pasteurisation efficiency of the basin solar still by the comparison of the bacterial count of contaminated water in an operational solar still to that of a control experiment in a dark container at set time intervals, and (ii) the pasteurisation effectiveness of the solar still by the evaluation of the rate of reduction of bacterial contamination.

<u>Table 1:</u> Experimental layout for study of microbiological water quality

Evaluation	Temperature (°C)	Sampling interval
Pasteurisation of product water	55°C, 50°C, 45°C, 40°C, 35°C and 32°C	8 hours
Pasteurisation of basin water	Single heat cycle: room temperature to 52 °C	30 minutes
	Thermo-regulator temperature-controlled water baths	Varying time intervals

The performance of the solar still was then verified in a field experiment, where no control over external conditions, such as temperature, could be maintained.

3.4 RESULTS

3.4.1 Pasteurisation of product water

A series of experiments was conducted to determine the transfer of microbial contamination from the still basin to the distillate. Samples were taken at three different points: in the experimental solar still basin, its distillate and in the control still basin. The counts of the model bacterial pollutant was zero for each water sample taken from the distillate at the different temperature settings, varying from 32°C to 56°C (see Figure 14). Table 2 summarises the observations for each sampling point.

Table 2: Summary of product water sampling results

Point of sampling	Observations
Product water from experimental still.	Microbial count was zero in all cases, i.e. at all temperature settings investigated and for all sampling intervals. No transfer of microbial contamination therefore occurred from the basin of the solar still to the distillate or product water.
Basin water from experimental still.	A reduction in the microbial count was observed for consecutive sampling intervals at specific temperature settings. In all cases, i.e. for all temperature settings, a zero microbial count was obtained after a period of time. Faster inactivation of microbial contamination occurred at the higher temperature settings, indicating that the reduction in microbial concentration was not only as a result of its natural die-off rate, but as a direct result of thermal inactivation due to elevated temperatures as maintained by the solar still.
Basin water from control still.	Microbial count increased due to growth of the microbial contamination.

3.4.2 Pasteurisation of basin water

Several experiments were carried out to evaluate the microbiological activity inside the still basin. Firstly, it was necessary to establish the role of the solar still in the inactivation of the microbial contamination, i.e. whether inactivation occurred merely due to the natural die-off of the specific microbe under investigation, or whether inactivation of the microbes was due to thermal inactivation resulting from the elevated temperatures inside the basin solar still. The cause of inactivation of the microbes was established from the experimental work reported on in the previous section. From Table 3 it is evident that elevated temperatures in the experimental solar still, compared to the control solar still, resulted not only in the deactivation of the microbes, but also impacted on the rate at which the deactivation occurred. Higher temperatures resulted in a faster rate of inactivation.

Secondly, it was investigated whether a correlation exists between the cardinal temperature profile of the microbe under investigation, and the minimum temperature required for thermal inactivation of the specific microbe. The results reported here were generated by exposing the microbiological indicator (*E.coli*) to a normal heating cycle (at dimmer setting 1) in the laboratory solar still. The temperature inside the solar still therefore increased with time, as indicated in Figure 15. At a specific temperature a sudden drop in *E.coli* concentration was observed (Figure 15). This temperature (approx. 45°C) indicated the threshold temperature that is required for pasteurisation of the specific microbe under investigation. This temperature also corresponds well to the maximum cardinal temp of *E.coli* in general (Figure 11). These results therefore confirmed the importance of correlating the actual temperatures inside the basin solar still with the cardinal temperature profiles of different microbial species in order to verify the effectiveness of pasteurisation.

Lastly, in order to determine the rate of reduction of *E.coli* at a specific temperature, it was decided to repeat a series of experiments at set temperatures in water baths controlled with thermoregulators. Figure 16 shows that for temperatures above the maximum cardinal temperature of *E.coli*, a maximum of 30 minutes was generally required for inactivation of the *E.coli*. The rates decrease significantly closer to the *optimum cardinal temperature of the organism, where, at this point, the concentration of* the *E.coli* actually increases, indicating that thermal inactivation becomes insignificant.

From these results it could therefore be deduced that:

- When temperatures are sufficiently high inside the basin solar still, the inactivation of microbes is not only as a result of the natural die-off rate, but that thermal inactivation plays an important role.
- A minimum or threshold temperature exists for pasteurisation of a particular organism. This temperature correlates well with the maximum cardinal temperature of *E.coli*.
- Below the threshold temperature the deactivation of the organism becomes very difficult, and the bacterium actually thrives under such conditions.
- The slight reduction in bacterial count at 40°C and below can be attributed to the natural die-off rate of the organisms.

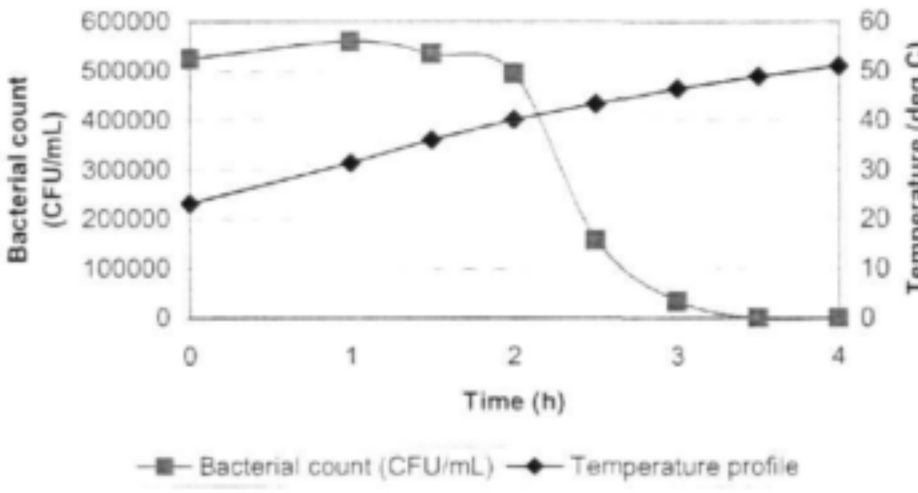

Figure 15: Pasteurisation of basin water in laboratory solar still.

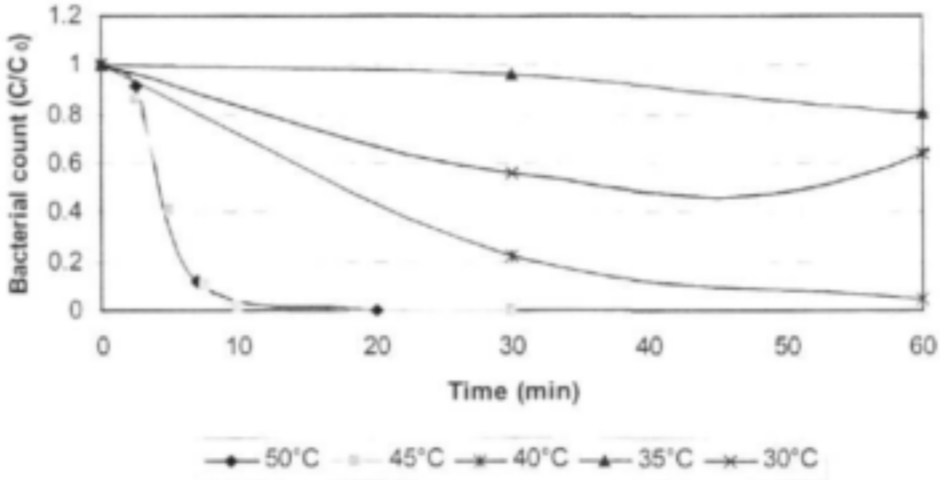

Figure 16: Pasteurisation of basin water in water baths.

3.5 FIELD TESTING

The above laboratory results were confirmed in a field test. Verification tests were carried out over two days in overcast conditions during the winter period (i.e. worst case). The tests were performed in an experimental solar still situated at the Forestry Department, Stellenbosch University. The same experimental conditions were used as in the laboratory, i.e. saline water and the model *E.coli* strain were introduced into the basin and samples were taken every 24 hours, for a total period of two days.

The temperature profiles (Figure 17) show that a maximum temperature of 40°C was reached during the first day of testing, while temperatures lower than 30 °C were reached during the next day. The impact of the difference in temperature is reflected in the decay curves, where the microbiological indicator could not be completely inactivated after 48 hours (Figure 18). (*Note:* due to the low basin water temperatures, no product water was distilled took place during the test period).

As the water temperatures fall well within the cardinal temperature range of the bacterium, it can be concluded that the natural die-off rate of the microbiological indicator, together with its exposure to UV-A (refer to Figure 10) could have contributed to the reduction in the bacterial count.

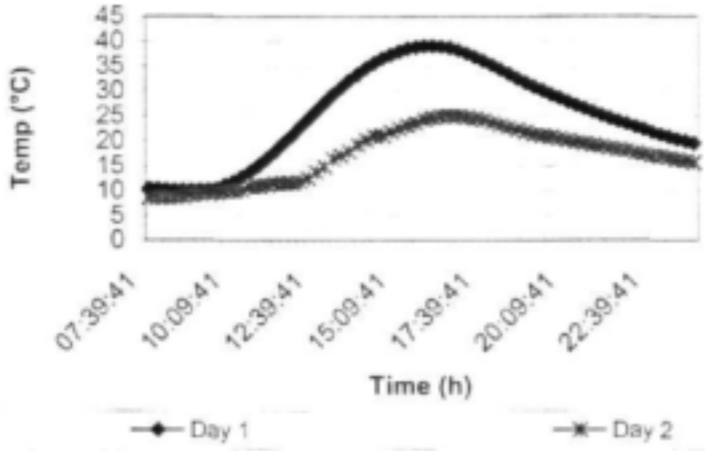

Figure 17: Temperature profiles of field test days.

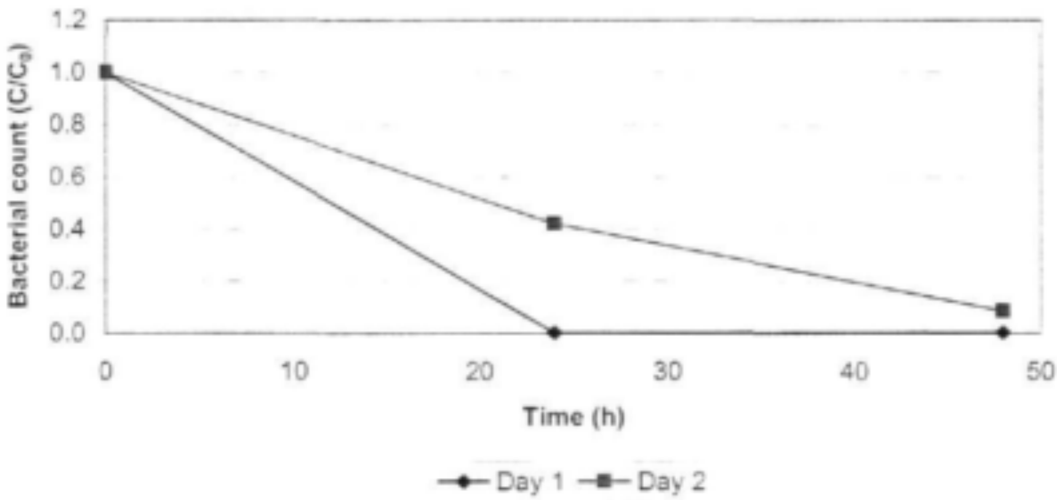

Figure 18: Bacteriological decay of microbiological indicator in solar still basin.

3.6 COMPARISON OF SOLAR PASTEURISATION SYSTEMS

Different water purification designs have been investigated for the utilisation of solar energy as a method of pasteurisation for the supply of potable water to rural communities (Cloete et al, Edberg et al, Meyer et al). These designs include:

- Closed solar pasteurisation systems (e.g. SODIS and SOLAIR systems), and
- Basin solar stills, such as the experimental design used in this study.

Both the SODIS and the SOLAIR system are based on filling standard water containers, namely 1,5 liter PET cold drink bottles and 25 liter PET water containers, respectively. The containers are ¾ filled with contaminated water, shaken vigorously (to increase the level of dissolved O_2 in the water) and placed in direct sunlight. The SODIS system utilises thermal, solar irradiation and oxidation, whereas the SOLAIR system utilises solar irradiation and oxidation.

The basin solar still, on the other hand, is open to the atmosphere and works on the basis of flow-through system. The product water leaves the still after the water vapour condenses on the glass panel and runs off into a gutter, from where it leaves the still. Inactivation of microbes inside the solar still basin can only take place via thermal inactivation and / or solar (UV-A) irradiation. A major advantage of the basin solar still, however, lies in its design, as microbial contamination present in the basin of the solar still cannot be transferred to the product water through the vapour phase. It can therefore be said that, although inactivation in the basin is via thermal inactivation or solar irradiation, the principal mechanism for cleaning the water is distillation. The selection of a specific solar pasteurisation system will be guided by specific requirements of the region, in terms of the source water (e.g. surface water, saline borehole water, etc [a] .), product water quantity and quality .

Unfortunately all three systems described above are dependent on suitable weather conditions. The effectiveness, requirements, constraints and performance of different solar pasteurisation systems system are compared in Table 3 below.

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[a] No faecal coliforms were measurable in the feed and product water of the Kerkplaas plant (Chapter 5).

Table 3: Inactivation mechanisms of different solar pasteurisation systems

Criteria	SODIS	SOLAIR	Experimental design
Design	Closed system	Closed system	Open system
Pasteurisation mechanism	Thermal inactivation UV-A irradiation	UV-A and UV-B irradiation and chemical inactivation (via dissolved O_2).	Thermal inactivation and UV-A irradiation.
Source water used	Clear water, free from chemical contamination, but may have faecal contamination.	Clear water, free from chemical contamination, but may have faecal contamination.	Requires clear water. May have high salt content and contain faecal contamination.
Chemical composition of product water	Does not differ from source water.	Does not differ from source water.	Desalination of product water.
Weather conditions	Requires suitable weather conditions.	Requires full, direct sunlight for a minimum of 4 h per day.	Requires suitable weather conditions.
Volume of water produced	Cannot treat large volumes of water – limited to 1.5 liters.	2-25 liters	Larger quantities of water (> 25 liters) can be treated.
Long-term effectiveness	Ageing of PET result in a reduction in UV-A transmittance. (But these are disposable containers and can easily be replaced)	PET plastic containers can deteriorate with time, resulting in a reduction in UV transmittance.	Glass surface effective over the long term, resulting in good UV-A irradiation over the longer term.
Pasteurisation effectiveness	Bacteria: E. coli, Vibrio cholerae, Streptococcus faecalis, Pseudomonas aerugenosa, Shigella flexneri, Salmonella typhii, Salmonella enteriditis, Salmonella paratyphi Viruses: bacteriophage f2, rotavirus, encephalomyocarditis virus Yeast and Mold: Aspergillus niger, Aspergillus flavus, Candida, Geotrichum	100% inactivation of total coliforms after 6 h and 100% inactivation of faecal coliforms after 4 h	The indicator microbiological indicator, *E.coli*, can effectively be inactivated within 30 minutes, provided that the weather conditions are suitable.

CHAPTER 4

IMPROVEMENT OF WINTER PRODUCTIVITY

4.1 BACKGROUND

Earlier studies (Goldie et al, WRC Report 1032/1/03) have shown that the productivity of a solar still unit can drop by as much as 90% from high summer to mid-winter, as can be seen from Figure 19.

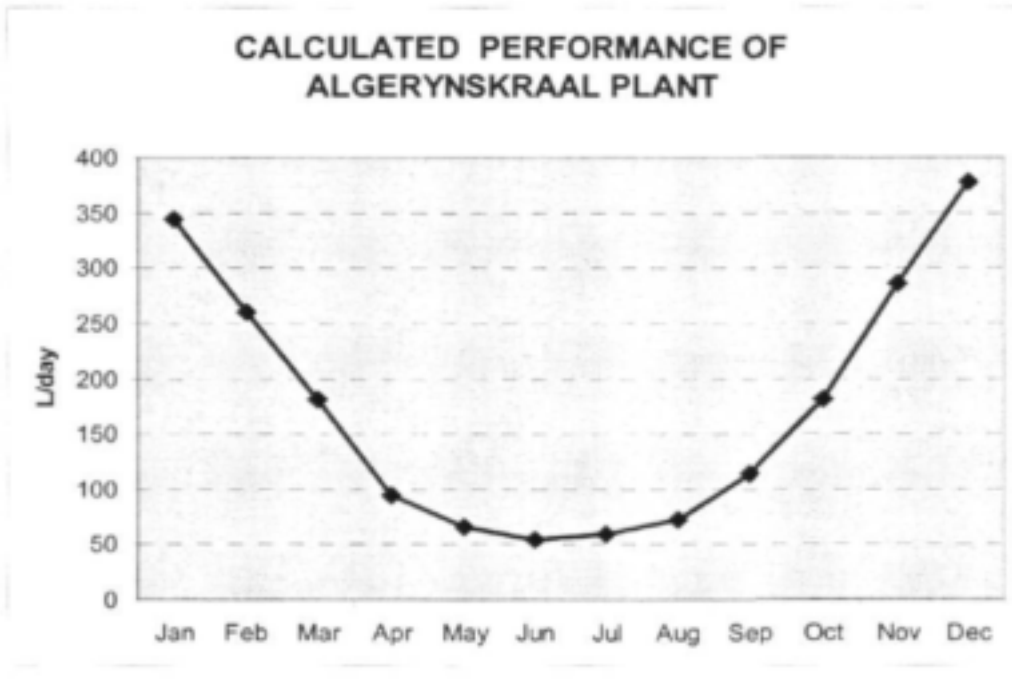


Figure 19: Calculated performance behaviour of the Algerynskraal solar still plant (deviations from the above productivity may occur as prevailing weather conditions vary).

Two performance enhancement techniques were investigated to improve winter productivity, namely (i) the addition of reflecting materials to the still to increase the amount of incident radiation, and (ii) the integration of rainfall harvesting, especially for potential use in winter rainfall regions.

4.2 REFLECTORS

While the seasonal use of removable reflectors attached to the solar still frame can potentially increase winter productivity (El-Swify, Goldie), correct reflector material selection and design engineering may even decrease overall water production costs. An experimental investigation into the cost-effective use of reflectors in combination with solar stills was consequently carried out.

4.2.1 Reflector angle

First, experiments were designed to perform in-house characterisation tests to determine the influence of different reflector configurations on solar still productivity. Figure 20 shows the still configuration used in these experiments. In all cases 24-hour radiation periods were employed.

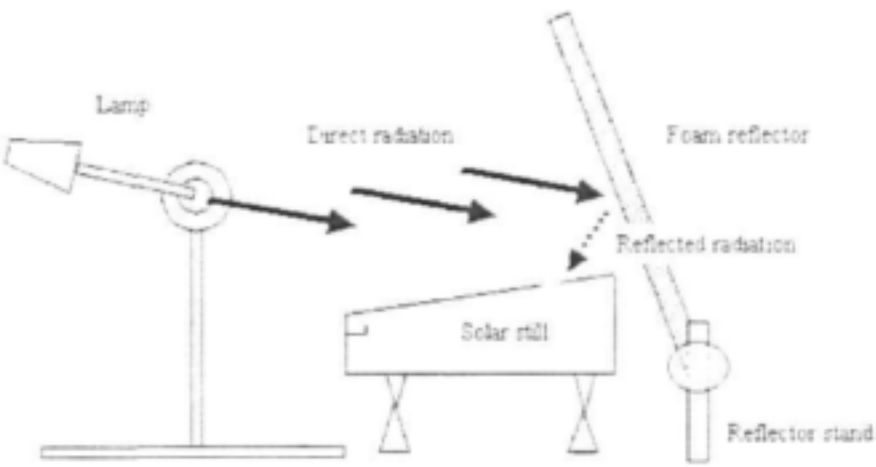


Figure 20: Solar still setup for testing the impact of reflectors on solar still performance.

A productivity increase of 26% was recorded with a 0,5 m^2 reflector placed vertically behind the still. Further investigations into an optimised reflector angle followed. The productivity increased significantly from having no reflector present to having a reflector tilted by 50° relative to the horizontal. The angle of incidence of radiation to the cover was 63° (where the transmittance of the glass is less than 70% of the maximum). When the reflector was adjusted from 70° through to 50° (relative to the horizontal), the productivity increased by 52%, to 70% (see Figure 21).

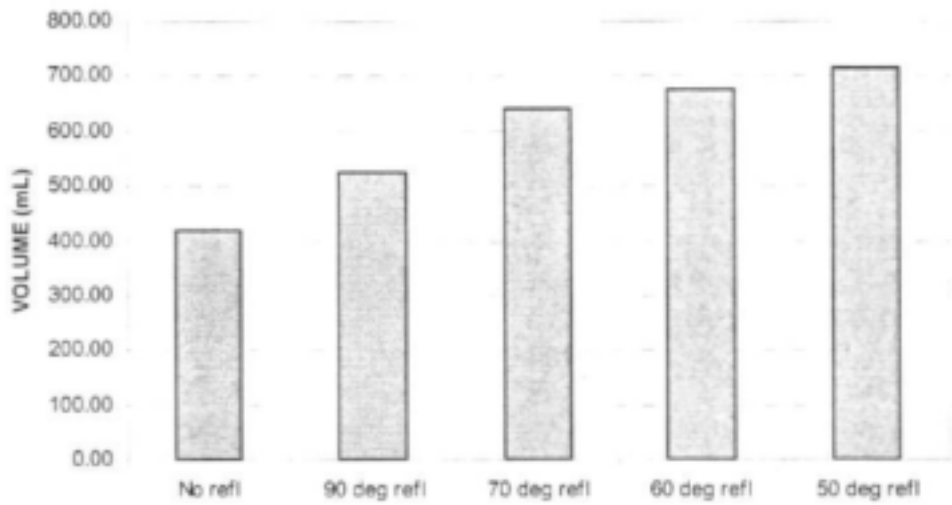


Figure 21: Influence of reflector angle on solar still productivity

4.2.2 Reflector material

Two different, readily available reflector cover materials were investigated, namely white gloss paint and reflective aluminium foil. The experimental setup of Figure 20 was used, and the reflector angle was 70 degrees relative to the horizontal. The reflector size was again 0,5 m^2. The productivity over a 24-hour cycle was recorded, together with maximum basin water and air temperatures. Summarised results are presented in Figure 22, which illustrates the performance advantages of the reflective metallic foil.

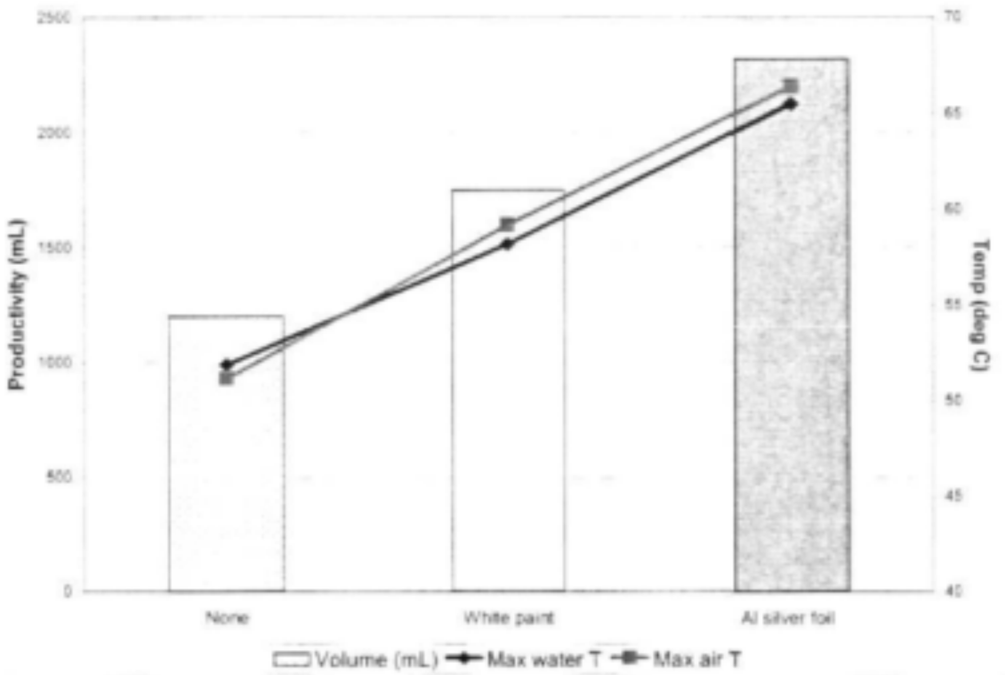


Figure 22: Influence of reflector type on solar still productivity.

4.2.3 Reflector area

The influence of the total reflector area behind the solar still on its productivity was also investigated for the two types of reflector material. Different reflector configurations were used to obtain different reflective areas. Figure 23 shows the results of this study, again illustrating the better performance obtained with aluminium foil. Even with the reflector placed inside the still (cheap construction procedure), the performance was better than with no reflector at all.

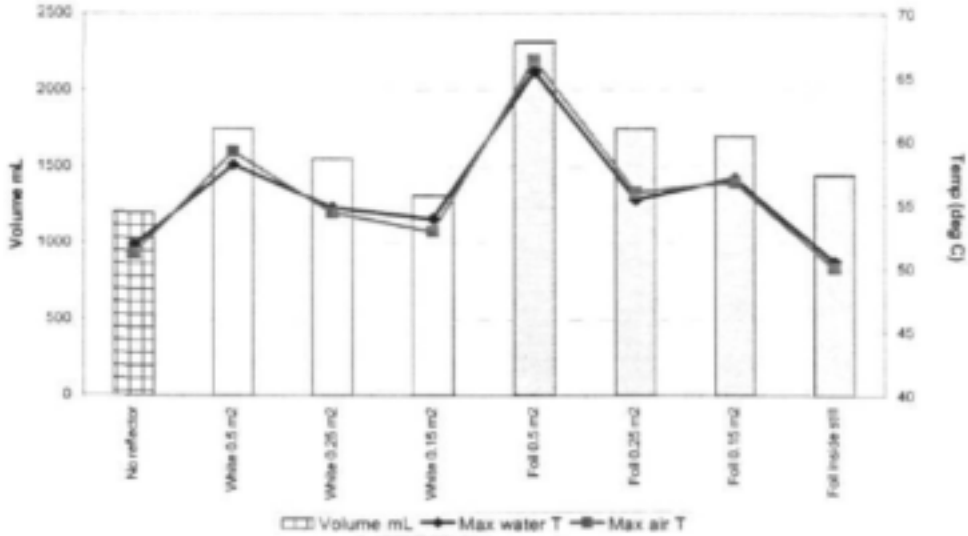


Figure 23: Impact of reflector area and type on solar still productivity.

4.2.4 Field testing

Operational field-site testing to confirm the above laboratory results were carried out next at the Stellenbosch test site. The test set-up is presented in Figure 24.

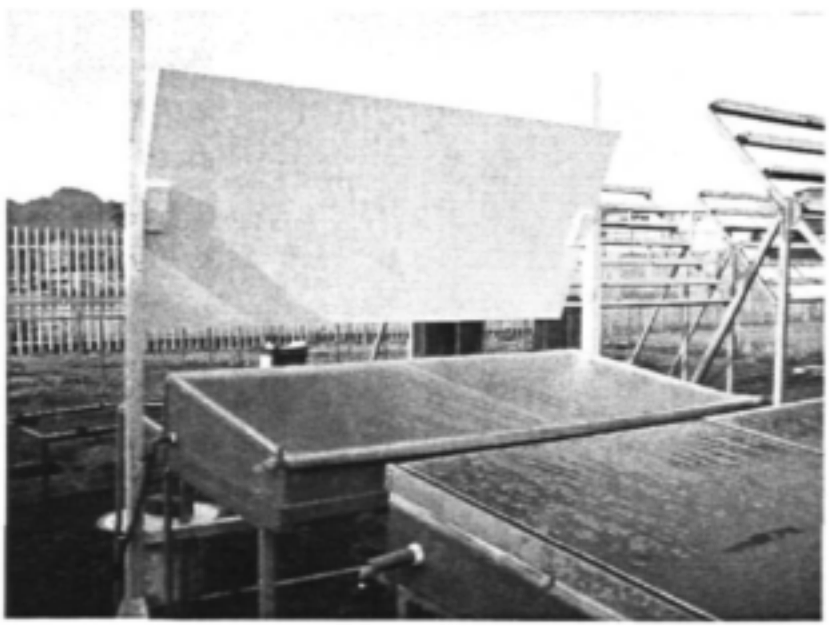
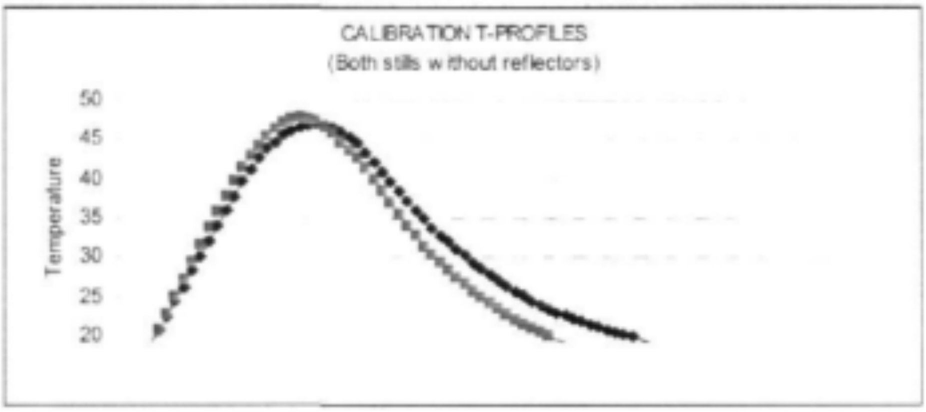


Figure 24: Experimental setup for field testing of reflectors (adjustable reflector sheet behind stills).

Experiments were carried out during June 2003, when typical wintertime solar radiation conditions prevailed. An second adjacent solar still, with similar performance behaviour but without the reflector, was used as control. Daily basin water temperature profiles and water production volumes were recorded. The laboratory configuration that produced the best results was scaled up for the initial experiments. A reflector of 1,6 m^2 was covered with reflective aluminium foil and tilted over the solar still at an angle of 70 ° (relative to the horizontal). Figure 25 shows the temperature profiles of the test and control solar stills on sunny, clear days. The increase in the basin water temperature due to the presence of the reflector can be seen.



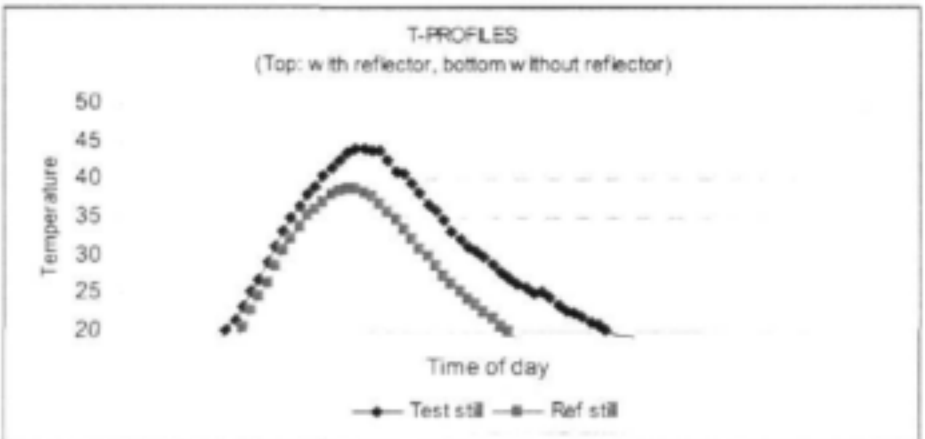


Figure 25: Temperature profiles of the water inside two solar still basins recorded on separate winter days (note the higher maximum temperature in the test still with the reflector).

Unfortunately the gain in basin water temperature did not translate into significant productivity gain, as an average increase of only about 5% in distilled water volume was recorded over the test period. This was far less than what was anticipated from the laboratory work, although the relatively slight temperature increase noted in Figure 25 was perhaps an indication that this was to be expected. The reflector angle was changed to 80 ° and then to 50 °, but with no significant improvement. Finally the experiments were also repeated with aluminium foil placed inside the solar still (where only a slight productivity gain was to be expected from the laboratory work), but no measurable temperature and productivity differences between the test and control stills were recorded.

Further work on reflectors was consequently abandoned for the following reasons:

- *Less radiation reaches the basin than it did in the laboratory.* The static, two-dimensional experimental setup in the laboratory did not simulate the three-dimensional movement of the sun from east to west during the day. The fixed radiation source concentrated the reflected radiation into the solar still basin, while with the field site arrangement significant amounts of radiation could be reflected away from the basin due to the sun's movement across the reflector plane, as well as the continuous change of the angle of solar radiation onto the solar still.
- *Insufficient increase in basin water temperature to effect distillation.* Another related factor is that, due to the low wintertime radiation intensity and despite the presence of the reflector, the basin water temperature does not increase enough to enhance the distillation process. Previous research (Goldie) showed that the basin water temperature must be above 48 ° C for distillation to take place. Figure 25 shows that even with the reflector this temperature could not be reached.
- *Economic viability.* It is estimated that the addition of a rugged, removable reflector that can withstand strong winds would increase the construction material cost of a solar still unit by about 10%. With the expected productivity increase of 5% during the winter months only, the cost of product water would not change significantly. Further capital cost increases can also be foreseen in terms of larger sized stands in solar still plants, as the shadow area behind the reflector cannot be used for the placement of a next row of stills. These factors make the use of reflectors in the current configuration economically unattractive. [Using the cost model developed earlier (Goldie et al, WRC

project K5/1032), it is shown that a wintertime productivity increase of at least 9% is required for economic viability].

4.3 RAINFALL INTEGRATION

The Kerkplaas solar still plant is situated within 20 km from Ladismith in the Klein Karoo. The monthly rainfall average for Ladismith is about 26 mm, with a higher average number of rainy days in winter (the average precipitation does not vary much between summer and winter, see Figure 26).

The micro-climate at Kerkplaas is considerably drier than described above, although occasional and unpredictable rainstorms do occur. A basic rainwater harvesting infrastructure (roof gutters and plastic tanks) was present there when the solar still project commenced, although it was not well-maintained. No disinfection practices was in place for the household use of rainwater from storage tanks.

During the course of the current project and with inputs from the community, it was decided to investigate the integration of harvested rainwater with product water from the solar still plant to increase the community's water supply (see par. 4.1). Two options were identified, namely, rainwater collection from the solar still covers, and upgrading of the existing rainwater catchment infrastructure.

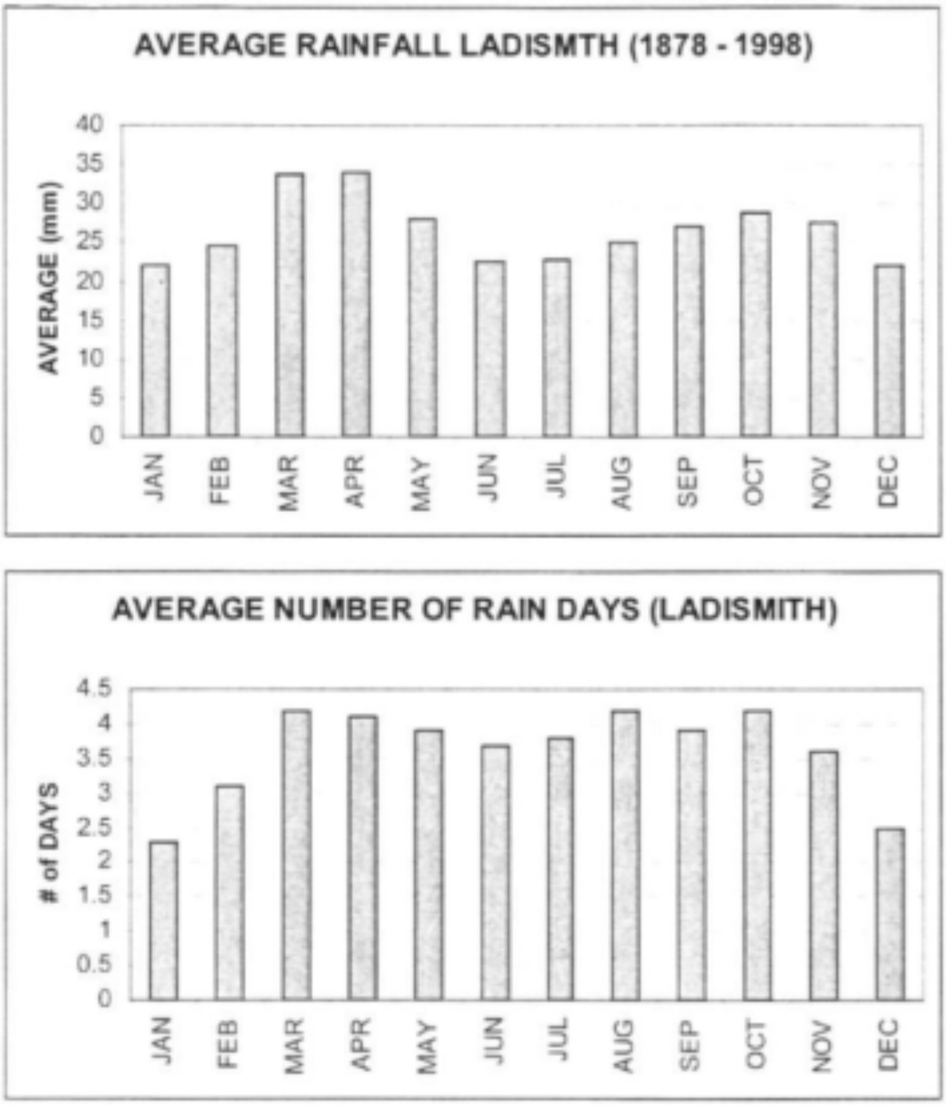


Figure 26: Average annual rainfall and number of rain days for Ladismith in the Klein Karoo.

4.3.1 Rainwater collection from solar still covers

Experiments to determine the efficiency of rainfall collection from solar still covers were conducted during the winter of 2002 at the test site at the University of Stellenbosch. A solar still was modified by addition of an aluminium gutter to the front of the solar still, and the gutter was connected with silicone pipes to collection containers on both sides of the solar still. Distilled water was collected in a separate container. Rainfall over specific test periods was recorded at the test site. Another adjacent solar still with similar productivity was used as control. The results are shown in Figure 27.

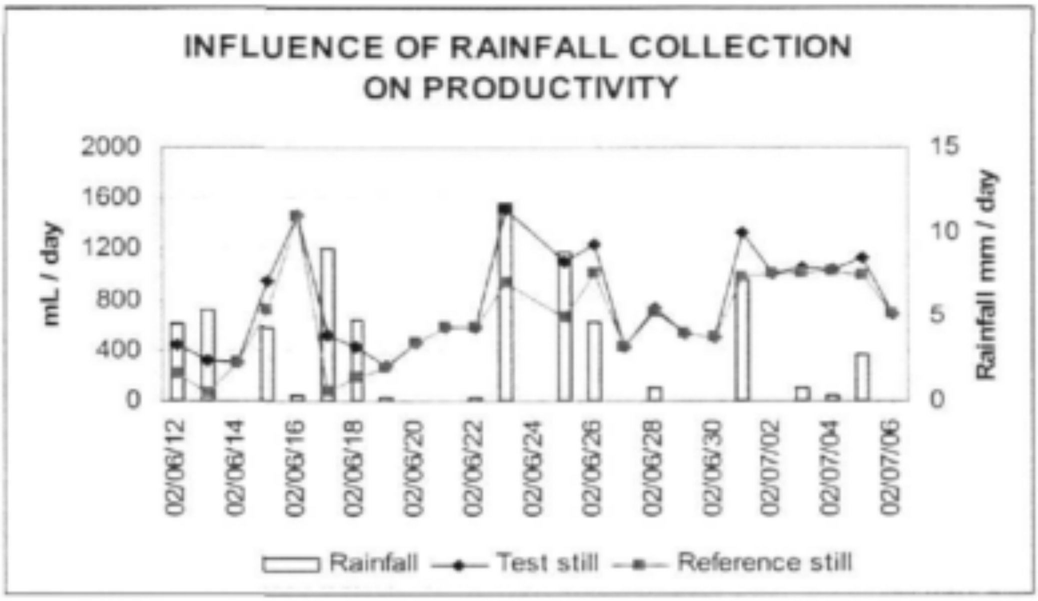


Figure 27: Influence of rainfall collection on solar still productivity.

The above Figure shows that rainwater collection on the solar still cover can be used to increase the output from a solar still. It was, however, not possible within the scope of this project to quantify the expected productivity gain on a daily basis due to unpredictability of the manner in which the rainfall reaches the solar still cover (i.e. the velocity of the precipitation).

The solar stills at Kerkplaas were then fitted with rainfall collection gutters as described above, but integration with the rest of the solar still plant was never completed due to practical considerations. The most important problem was the rapid collection of windblown dust and sand in the gutter, and consequent transfer thereof into the blending and pumping infrastructure of the plant, causing product water contamination and pipe blockages. It was therefore decided to rather upgrade the existing rainfall harvesting infrastructure of the community.

4.3.2 Upgrade of rainfall harvesting infrastructure

The existing rainfall harvesting infrastructure at Kerkplaas consisted of roof gutters (mostly in need of repair) and plastic collection tanks around the main church building.

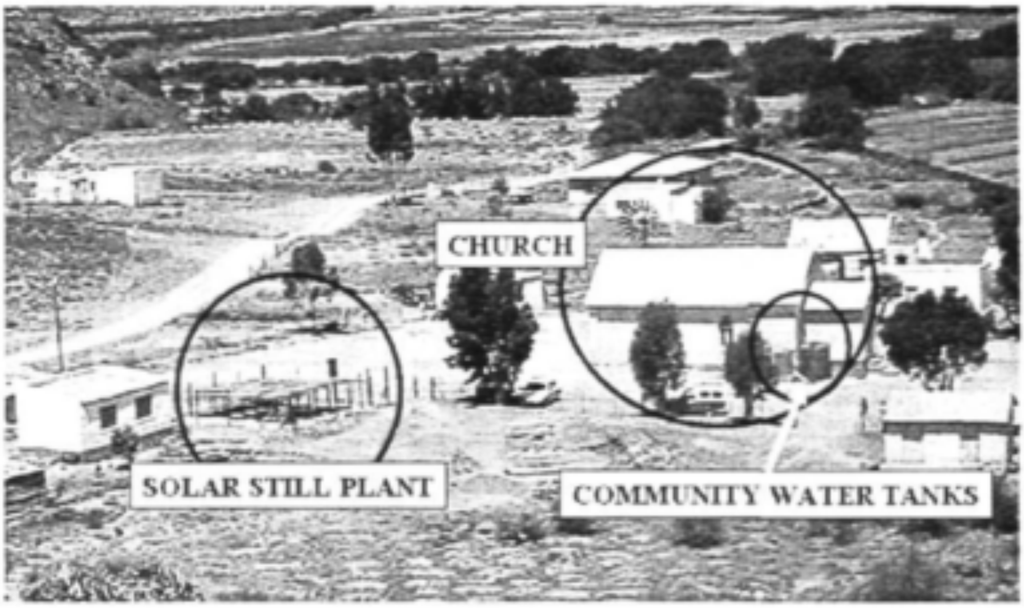


Figure 28: Kerkplaas with the solar still plant and community water tanks.

The following steps were then taken to combine the two household water supplies:

- Another 5 m^3 water storage tank was placed next to the existing tanks;
- The roof gutters of the church were repaired;
- Community members were trained to manage water levels in the different storage tanks, to ensure maximum supply capacity; and
- Water disinfection procedures were implemented whereby 0,03% NaOCl (in the form of 32 mL household 'Jik' per m^3 water) was added to the storage tanks on a weekly basis.

CHAPTER 5

SOCIO-ECONOMIC ASPECTS

5.1 BACKGROUND

As the technology demonstration phase of the Kerkplaas solar still project reached its conclusion with the end of this WRC project, the project team saw it fit to gauge the perception and opinion of the Kerkplaas community about the project and the future transfer of the plant to the appropriate local authority. The broader aim was therefore to investigate the socio-economic impact of such a project on a typical target community. This study was conducted, independent from the technical project by the Health Sciences Department of the Peninsula Technikon during September 2003.

5.2 KEY FINDINGS

The key findings / results of this investigation, are as follows (the complete report is in Appendix A):

- The community perceived the project aims to be that of purifying the water and making it usable for cooking and drinking.
- The borehole water was very brackish, salty, unsuitable for consumption and only used for washing clothes and not drinking.
- The project involved full community participation.
- The community is not familiar with the technical names of the plant components but they have a solid understanding of how it works.
- There is now a distinct difference in the quality and taste of the water.
- Water is fairly distributed among community members.
- No further technical improvement is necessary mainly due to the high reliability of the water supply.
- There is a strong dependency on one community member for water management and this needs to be addressed.

- The community has to be involved with future plant project management and day-to-day operations, through an equal partnership with the appropriate local authority.
- Before handing over the project the community needs to be well informed and capacitated on local government water installation and regulations.
- The community is willing to pay for minor maintenance but not for water.
- The project was successful in providing free and clean water.

From the above findings it can be concluded that, from the community's point of view, the project at Kerkplaas had been successful. This was evident from their perception of the benefits that they are reaping as a result of the project. The community was however clearly not empowered on how to absorb and execute activities and responsibilities that had to date been executed by the project team. [This shortcoming has to be addressed as part of the Kerkplaas plant transfer process, as well as early in the project phase of similar future projects.]

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The following conclusions are made to this research project, carried out to investigate three specific problem areas associated with solar distillation technology:

6.1.1 Durability of basin solar stills

From the results of accelerated ageing and weathering tests it is shown that flexible polypropylene is better suited than rigid polypropylene for use as a liner material for operational basin solar stills than rigid polypropylene sheets. It exhibits better resistance to degradation and its is more chemical inert. It has the further practical advantage of allowing easier and improved incorporation into the still during construction, which can limit or, in cases, eliminate basin leaks during operational use. It has further been shown with a newly constructed solar still plant that the performance of solar stills is not negatively affected by the use of such flexible polypropylene liners.

Scaling will occur inside the solar still basin in cases where it is used to desalinate hard water. Water softening devices may be used for the pre-treatment of the feed water, but such equipment may complicate the relative simple operation of a solar still plant. During this study it was shown that a combination of plant layout design (eliminating cascading overflow) and exposure of the feed water to specific types of metal or metal alloys (in this case Zinc) can substantially change the physical characteristics of the scale and so reduce the amount of scale present in the solar still during operational use.

6.1.2 Microbiological water quality of solar distilled water

As it is impossible to test for all possible waterborne contaminants, *E.coli* was identified from the South African Water Quality Guidelines handbook as suitable for this investigation. It is however important to note that successful inactivation of *E.coli* would not necessarily imply inactivation of more heat resistant microbes such as the protozoa *Giardia* and *Cryptosporidium* in the water of the solar still basin.

Experimentally it was shown that, due to the mechanism of distillation, microbial contamination in the feed water cannot be transferred to the product water of the solar still. Therefore, even if inactivation of microbial contamination in the basin of the solar still is ineffective, the pathogens will not be transferred to the product water. It is however important to note that for the production of sufficient quantities of potable water at Kerkplaas, the product water from the solar still is blended with the source water in a 1:1 ratio, producing the final water supply that is stored in a storage tank. If a microbial contamination (e.g. faecal contamination) is introduced into the water system at the source, this contamination will be blended back into the final water that is stored in the storage tank.

The microbial activity in the feed water inside the still basin is temperature dependent, and where inactivation occurs above a specific threshold temperature. This threshold temperature correlates well with the cardinal temperature profile of the specific microbe. Above the threshold temperature, effective thermal inactivation of the microbiological indicator takes place. At lower temperatures, the temperature obtained inside the solar still is not sufficient to inactivate the pollutant. On the contrary, the temperatures can be conducive its growth.

6.1.3 Improvement of winter productivity

Two methods of increasing the available water supply capacity of a solar distillation plant were investigated, i.e. using reflectors to increase the amount of solar radiation reaching the saline water in the solar still basin, and / or using the solar still cover area to collect and channel rainwater into the solar still plant.

Laboratory testing showed that solar still productivity may be increased by 100% or more, depending on the type and area of the reflector used. It was found that a reflector of approximately equal area to the solar still cover, and covered with aluminium foil, yielded the best results. In field testing under typical winter conditions of low solar radiation, the highest productivity gain achieved was only 5%, which did not allow for an economically viable design change to be implemented (the difference between the laboratory and field results can be attributed to the smaller amount of radiation and the lower intensity thereof). Modification of the existing Kerkplaas plant to accommodate reflectors was consequently not carried out.

A simple design modification, whereby rainfall collection on the solar still cover could be carried out, was demonstrated at the field test site. The lack of sufficient data, which takes into account all variables associated with rainfall, made it impossible at this stage to express the productivity gain in terms of mm precipitation. The design change was nonetheless implemented at the Kerkplaas plant, but it affected the product water quality negatively in that bird droppings, dust and physical particles, that inevitably collect on the solar still covers, were now washed into the plant and caused the product water to become turbid and contaminated. This modification was therefore also not completed, although the combination of the storage tanks for solar still product water and rainwater (collected on nearby roofs) was successfully implemented.

6.1.4 Socio-economic study at Kerkplaas

An independent socio-economic study was carried out at Kerkplaas to determine the community's perception of the solar still project and its future. From this it became clear that the community viewed the project as being very successful, despite important areas of ignorance concerning the more sophisticated parts of the plant. Their biggest concern, however, was that the transfer of the plant to the municipality would lead to the household water becoming unmanageable and unaffordable, so that the plant will deteriorate and eventually become obsolete.

6.2 RECOMMENDATIONS

The following recommendations for future consideration are based on the preceding conclusions:

6.2.1 Durability of basin solar stills

Flexible polypropylene is a most suitable liner material due to its chemical and physical stability as well as its relative ease of processability during construction.

The hardness of the feed water plays a role in the design of a solar still plant, as it will determine the need for water softening devices. It is recommended that the cascade-type plant layout not be used with feed water of high scaling potential, but that in such cases the overflow from each still should be taken directly to waste to minimise the risk of scale blockages.

6.2.2 Microbiological water quality of solar distilled water

Appropriate operation of the stills is necessary to prevent accidental transfer of microbial contamination from the basin to the distillate, or to the end-user. This can typically include: (i) feeding of raw water below the basin water surface to avoid spray or mist inside the still, whereby the microbes can be transported from the bulk water to the collector duct, (ii) draining the basin regularly (as is currently done at Kerkplaas) to prevent concentration effects and (iii) preventing the re-use of the basin water for other household purposes e.g. by channelling the flush water to evaporation ponds.

Preventative disinfection measures should always be taken in cases where solar distilled water is blended with raw feed water to ensure that any microbiological contamination found in the community storage tank is eliminated. Sufficient chlorine can be added for chemical inactivation in such storage tank. This introduces residual chlorine levels in the storage tank, resulting in effective inactivation of any remaining microbiological contamination.

Due to the dependence of the pasteurization effectiveness of the open basin solar system on minimum weather specifications, this basin solar still should not be promoted in the market as a vehicle for the pasteurization of faecal contaminated water.

6.2.3 Improvement of winter productivity

The use of reflectors with the current basin solar still design is not recommended, as no economic advantage in terms of product water costs can be expected. Integration of product water from a solar still plant with the rainfall collection infrastructure can be considered in winter rainfall areas, but this will first require that disinfection procedures for the water in the storage tanks be put in place.

6.2.4 Socio-economic aspects

With the implementation of a new solar still project, as with all such types of projects, it is essential to involve the community from project onset to completion. It is therefore recommended that community members be present at all decision making meetings that will determine the current and future operation of the particular plant, thereby ensuring their continued commitment to the general good maintenance and operation of the plant.

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APPENDIX A

The Socio-Economic Impact of a Complete Distillation Plant on the Kerkplaas Community

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October 2003

EXECUTIVE SUMMARY

The maintenance and operation of the solar still was the responsibility of the project team, and this must now be transferred to the relevant Local Authority as the project is in its final stage. It thus became necessary, for the sustainability of the desalination plant, to gauge the perception and opinion of the Kerkplaas community around this transfer. The aim of the study was to investigate the socio-economic impact of a complete distillation plant on a typical target community in Kerkplaas, where desalinated water was provided free of charge to the community.

The research made use of a qualitative research method commonly known as focus group technique. The Kerkplaas community was divided into two groups of 5 persons, with each household in the community being represented.

Key findings were:

- The community of Kerkplaas prior to 1999 consisted of 7 households with a population of 25 people which has now been reduced to 5 households.
- The borehole water is very brackish, salty, unsuitable for consumption and only used for washing clothes and not drinking.
- The community perceived the project aims to be that of purifying the water and making it usable for cooking and drinking.
- The project was initialised with the testing of the water and involved full community participation.
- The community is not familiar with the technical names of the plant components but have a solid understanding of how it works.
- There is now a distinct difference in the quality and taste of the water.
- Water is fairly distributed among community members.
- No technical improvement is necessary mainly due to the high reliability of the water supply.
- There is a strong dependency on one community member and this needs to be broken.
- The community must be involved with future plant project management and day-to-day operations, through an equal partnership.
- Before handing over the project the community needs to be well informed and capacitated on local government water installation and regulations.

- The community is willing to pay for minor maintenance but not for water.
- The project was a tremendous success in providing free and clean water.

In conclusion, the community has reaped many benefits and proper community exit and sustainability processes must be followed in order to maintain and sustain these benefits.

TABLE OF CONTENTS

1. INTRODUCTION

The effective use of solar still plants for the production of potable water for small rural communities in arid regions in Southern Africa has been demonstrated as part of an earlier Water Research Commission (WRC) project (K5/1032). It has been shown that this technology offers an economic alternative to fresh water piping or transport. In many of the target communities other desalination techniques cannot be considered due to either the small size of the community, the lack of electricity supply, or the incapability of the community to manage/maintain sophisticated purification equipment.

Kerkplaas is a Mission Station situated approximately 15 km's from Ladismith (Western Cape), 315km from Cape Town, about 115km from Oudtshoorn, a regional centre, and about 160km from the coastal town of George. For most of the year, the community comprises of mostly older people and young children. Those of working and school-going age reside in boarding school residences or in places of work. The main water problem, as experienced by the community, is that the raw water is extremely saline, making it unsuitable for use in daily domestic activities, such as cooking, drinking and washing- person and clothing. As a typically rural community, the Kerkplaas residents obtain an income from seasonal work on the surrounding fruit farms and for the rest of the year they are unemployed.

The maintenance and operation of the solar still was the responsibility of the project team, and this must now be transferred to the relevant Local Authority as the project is in its final stage. It thus became necessary, for the sustainability of the desalination plant, to gauge the perception and opinion of the Kerkplaas community around this transfer. To this end, a community impact study had to be conducted to establish the perceptions and opinions of the community around future operations and management of the plant.

2. AIM

The aim of the study was to investigate the socio-economic impact of a complete distillation plant on a typical target community in Kerkplaas.

3. OBJECTIVES

- Explain the community participation process
- Describe the community's perception and understanding of the plant
- Determine the benefits to a typical target community
- Describe the level of acceptance
- Investigate the preparedness to pay for water produced by the plant
- Identify factors that will promote sustainability of the management, operation and maintenance of the plant

4. METHODOLOGY

4.1 Study Design

The research made use of a qualitative research method commonly known as focus group technique. The Kerkplaas community was divided into two groups of 5 persons. Each household in the community was represented. This technique allowed the researchers to look at unanticipated issues by exploring how the community perceive and conceptualise issues as expressed through their own opinions and concerns. The focus group technique encourages interaction and data was produced via the group dynamics. During these group settings participants provided checks and balances, thus minimizing false or extreme views.

4.2 Data Collection

Group discussions were facilitated through open-ended questions and the answers recorded by a rapporteur. Tape recordings in conjunction with written notes were used. Probing techniques were utilised when respondents gave incomplete or irrelevant answers. The facilitator controlled the discussions and balanced out participation, thus preventing individuals from dominating the discussions.

4.3 Data Analysis

After the sessions the researchers assembled the notes, summaries, pictures and analysed frequently aired opinions, trends and patterns.

5. FINDINGS

5.1 Community Profile

The community of Kerkplaas prior to 1999 consisted of 7 households with a population of 25 people. Over time many of the community members have left to seek opportunities for employment and education purposes in the nearby towns. This continuous movement of people out of the community has changed the population makeup leaving only the elderly and young children at home during the week. The number of households has been reduced from the 7 in 1999 to 5 in 2003. The basic household source of income is mainly from government grants and pensions.

The houses are well constructed with basic materials such as: cement and clay bricks for the walls, metal and wooden frames for the windows and corrugated sheeting for roofing. Fossil fuels seem to be the main source of energy. Wood stoves are used for cooking and together with paraffin for heating during winter. Candles and lamps provide illumination during the evenings.

There are no recreational facilities in Kerkplaas itself but community members find relaxation through a game of dominoes.

Table 1: *Age and Gender Breakdown*

Age (in years)	Total (Female)	Total (Male)	Total (for ages
< 5	0	0	0
6 – 13	2 (10%)	0	2 (10%)
14 – 18	1 (5%)	4 (20%)	5 (25%)
19 – 30	1 (5%)	1 (5%)	2 (10%)
31 – 45	1 (5%)	1 (5%)	2 (10%)
46 – 55	3 (15%)	1 (5%)	4 (20%)
56 – 60	2 (10%)	1 (5%)	3 (15%)
> 60	1 (5%)	1 (5%)	2 (10%)
Total (for gender)	**11 (55%)**	**9 (45%)**	**20**

Table 2: *Education levels*

Education level	Total community members
Primary school complete	6 (30%)
Primary school incomplete	2 (10%)
Secondary school complete	0
Secondary school incomplete	12 (60%)
Post-secondary qualification complete	0
Post-secondary qualification incomplete	0

5.2 Water Problem Before the Project

Before the Project was introduced, the community fetched water from a well. When there's no rain then there's no fresh water. The well has dried up and they had to make use of borehole water. The borehole water is very brackish, salty, unsuitable for consumption and only used for washing clothes and not drinking. Various people remarked that if coffee is made it tastes like seawater and one could actually taste the salt. Both groups reported that if you boil the water then there's a stony and lime-like residue that remain in the pot.

5.3 Community's Perceptions of Project Aims

The responses given was that the projects aims were to:

- Change the water
- Make it softer
- Purify it so that they could make food and coffee
- Remove the salt form the water

5.4 Project Initialisation

The project began with Andrew testing the water on request from his cousin in the community. The test results indicated that the water was unfit for human consumption. A meeting was then arranged with the community. The main initiators were Andrew, F Plaatjies, Bob Reinecke and the then Pastor. The whole process is illustrated in Fig 1 and Fig. 2.

Fig. 1. Project Initialisation and Community Participation

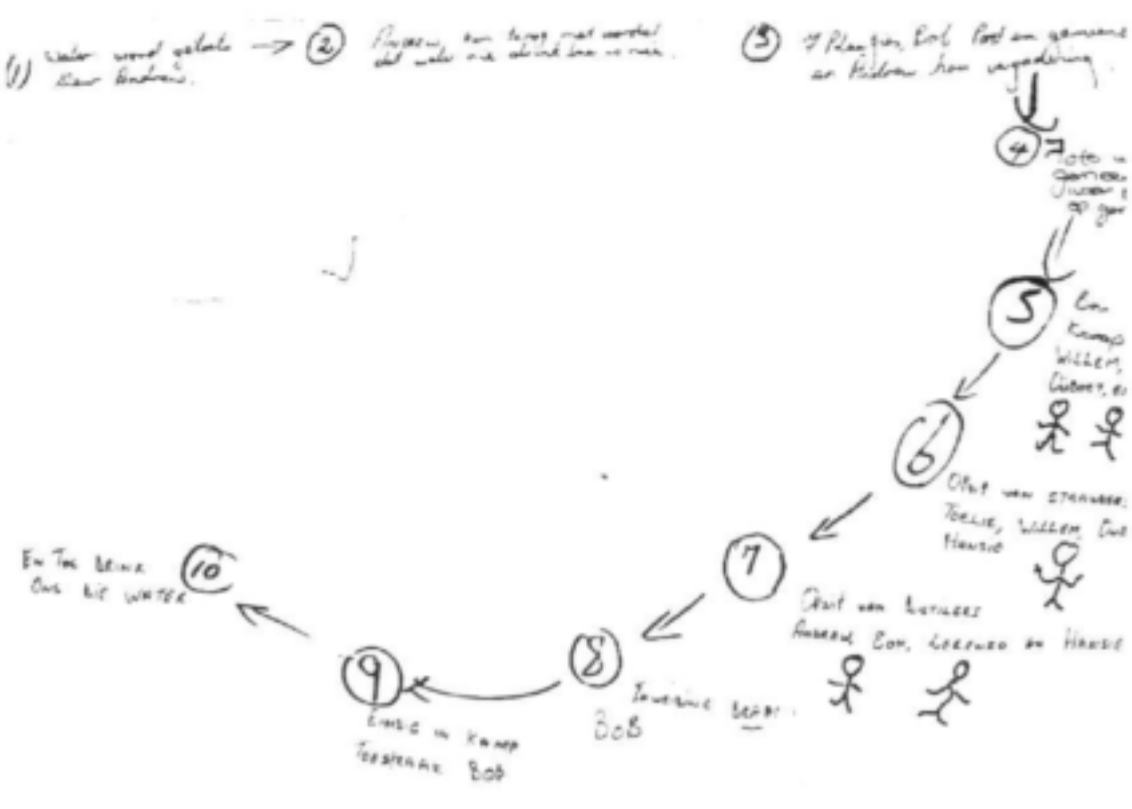
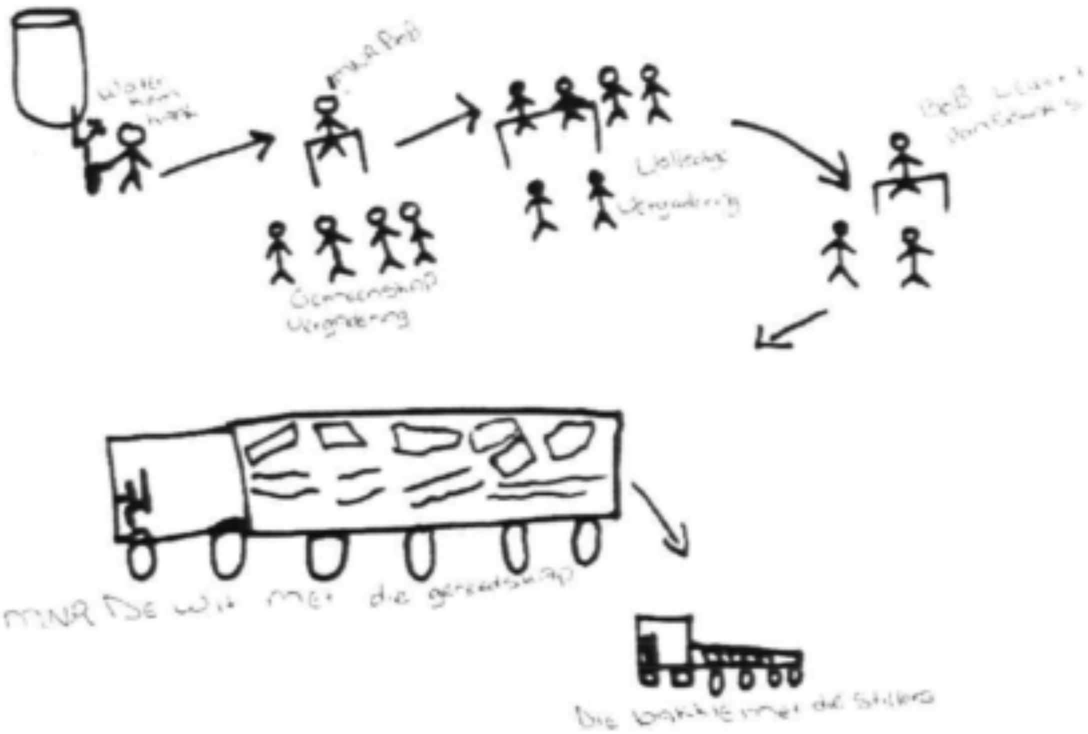


Fig. 2. Project Initialisation and Community Participation



5.5 Community Involvement

Figures 1 and 2 also illustrate that the community was involved from the initialisation phase right up to the construction phase.

5.6 Acceptance of Water Project

At first some of the community members were very sceptical about the process of desalinisation. They wondered how the salt would be removed out of the water. They now accept the Project fully because they are experiencing the following benefits:

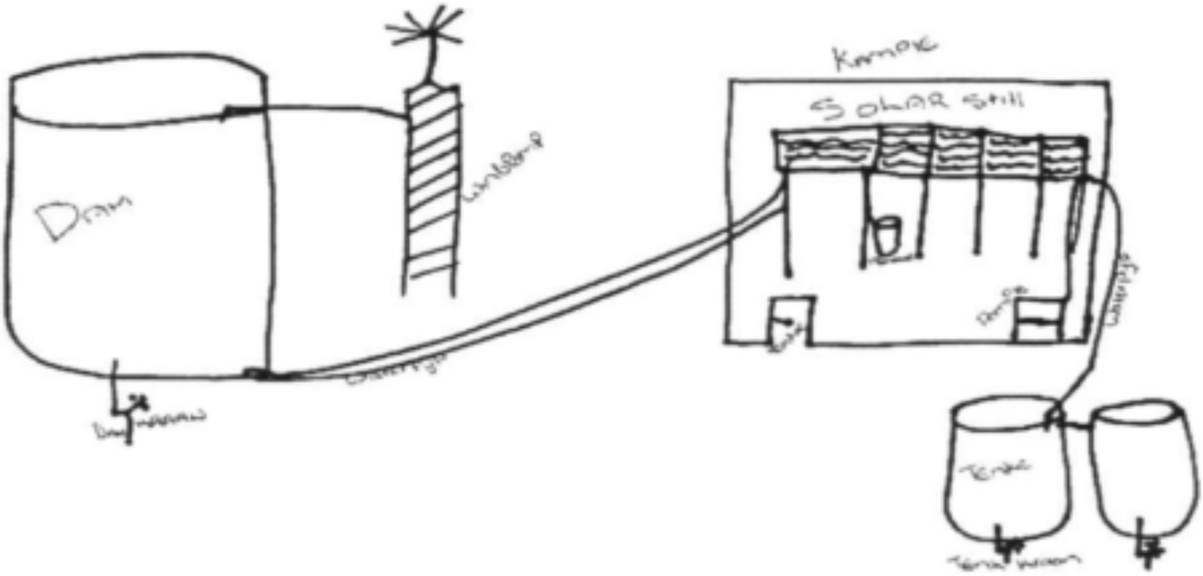
- The water is nicer and taste better and the people who never drank Kerkplaas water are now drinking it. Even the people from surrounding communities, townspeople and visitors are now enjoying the water.

- There are no residuals in the pots and cups
- The water foams faster and better
- Food cooks soft at a faster rate
- More water is available for consumption
- Better looking colour
- It is cleaner, shinier and fresher

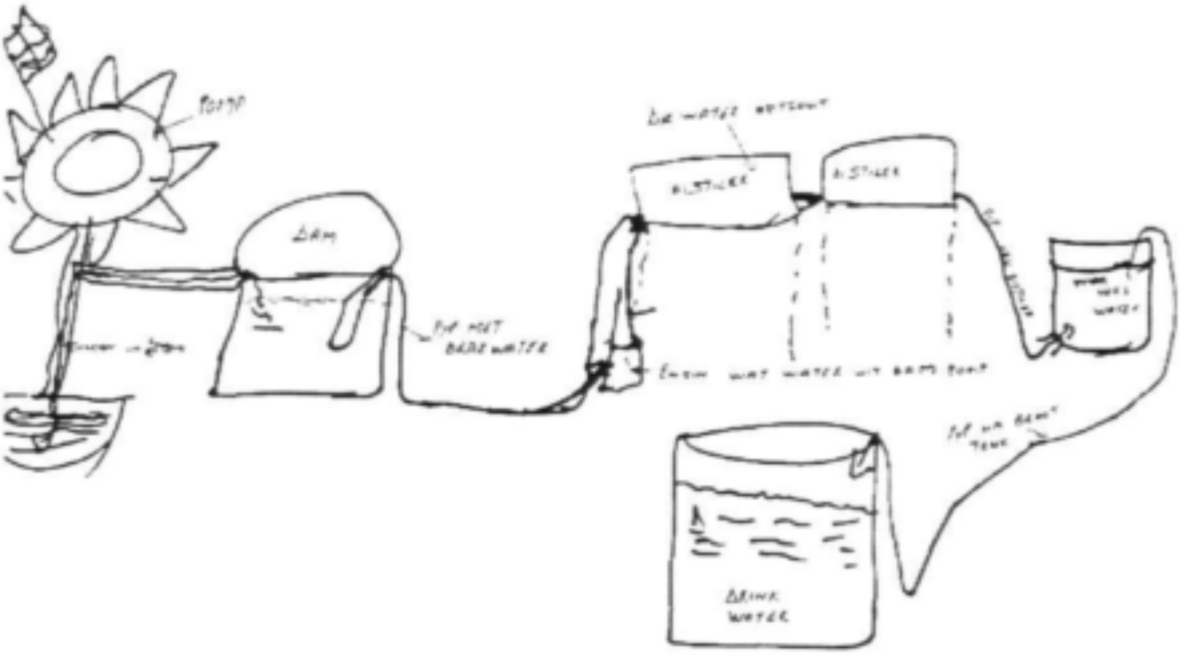
5.7 Understanding of how the Technology and Water Supply Process Works

Figures 3A and B illustrate that the community is not familiar with the correct technical/scientific terms but have a solid and good understanding of how the technology works to supply fresh water.

Figure 3. Technology and Water Supply Process (3A)



(3B)



5.8 Perception of Water after Project Introduction

The groups reported that they can see a clear difference regarding the quality and taste of the water. The water is used frequently and therefore do not stand in the tank for long periods. They also referred to the benefits as mentioned previously. One response was that they are using the project water more and more for food and drink.

5.9 Distribution of Water to the Community

The groups responded by stating that the water was fairly distributed among community members. Everyone receives water when they need it, even if it is for their visitors. The tap on the tank is locked in times of scarcity and the supervisor only opens up once a day. During these times the community fetches water at the same time and everyone gets the same amount. If Oom Hansie goes on vacation, the15 year old son of a community member takes over. If both of them are away a responsible person in the community is asked to take over the water distribution duties.

5.10 Recommendations for Technical Improvements

The groups suggested no recommendations and this was mainly due to the high reliability of the water supply. The tanks sometimes run low but never empty.

5.11 Recommendations for Water Supply Management and Community Involvement

The groups emphasised the strong dependency on Oom Hansie. One group responded by saying that even if Oom Hansie is sick he must still see to the plant. This dependency will be minimized if assistance is found for Oom Hansie because no one else knows what is going on with the Project duties. It is recommended that the relief be an adult because the youth are not reliable and you need an adult to prevent the children from throwing objects onto the panels.

5.12 Project Management as from January 2004

The groups requested that the Kerkplaas people must be involved with the municipality through an equal partnership. They felt strongly that the management body must be in Kerkplaas and that the current management principles and style be upheld. The community are used to having their interests met and if they keep Oom Hansie in his position they will still have a voice. If the Municipality takes over they might loose their voice. One person indicated that there is no need for the municipality to take over. There were also fears that if the Municipality takes over the community might have to pay for water that is currently free.

5.13 Day-to-Day Operations as from January 2004

As a community we must choose a person who can maintain and give advice if problems occur. A community manager will always be in charge and any problems will be reported to the municipality. Suggestions were for a group or a forum to handle the project. Problems envisaged are that the Municipality will say we must pay for water because they can't come regularly due transport costs of municipal officials.

5.14 Information Required Before Handing Over to the Municipality

Responses were that the community is not well informed regarding the ending and handing over of the Project. They are also not familiar with the municipality's water installations and regulations. Clarity is needed on who will be in charge of the water and who will manage it. Currently there is no formal agreement and this also needs to be cleared out. One group indicated that there is a current problem with community cohesiveness and that they do not know how to foster community participation and cohesion.

5.15 Willingness to Pay for Plant Maintenance

There were mixed responses from the group. One group indicated that they have paid at some stage for routine maintenance by organising a song evening to purchase pipes. The community has a nest egg but they usually take out of their own pockets. One person remarked that if the municipality takes over and he must pay for water then they could take the Plant away! Others felt that they are willing to pay but the community must stand together to raise funds and not wait for municipality to come and fix it. They will sort it out themselves by meeting to discuss the problems.

5.16 Success of the Project

The Project was a great success because there has been no breakages, people don't neglect it, community accepted it, school kids don't play there they grew up with the project. The project is maintained in a good condition and is still the same as when it was built.

6. DISCUSSION

The growth and development of technology creates unprecedented potential for sustainable livelihood. The community development and participation process in technology acceptance and usage in Kerkplaas has been properly introduced and the proper entry methods were followed. The positive initiatives and activities associated with water and water usage has been successfully integrated with the livelihoods of the Kerkplaas community.

A partnership is as an evolutionary process that starts with planning and ends with changes in the broader society. A strong partnership was formed between the community and all stakeholders with the project. This resulted in a high level of acceptance, understanding and positive perception of the distillation plant. The changes in the broader society are evident in the benefits that they are reaping.

Some major problems faced by the Kerkplaas community are the high unemployment rate and lack of income. The community is willing to raise funds for minor maintenance but is strongly against paying for water usage.

The handing over of the project to the municipality is a critical issue. Communities and authorities should be flexible in meeting each other's changing needs. Greater flexibility is strongly associated with greater responsiveness to needs. It is essential to maintain high ethical standards as ethical failures create distrust among community members. Community and the authorities don't have to have equal skills, funds or even confidence but they do have to trust each other and share commitment. Ethical action is the only hope for developing and maintaining trust.

The processes of capacity building and empowerment was focused on a single member hence the strong dependency on that person. Capacity building should include an active process of how to harvest it and should be extended to the broader community. Capacity building is based on the premise that people can lead their own change processes in order to become actors and not merely subjects of change.

Clear distinction must be made between empowerment and sustainability. The confusion arises when empowerment is seen as sustainability. The fact that partners have been capacitated and empowered does not mean that they are now fully sustainable. Sustainability is a process on its own and should have been properly introduced at the start of the project. Community persons should be educated on this process and the consequences of sustainability should be made clear.

7. CONCLUSION

The project has been a tremendous success in providing free and clean water to the Kerkplaas community. This is evident in the many benefits that the community are reaping as a result of this project. A major shortcoming is that capacity building and empowerment mainly concentrated on the day-to-day operation and management of the distillation plant. The community was not capacitated on how to absorb and execute the activities and responsibilities of the project team. It is vital that the capacitating and empowerment processes include aspects of sustainability and broadened to the rest of the community.

8. RECOMMENDATIONS

The following are recommended in order to maintain and sustain the benefits of the distillation plant:

1. The community have great respect and obedience towards their leadership. The pastor, schoolteacher and two elders should represent the community in all stakeholder meetings and negotiations regarding the project exit process.
2. Visibility is important to the community. The representatives of the municipality must introduce themselves and it must be made clear as to what their portfolios and responsibility are in terms of the distillation plant.
3. Capacity building and empowerment workshops should be held with the main focuses on fostering community cohesiveness, power relations, decision making, goal setting, effective communication, resource generation and utilisation, devolution of responsibilities, local government governance and operation.
4. A memorandum of understanding or an agreement must be reached with the Kerkplaas community regarding the operation and maintenance of the distillation plant. This must happen before the handing over of the project. The handing over should be a visible one and take place at Kerkplaas and not administratively in an office.

Other related WRC reports available:

Development of a solar powered reverse osmosis plant for the treatment of borehole water

GJ Louw

The main aim of the project was to design and construct a reliable reverse osmosis (RO) unit, powered by solar energy which was capable of producing potable water from brackish borehole feed for rural households or small communities. The concept is relevant to areas where small communities are spread over large areas, where the high cost of erecting large desalination plants and reticulation of desalinated water, or, alternatively, the piping of freshwater from other sources, is neither practically nor economically viable.

The unit was evaluated at a few relevant sites over an extended period. It proved to be easy to operate, very durable, and required little maintenance. Additional operator input did, however, prove to increase production, although stand-alone operation rendered acceptable production figures. The test work, completed mainly during the winter months, indicated that the unit produced potable water at 750 ℓ/d with little input from an operator. This is sufficient to supply a full water service to five rural units or to meet the drinking water requirements of up to 40 people in a rural setting. Basic and practical guidelines are provided for the sizing and choice of a reverse osmosis unit and a solar cell combination, which will be useful to all consultants and decision-makers responsible for the planning and implementation of water supply from saline groundwater sources.

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