SOLAR HEATING AND DISINFECTION OF WATER

An Application for Rural Areas in Southern Africa

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ABSTRACT

Life is not easy for the low-income rural population of Southern Africa. This includes those living in the informal settlements around cities. It is in part due to shortcomings in basic services such as water, sanitation and electricity.

More than half of the households are without running water. One of the day-to-day problems is gathering and carting sufficient water for domestic use from communal water sources. The water is often of dubious quality, and waterborne pathogens cause a range of bacterial, viral and parasitic diseases. Children and people with compromised immunities are especially at risk.

Traditional energy sources for heating this domestic water, such as firewood and charcoal, are also scarce and expensive. This, inevitably, leads to a compromise in hygienic practices, and have a negative outcome on the health of the people.

A device is thus envisaged that can assist the people in transporting, disinfecting and heating their water. The use of solar energy for heating the water will reduce the dependency on traditional and conventional energy sources. Southern Africa is blessed with abundant solar insolation. As a result, solar water heating was selected to be used for this device, but it must then have the ability to store the hot water until at least in the evening.

The technology and regulatory background of solar water heating were studied. An ICS type solar water heater, with insulation and glazing, was selected for implementation. The mobility of the device was modelled on the familiar wheelbarrow; therefore the device was christened as the *Solar Heat Barrow*, or *SHB*. The physical and performance requirements of the *SHB* were determined and specified.

A study of the history and practice of water disinfection led to the realisation that solar pasteurisation, though possible in the *SHB*, will not reliably meet the day-to-day requirements. An additional requirement for chemical disinfection was formulated. A concept was generated for a disinfectant dispenser that could be added to the *SHB* where necessary. This device was named the *Dispenser*. It could, however, not use

chlorine as disinfectant due to the chemical's sensitivity to heat degradation. A South African produced disinfectant, *Steripure*, was then selected for this purpose.

Prototype *Solar Heat Barrows*, in two batches of ten and fifteen, were manufactured using representative processes. The first batch was tested for performance and conformance to requirements. It showed that the goals set were mostly fulfilled. In mid-winter, water could be heated to an average of 60°C by mid-afternoon. Water at 40°C was still available at 20:00, and this performance could easily be improved with simple human intervention. Some problems were experienced in both manufacturing and testing. It can, however, be solved with relatively straightforward development of the device.

A single prototype of the *Dispenser* was also manufactured. It served the purpose of proving the functional principles, and a large scale manufacturing approach would be needed for further development. The manufacturing process thereof especially has to be addressed. The use of *Steripure* in the *Dispenser*, from the perspectives of both disinfection and longevity at temperature, will also have to be proven.

The commercial viability and user acceptance of the *Solar Heat Barrow* were evaluated. A costing exercise showed that the direct production cost of units would come to approximately R 380. With the additional costs of operations, distribution and marketing, the units would have to sell for at least R 600 to be commercially viable. This would depend on a market for 60 000 units over a five year period, which was shown to be realistic. Assuming the same market, the *Dispenser* will have to be sold for at least R 100 to be commercially viable.

Users in the rural community of Mabedlane, KwaZulu Natal, evaluated the second batch of fifteen SHB units over a two-month period. Although they were more than satisfied with the performance of the *SHB*, none could afford to pay more than R 100 for the product. Other surveys in the informal settlements around Pretoria indicated that a selling price of R 300 could still attract reasonable sales. It was, however, shown that a policy environment does exist, in South Africa in particular, to count on institutional support for some of the shortfall in affordability.

ACKNOWLEDGEMENTS

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NOMENCLATURE

Abbreviations and Acronyms

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CAD	Computer aided design
CARE	Cooperative for Assistance and Relief Everywhere International
CCC	Chlorine Chemistry Council
CDC	Centers for Disease Control and Prevention
CDM	Clean Development Mechanism
COTS	Commercial off the shelf
CSIR	Council for Scientific and Industrial Research
DH	Department of Health
DME	Department of Minerals and Energy
DOH	Department of Housing
DWAF	Department of Water Affairs and Forestry
DTI	Department of Trade and Industry
ECA	United Nations Economic Commission for Africa
EHP	Environmental Health Practitioner
EPA	Environmental Protection Agency
EPDM	Ethylene-propylene-diene terpolymer
EUWAG	Swiss Federal Institute for Environmental Science and Technology
HDPE	High density polyethylene
ICS	Integrated collector storage

IMDG	International Maritime Dangerous Goods
ISO	International Standards Organisation
ISO/TC	Technical Committee of ISO
LDPE	Low density polyethylene
LLDPE	Linear low density polyethylene
MUE	Maximum useful efficiency
NaDCC	Sodium dichloroisocyanurate
NBR	Acrylonitrile-Butadiene Rubber
NBRI	National Building Research Institute
NC	Numerically controlled
NCF	Net cash flow
NGO	Non-governmental organisation
NPV	Net present value
NTU	Nephelometric turbidity units
ORS	Oral rehydration solution
PAHO	Pan American Health Organisation
PASASA	Paraffin Safety Association of South Africa
PC	Polycarbonate
PE	Polyethylene
PET	Polyethylene terephthalate
PP	Polypropylene
PV	Photo-voltaic
RDP	Reconstruction and Development Programme
R&D	Research and Development
SABS	South African Bureau of Standards
SANDEC	Department of Water and Sanitation in Developing Countries

SANS	South African National Standard
SDWH	Solar domestic water heater (or heating)
SHB	*Solar Heat Barrow*, the name selected for the device defined here.
SM	Standard Method
SMME	Small, medium and micro-enterprises
SODIS	Solar Disinfection, the SANDEC process.
SWH	Solar water heater (or heating)
TCC	Trichloroisocyanuric acid
TDS	Total dissolved solids
TIM	Transparent insulation material
TON	Threshold odour number
UNICEF	Originally "United Nations International Children's Emergency Fund" but shortened to "United Nations Children's Fund" in 1953.
uPVC	Unplasticised Polyvinyl Chloride
USAID	United States Agency for International Development
USPC	United States Peace Corps
UV	Ultraviolet
WAPI	Water Pasteurisation Indicator
WHO	World Health Organisation

Symbols

α	Absorptivity of collector surface (dimensionless)
α_1, α_2, α_3	Empirically determined constants for SWH system
η	Collector efficiency to ASHRAE
η_w	Dynamic viscosity of the water (Pa.s)
ρ	Density of working fluid in collector (kg/m^3)
ρ_s	Solid density (kg/m^3)
ρ_w	Water density (kg/m^3)
Φ	Void fraction in bed
τ	Glazing transmissivity (dimensionless)
Δp	Pressure drop across filter bed (Pa)
μ	Maximum useful efficiency, or MUE (dimensionless)
A	Collector aperture area (m^2)
C_P	Specific heat capacity of working fluid (J/kg.K)
C_s	Total heat capacity of hot water mass in storage tank (J/K)
C_w	Specific heat capacity of water (J/kg.K)
D_p	Diameter of particle (m)
D_b	Diameter of filter bed particles (m)
F_R	Collector heat removal efficiency factor (dimensionless)
g	Gravitation constant (9.81 m/s^2)
H	Daily solar irradiation at collector aperture (MJ/m^2/day)
H_w	Convective heat transfer coefficient (W/m^{2}K)
I	Solar energy incident on collector surface (W/m^2)

k	Cost of capital, as a fraction of 1
L	Thickness of filter bed (m)
M_w	Mass of water contained in the ICS SWH (kg)
n	Life of a product in total number of time periods
p	Time period or financial calculations
Q	Daily heat output of system ($MJ/m^2/day$)
Q_u	Useful energy delivered by collector to the working fluid (J/s)
t	Time (s)
T_a	Ambient air temperature (°C)
T_{aav}	Average ambient air temperature (°C)
T_{cav}	Average cold water inlet temperature (°C)
T_{fin}	Final temperature of the water (after mixing) in storage tank (°C)
T_{in}	Working fluid inlet temperature (°C)
T_{init}	Initial temperature of water in storage tank (°C)
T_{mav}	Averaged maximum temperature reached by the water (°C)
T_{out}	Outlet fluid temperature from collector (°C)
T_{pav}	Average temperature of collector plate surface (°C)
T_{sav}	Averaged starting temperature of water at sunrise, or at filling (°C)
U_L	Overall heat loss coefficient (W/m^2K)
U_s	Heat loss coefficient of specific hot water storage tank (W/K)
u_s	Settling velocity (m/s)
V'	Volume flow of water through collector (m^3/s)
v_s	Superficial flow velocity (m/s)
V_w	Wind speed (m/s)

CHAPTER 1: INTRODUCTION

1.1 Background

Living in Southern Africa's[1] rural areas[2] is neither for the faint hearted, nor for those with sensitive dispositions.

One of the problems for people living here is access to water in general for domestic use and drinking water. Both the quantity and quality of available water leave much to be desired for. Personal hygiene and health of the inhabitants are therefore compromised as a result.

1.1.1 Rural water sources

Most governments in Southern Africa, and the South African government in particular, are hard at work to establish an adequate supply of potable water to all its subjects. Reports on new and improved rural water schemes are at the order of the day. A basic appreciation of the logistics involved, however, suggests that this supply, to every individual household, will not be established in the immediate future.

A survey by Taylor (2001) in urban and peri-urban informal settlements in and around Pretoria suggests that about half the people living here does not have access to running potable water at their houses. Communal taps are, however, available, and are connected to the main potable water supply system. The average collection distance for water from the communal taps is 150 meters, with some people having to collect water from as far as a kilometre away.

Another survey conducted by Le Roux (2003) in Mabedlane, rural KwaZulu-Natal, shows that 60% of people depend on water collection directly from the Umngeni river, while the rest collect water from communal taps in the settlement.

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[1] Southern Africa is defined for the purpose of this study as those parts of the countries of South Africa, Lesotho, Swaziland, Mozambique, Namibia, Botswana, Zimbabwe, Angola, Zambia, Malawi and Madagascar south of the 15° southern latitude.

[2] Included in these areas are not only the deep rural areas far from the main centres, but also the hallmark urban and peri-urban informal settlements of Southern African cities.

Other common water sources include boreholes, dams, lakes, stored rainwater, and even stagnant pools in the dry season. Very few of these sources are formally treated to ensure a potable quality of water supply.

1.1.2 Common waterborne diseases

Outbreaks of cholera, a disease causing diarrhoea and vomiting, are regularly reported in the Southern African media. With every outbreak the efforts by governments and NGO's to solve this recurring problem are debated (Riley *et al,* 2001; Rapport, 2002; This Day, 2003). Bulletins also warn those with a choice how to avoid infection (Netcare Travel Clinics, 2001), or on the status and risks of temporary vaccines (CDC, 2002[a]).

A South African study of surface water health risks (Kühn *et al*, 2000) showed that most of the surface water in the study areas had very high to high potential health risks due to faecal pollution of the water. This is shown as the red (very high risk) and yellow (high risk) areas in Figure 1-1.

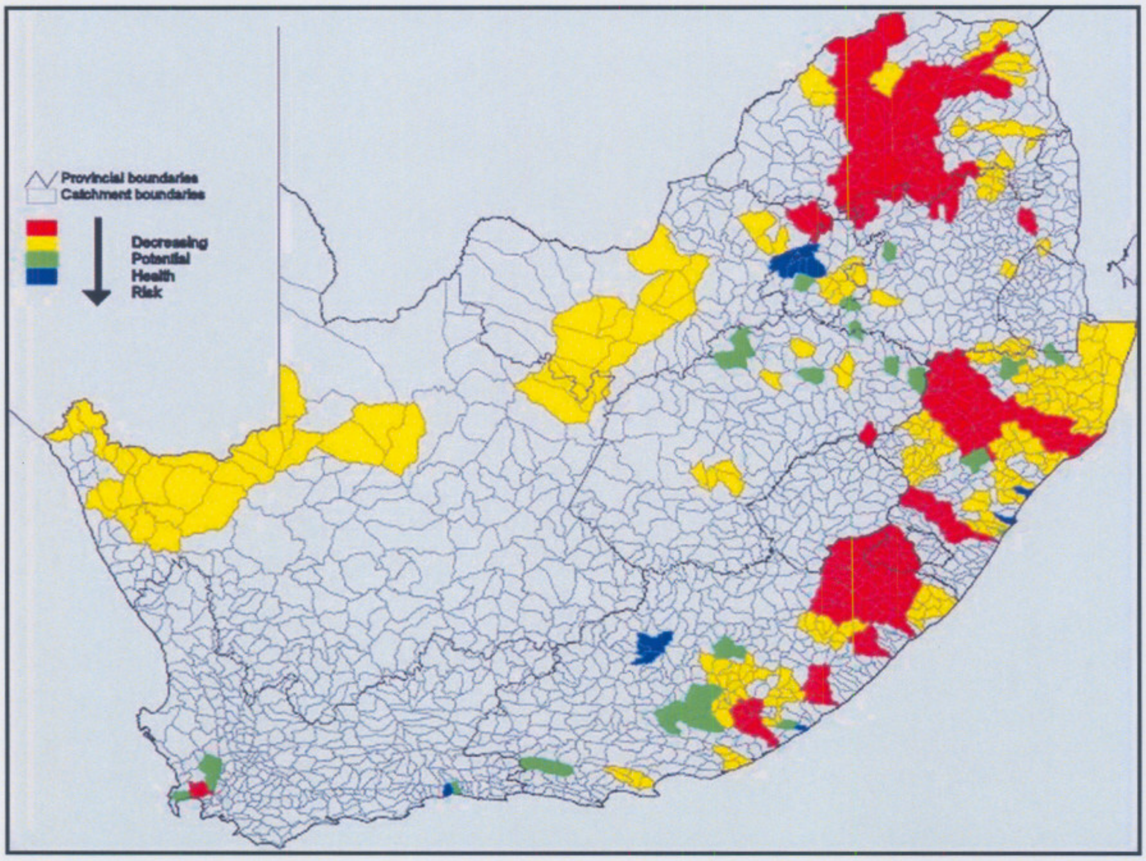

Figure 1-1: Health risk areas in RSA due to faecally polluted surface water (Kühn *et al*).

South Africa specifically has not had serious cholera epidemics in the decade preceding the turn of the millennium. Her north-easterly neighbours, however, did have a relatively high incidence of endemic cholera. In late 2000 this cholera spilled over into South Africa and caused a major epidemic.

The cholera epidemic as such was only declared over in April of 2002. Figure 1-2 and Figure 1-3 show the total number of cholera cases and fatalities for the period as reported by the National Disaster Management Centre (NDMC, 2002). The relatively low number of fatalities can only be ascribed to a robust health system harnessed against the disease. Other Southern African countries do not all have such robust health systems, with the result that higher fatality rates can be expected during cholera epidemics.

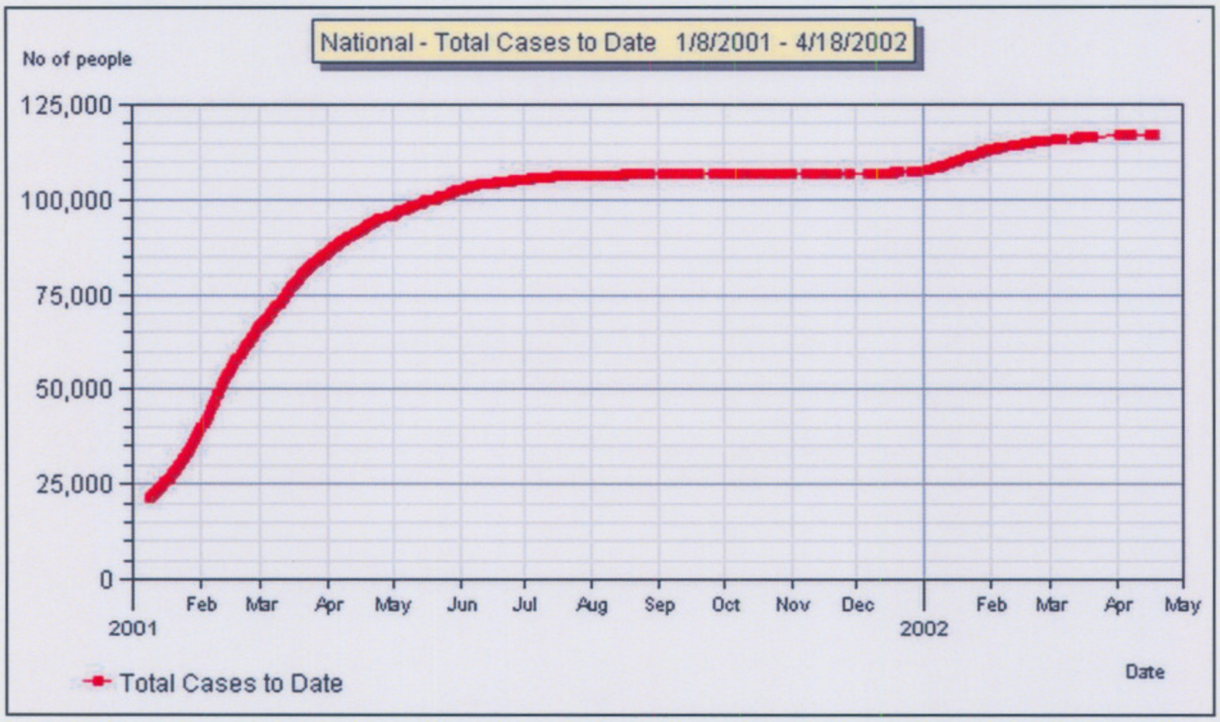

Figure 1-2: Cholera cases during 2001 – 2002 epidemic in RSA (NDMC)

Notifiable disease statistics from the South African Department of Health (DH, 2003) also show that, especially since the abovementioned cholera epidemic, the number of cholera cases and -fatalities is comparable to the number of malaria cases and -fatalities. This is shown in the comparative graphs of Figure 1-4 and Figure 1-5.

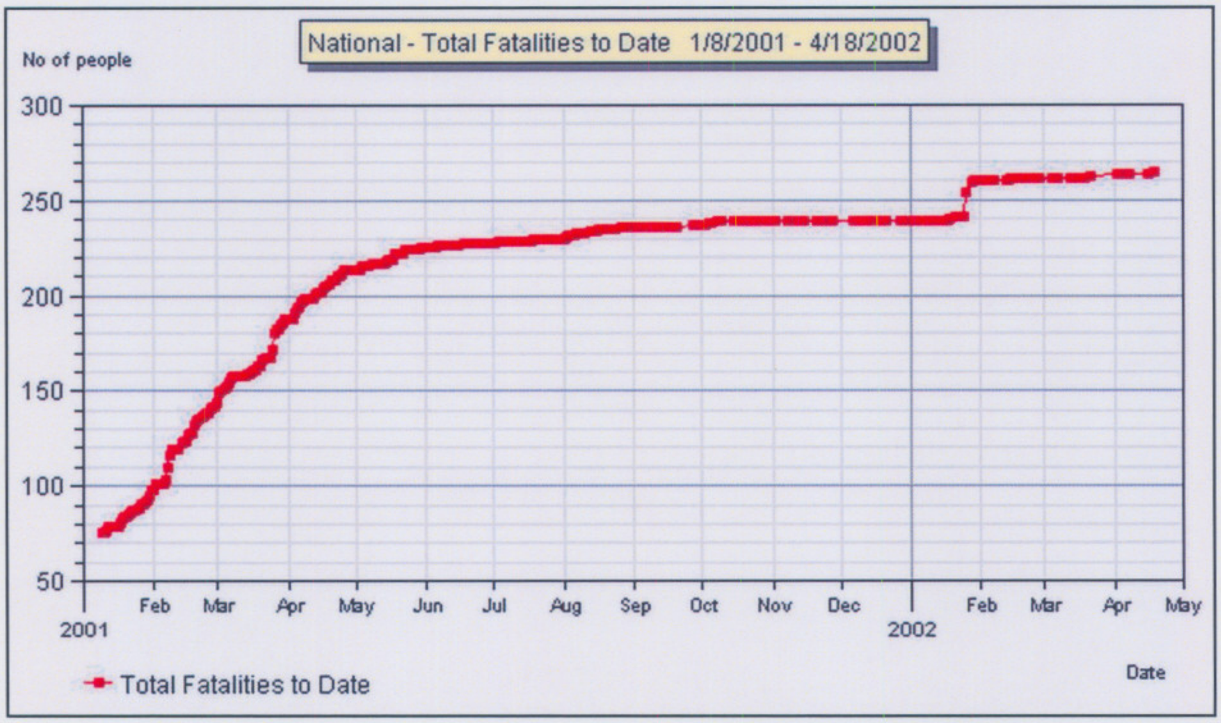

Figure 1-3: Fatalities during 2001 – 2002 Cholera epidemic in RSA (NDMC)

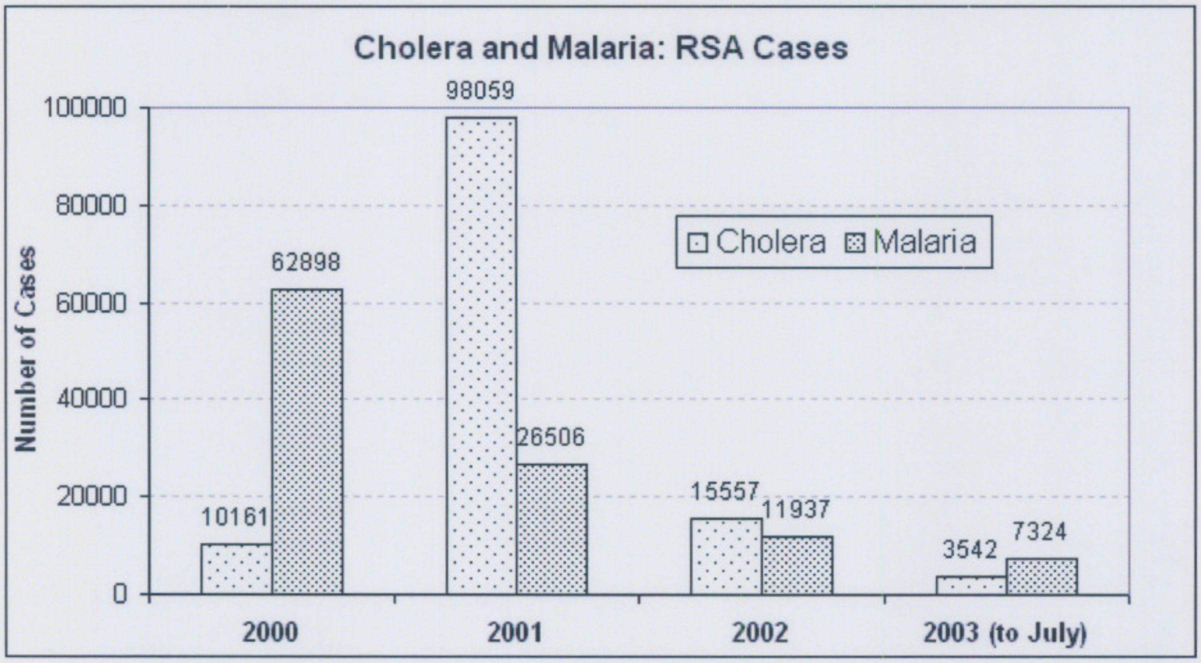

Figure 1-4: Cholera and Malaria cases in RSA (DH)

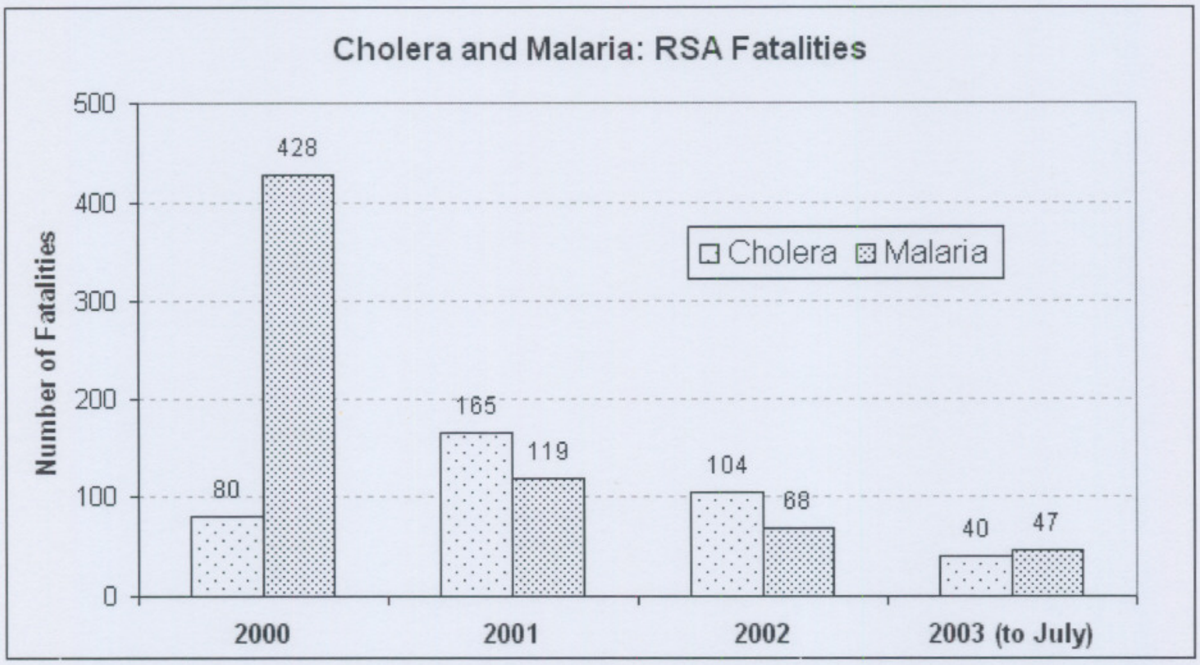

Figure 1-5: Fatalities due to Cholera and Malaria in RSA (DH)

Cholera is, however, not the only waterborne disease in Southern Africa. Though not as common in Southern Africa, a host of other bacterial, viral and parasitic infections can be contracted from the use of contaminated water (Burch & Thomas, 1998).

The most common bacterial waterborne diseases are described by the globally authorative Centers for Disease Control and Prevention (CDC, 2002[b]). The bacterial pathogens of concern are:

- *Vibrio cholerae*, causing cholera with profuse watery diarrhoea and vomiting. It commonly originates from undercooked fish and shellfish, but is then easily transmitted through the faeces of infected persons, often causing epidemics.
- *Campylobacter jejuni*, a spiral shaped bacteria causing campylobacteriosis with bloody diarrhoea. It is commonly spread by chicken, bird or cow faeces.
- *Salmonella*, a rod shaped bacteria causing salmonellosis with diarrhoea, fever and abdominal cramps (subtypes *S.typhimurium* and *S.enteritidis*), and the more serious typhoid fever with a mortality rate as high as 20% (subtype *S.typhi*). It is commonly spread by human faeces (all subtypes), chicken eggs (*S.enteritidis*) and reptile faeces (excluding *S.typhi*).

- *Shigella*, a bacteria group that causes shigellosis with fever and often bloody diarrhoea (subtypes *S.sonnei* and *S.flexneri*), and the more serious dysentery fever with a typical mortality rate of 5 –15% (subtype *S.dysenteriae*). It is commonly spread by infected human faeces and the flies breeding in it.
- *Escherichia coli*, coliform bacteria with many different subtypes that causes watery or bloody diarrhoea, with or without abdominal cramps and fever. It is commonly spread though infected human and animal faeces.

The most common waterborne viral infections are the entire enteric group of viruses and are also described by the CDC (2003[a]). Although the acidic environment of the stomach and the bile salts of the upper small intestine form hostile environments for these viruses, they are responsible for a large percentage diarrhoea cases caused by viral gastroenteritis. Transmission of the *enteroviruses* and *Hepatitis A* virus, both in the *picornavirus* family, and the familiar *rotavirus* also follow the oral-faecal route. Under the right circumstances, this may lead to waterborne infection of humans.

Dealing with parasites, the trophozoite, or one-celled parasite, *giardia lamblia* is a major cause of diarrhoea. It causes giardiasis by adhering to the lining of the small intestines (CBS, 2003; CDC, 2003[b]). Its eggs are expelled in the human faeces and can infect water sources thus causing further infection. Giardiasis leads to chronic diarrhoea and dehydration, especially in infants.

Another emerging microscopic parasite is *Cryptosporidium parvum*. It lives in the intestines of humans and animals and is passed in the faeces of both infected people and animals. The parasite and its eggs are protected by an outer shell that allows it to survive outside the body for long periods of time. It also makes it very resistant to chlorine disinfection, resulting in waterborne transmission even if disinfected. The parasite causes so called 'Crypto', or Cryptosporidiosis, with the usual symptoms of diarrhoea, stomach cramps, and a slight fever. Children and sick people are most at risk of severe dehydration.

Worldwide these pathogens cause an estimated 3-5 billion cases of diarrhoea every year. At least half of these infections are caused by waterborne transmission after contamination by human or animal faeces (CDC, 2002[b]). The CDC and UNICEF (MWWR, 1991; CDC, 2002[b]; Burch & Thomas, 1998) conservatively estimate that these cases lead to the death of approximately 3 million people, of which more than half are infants and young children.

Non-diarrhoea causing parasitic infection of humans can also follow the oral-faecal route and may again lead to the contamination of water sources (CBS, 2003). The most common parasites of this type are *Ascaris* type intestinal roundworms occurring in both humans (*A.lumbricoides*) and pigs (*A.suum*), while the hookworm *Ancylostoma duodonale* tends to only occur in humans (CBS, 2003; CDC, 2003[c]). The health effect of these parasites is lung ailments due to juvenile parasite migration to the lungs (roundworms) and anemia due to chronic intestinal bleeding (hookworms).

1.1.3 Water requirements for domestic use

Water is used in rural households predominantly for drinking, cooking and hygiene purposes. The accepted norm in South Africa is that each person in a household requires at least 20 litres of potable water per day, half of which is for personal hygiene use. This corresponds well with studies by Reiff *et al* (1996) in rural Latin America where the average domestic requirement is between 40 and 60 litres of potable water for an average family of five.

Cooking and the preparation of coffee and tea obviously require the boiling of water. Cold water between 5°C and 19 °C is normal for drinking (Health Canada, 1979) and the rinsing of unprepared food. Hot water is usually preferred for hygiene purposes such as bathing and the washing of dishes, and sometimes for the washing of clothes. The survey of rural households in the Pretoria area by Taylor (2001) testifies to this and the results are shown graphically in Figure 1-6.

Further results from this survey shows that the use of hot water during the day is approximately the same for the morning and evening, but with lower use during the afternoon. This is shown in Figure 1-7.

Hot water used in the evening is predominantly for personal hygiene in the form of bathing or washing. Taylor (2001) shows that over 60% of the people interviewed perform this function between six and eight o'clock in the evening (Figure 1-8). This coincides with the time that they would arrive home from work and play.

He further suggests that the temperature for bathing water should be 30°C higher than the temperature of tap water measured at the same time of day. This is a vague value, but in a detailed study, Zingano (2001) deduced that a temperature of around 40-41°C is preferred for bath water in Southern Africa. Of interest is the range of bathing water temperatures, which were from as low as 27°C to as high as a scalding 51°C.

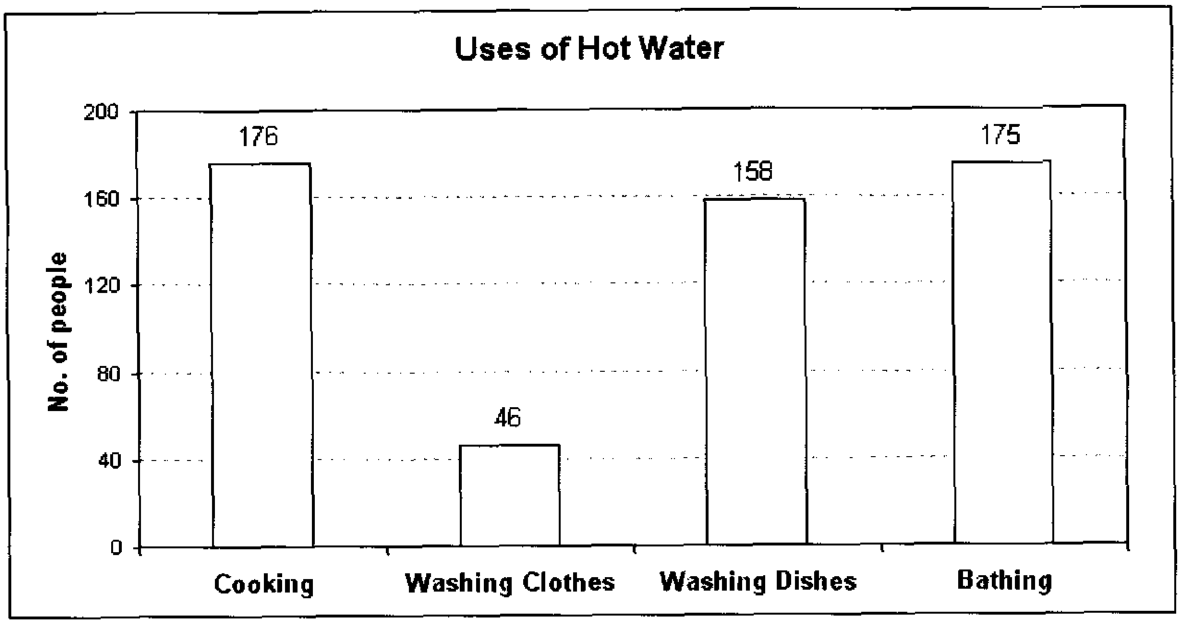

Figure 1-6: Uses of hot water (Taylor)

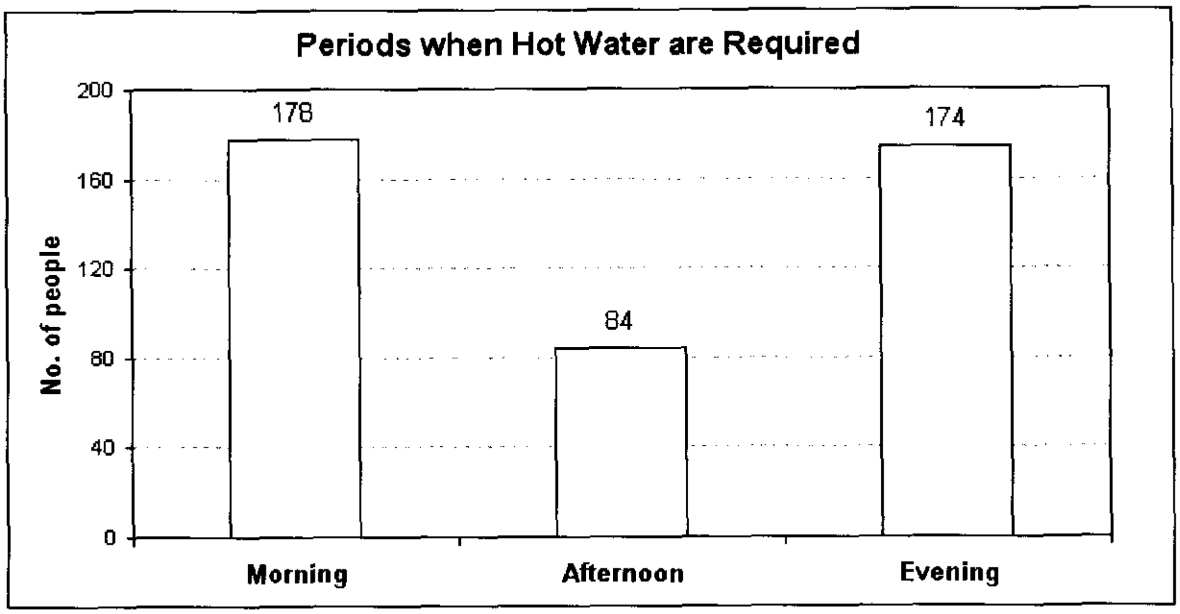

Figure 1-7: Periods when hot water are used (Taylor)

1.1.4 Energy sources for water heating

The traditional energy source for heating water in rural Southern Africa is firewood. Population and environmental pressures, especially around urban centres, caused this once renewable energy source to be over utilised to the point where its use is not promoted any longer (Biermann *et al,* 1999; DME, 2002; Peter *et al,* 2002).

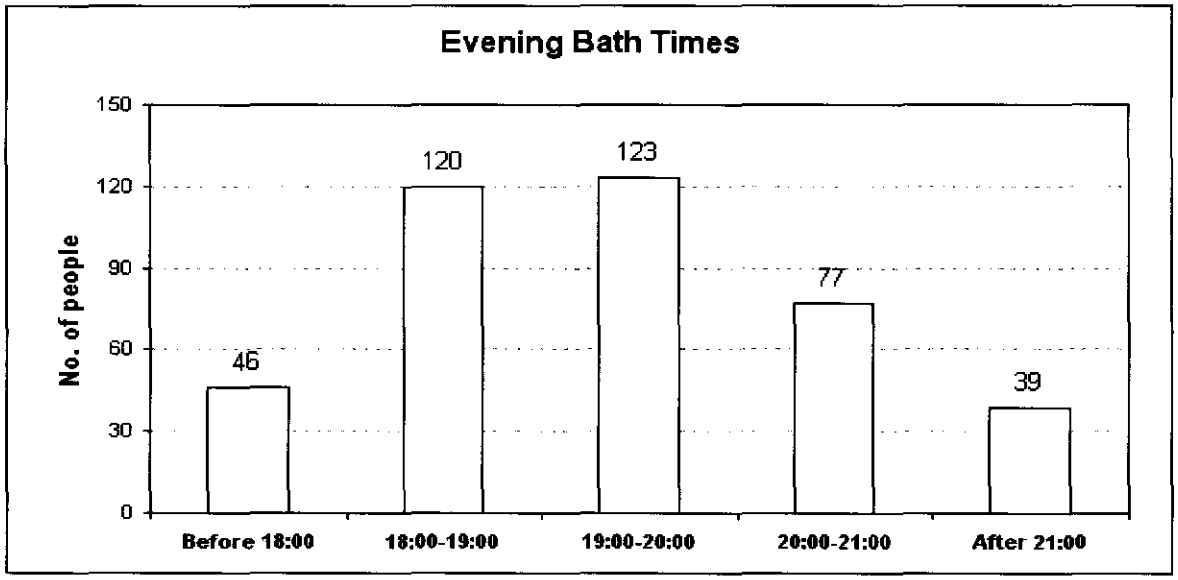

Figure 1-8: Times when people bath at night (Taylor)

Historical factors and a lagging infrastructural supply of electricity to rural areas caused fossil fuels to take the place of wood. Paraffin is the fuel of choice in peri-urban areas (Jones & Thompson, 1996), with electricity making advances in the urban informal settlements as shown in Figure 1-9. The deep rural population is, however, still to a large extend dependant on firewood.

An abundant renewable energy source, in the form of solar radiation is, however, readily available. The distribution of total solar radiation intensity on a global scale is divided into four belts around the earth (Acra *et al,* 1984). These are illustrated in Figure 1-10. The most favourable belts lie between the 15° and 35° latitudes, but is not illustrated accurately as the southern most point of South Africa is just north of 35° south.

In the southern latitudes, it embraces the whole of Southern Africa. There is usually over 3,000 hours of sunshine per year (8760 hours). Of importance is the relatively small seasonal variation in solar intensity.

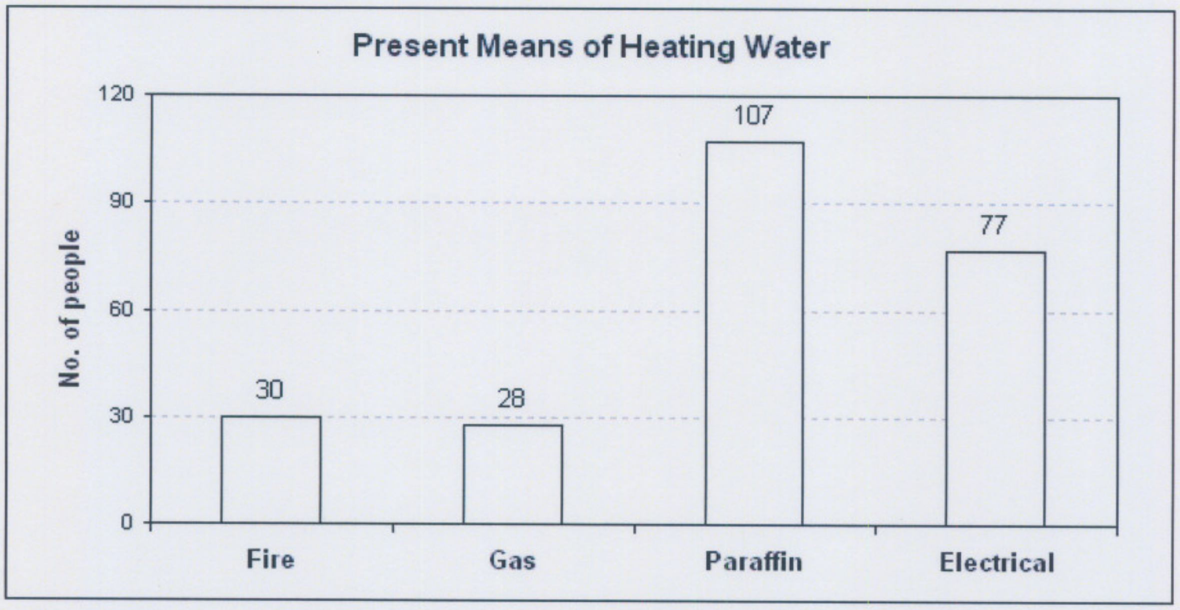

Figure 1-9: Present energy sources use for heating of water (Taylor)

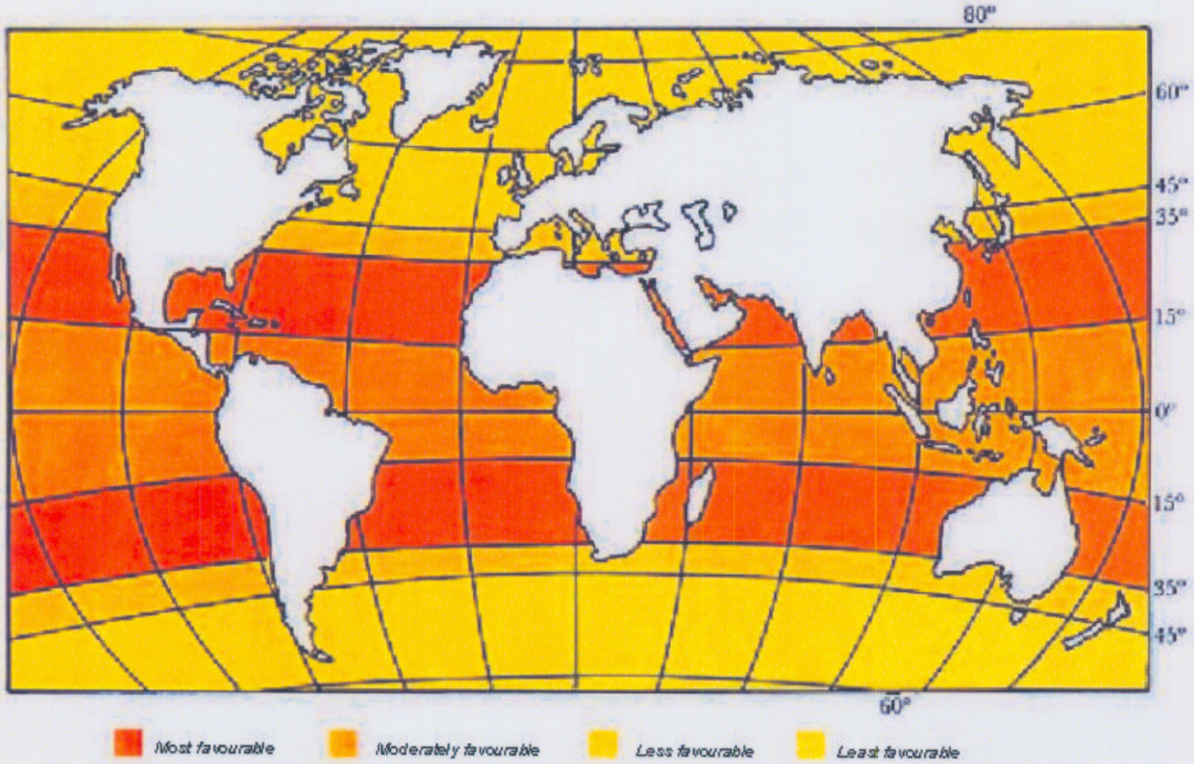

Figure 1-10: Distribution of solar radiation into belts indicating feasibility of solar applications (Acra *et al*)

A less favourable belt lies between the latitudes 35° and 45°. Though the total annual solar radiation is similar to the previous belt, larger seasonal variations in both solar intensity and daylight hours cause solar radiation during the winter months to be lower than for the rest of the year. The southern most regions of South Africa borders on this belt, however, the effect on seasonal variations are amplified by the winter rainfall climate of the coastal regions of the Western and Southern Cape provinces.

Detail studies on available total solar radiation for South Africa gives average yearly insolation of between 6000 and 9500 MJ/m^2 for South Africa (CSIR and Eskom as reported by DME, 2002). This is shown graphically in Figure 1-11. The rest of Southern Africa receives an average yearly insolation of between 7000 MJ/m^2 (Page-Shipp, 1980) and 9500 MJ/ m^2 as in the Kalahari region of South Africa.

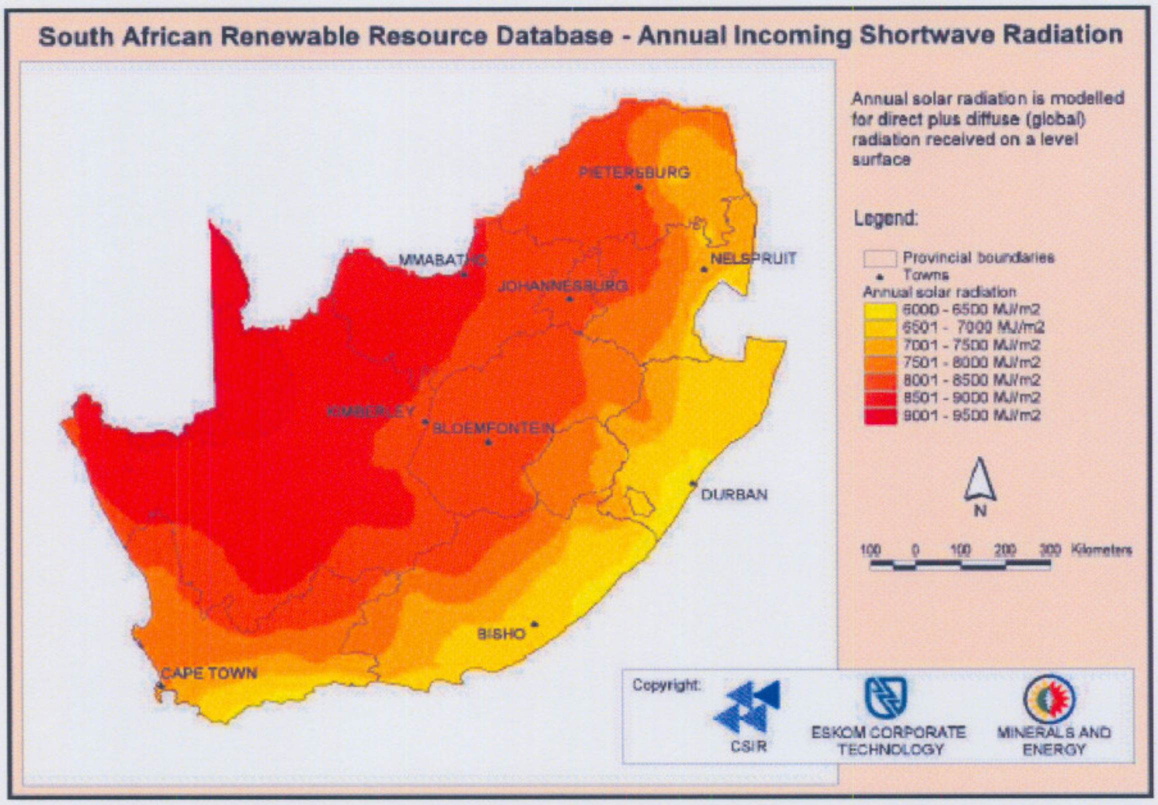

Figure 1-11: Annual direct and diffuse solar radiation for South Africa (DME)

The South African daily average insolation of between 4.5 and 6.5 kWh/m^2 (16 and 23 MJ/m^2) compares well to about 2.5 kWh/m^2 for Europe and the United Kingdom and about 3.6 kWh/m^2 for parts of the United States (Stassen as reported by DME, 2002).

The South African daily average does, however, seem to be averaged for a full year at a specific location. It converts directly to the annual average as shown in Figure 1-11, and quantitative seasonal variations in the average daily insolation are not readily available.

1.2 Problem addressed

This study addresses only some of the water problems experienced by the inhabitants of rural Southern Africa.

1.2.1 Source of water

A continuous water supply is seldom available at the domestic consumption level and has to be collected from some distance away. This may entail several excursions per day to fetch water from a communal tap, a river, or whatever source available to the community.

1.2.2 Quality of water

The water source used is often not of potable quality thus leading to possible waterborne infections even if it is only used for personal hygiene purposes. This may be exacerbated by poor or non-existent sewerage systems, causing contamination of the few available water sources with human and animal faecal run-off.

1.2.3 Heating of water for domestic use

Heating a reasonable volume of water for domestic use is difficult and expensive for the mostly poor inhabitants of rural Southern Africa. Boiling small volumes of water for drinking and hygiene use are therefore often the only option to ensure adequate disinfection.

1.2.4 Energy source for water heating

The availability of traditional and conventional energy sources for water heating is limited and expensive. Fetching and making firewood is time consuming, and leads to environmental degradation in heavily populated areas. Infrastructural problems may also interfere with the delivery and add to the cost of conventional energy sources such as paraffin and electricity.

1.2.5 Storing of hot water

Once heated, the storing of hot water for use later in the day is difficult. Conventional isolated geysers and containers are not commonly available, and the usual practice is to heat and use the water immediately. With the preferred bathing time in the evening it results in delays to the bather, even if someone in the household was available to heat the water earlier in the day.

1.3 Study objectives

This study is about promoting the use of the readily available and abundant solar energy potential of Southern Africa to help solve some of the problems connected to hot water availability for rural domestic use. Like in Australia where the importance of personal hygiene on the health outcome of the rural Aboriginal people was realised (Pholoros *et al* as reported by Lloyd, 2001), health and quality of life improvement in rural Southern Africa is the target.

The main objective of this study is to investigate the potential of an affordable device for the Southern African rural market that can perform the following functions.

- Transport a sufficient quantity of water from communal water sources to the residence, taking the limitations of human effort as motive force into account.
- Disinfect, if necessary, that quantity of water from bacterial waterborne pathogens so that the quality of water is acceptable for domestic and hygienic use, and even for drinking to guard against unintentional ingestion.
- Heat that quantity of water on most days of the year to a temperature acceptable for general domestic use by using only solar energy, irrespective of the season.
- Store that quantity of hot water for potential domestic use later in the day so that water at a temperature acceptable for bathing is still available in the evening.

- Maintain a potential to enjoy success as a commercial product to the intended market.

The device developed during this study will still be only a prototype. The objective is not to develop a production ready device, but to obtain sufficient information to decide on the final design and production of a marketable product.

1.4 Study method employed

The method employed for this study is a typical product development strategy. The fields of solar water heating and water disinfection were surveyed for applicable technology and practice. By addressing these fields separately, the potential pitfalls of a single approach to both problems were avoided at an early stage. The results from these studies led to specifications for both the solar water heating device and disinfection strategy to be developed.

Several concepts for a solar heating device were evaluated from a functional and manufacturability point of view. The next step of the study was to design, manufacture and functionally test prototype units of these devices. A batch of prototypes of the solar heating device, representative of the intended final product, were manufactured for testing, demonstration and evaluation purposes. Typical prototype tooling was used only where necessary due to funding constraints.

The solar heating device was deemed more important and received the larger portion of the budget, while only one disinfecting device was manufactured to serve as a functional proof of concept model.

A further batch of prototype solar heating devices was subjected to a two month field evaluation by inhabitants of a rural community in KwaZulu-Natal. The purpose of this trial was to obtain user feedback into the suitability and acceptability of the product by representative users.

The last, but still important, part of this study was to estimate the cost of manufacturing units to different production strategies. The acceptance and affordability of the device were then tested against user feedback and alternative marketing options.

1.5 Structure of this dissertation

This dissertation is divided into six chapters.

1.5.1 Introduction – Chapter 1

The first chapter provides a background for the problems involved in securing hot water for domestic use in rural Southern Africa. It also provides the motivation for selecting solar energy as the heating source. It further clarifies the objectives and methods used for the study, and set its boundaries.

1.5.2 Solar water heating – Chapter 2

This chapter contains the study that helps to define the solar heating aspects and technical parameters of the prototype solar water heating device to be developed for evaluation.

1.5.3 Water disinfection – Chapter 3

This chapter examines water disinfection theory and practice. The study provides the parameters for a broad specification and concept for the disinfecting of the water contained in the solar heating device.

1.5.4 Prototype Development – Chapter 4

The design, manufacture and testing of the prototype devices are described in this chapter. The results of functional performance testing of these units are included. It also reports on cost estimates for units produced to different strategies.

1.5.5 Evaluation and Affordability – Chapter 5

Marketing options against the policy background for the provision of basic services to rural areas are addressed in this chapter. The affordability and acceptance of the units is also examined using feedback from field trials. The chapter closes with a business case for both devices.

1.5.6 Conclusions – Chapter 6

The final chapter gives a summary of the most important results of this study. It concludes on the measure with which the objectives were reached, and recommends on further work to be done for a market ready product.

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CHAPTER 2: SOLAR WATER HEATING

2.1 Technology of solar domestic water heating

The technology of solar water heating to temperatures below the boiling point of water is fairly mature. The dos and don'ts are well established, and the efficiencies of more than 50% for the more sophisticated systems are impressive (ASHRAE, 2000). The life cycle cost of solar water heating with relatively long break-even periods compared to especially electrical systems, still make the systems uncompetitive in Southern Africa (Kok, 1994; Mathews & Rossouw, 1997). The low cost of electricity and the need for back-up heating to supply hot water during longer overcast spells, provide little incentive for private home owners to install solar domestic water heating systems.

2.1.1 Predominant types and examples

Three types of solar water heaters are predominant for domestic use (ASHRAE, 2000; SANS 1307, 2003). They are:

- Two component split systems with a flat plate collector and direct or indirect heating of water in a separately installed vertical or horizontal storage tank. These are the more expensive systems in the SDWH arena.
- Close-coupled systems with a direct or indirect heating flat plate collector and a separate horizontal storage tank situated at the elevated end of the collector. The close-coupled systems are usually cheaper and easier to install than the split systems.
- Integrated collector storage, or ICS, systems where the storage of hot water is integrated in the direct heating collector. These are the cheapest but least efficient systems available.

The two most popular types for use in middle to high-income groups are the two component split- and the close-coupled systems. The higher cost of indirect heating systems is only justified if potential freezing of the water in the collector is expected. Even then drain-back systems for the two component systems may be more economical (ASHRAE, 2000). These storage tanks are often fitted with electrical heating elements to serve as a back-up heating source.

Collectors can be fitted in parallel, in series, or in a combination thereof, to serve larger residential installations as is shown in Figure 2-1. The water storage tanks for such a system would usually be remote from the collectors, and circulation through the collector array will be pump driven making them so called active systems.

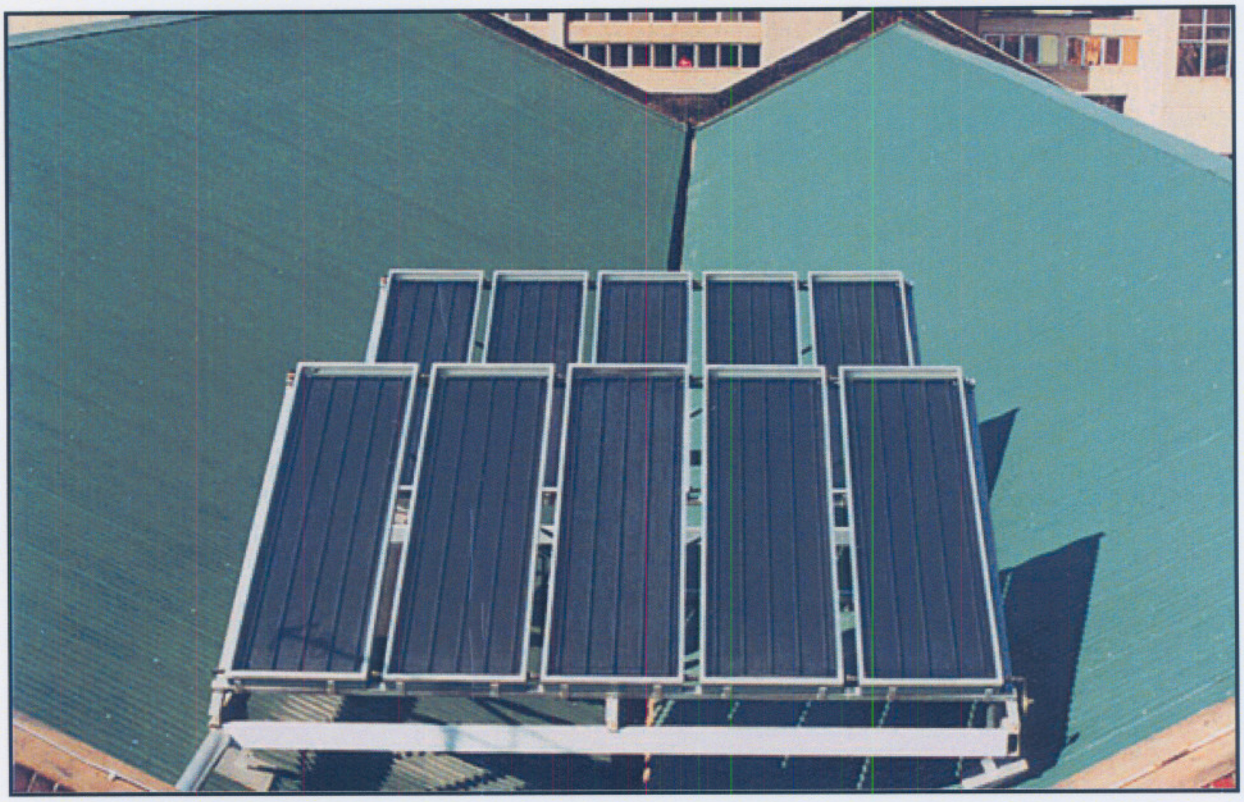

Figure 2-1: An array of 10 flat plate solar collectors assisting with hot water supply for a hostel

Though limited, large multi-collector flat plate systems similar to this technology are even used to supply hot water for industrial use. Nagaraju *et al* (1999) describes such a system for a plant making egg powder in Veligerla in India. The average daily insolance at the site is 6 kWh/m^2. It has an array of 1280 direct heating flat plate solar collectors of $2m^2$ each, four storage tanks of $57.5m^3$ capacity each, and supply 110 000 litres of hot water at 85°C on an average day. The system efficiency to the ASHRAE method is 52%, and the net savings on furnace oil consumption is 78%, or 260 kL, per year.

Where a two component split system with a flat plate collector is installed on a dwelling with a north facing pitched roof, the storage tank is often installed just inside the roof in such a position as to use the thermosiphon effect to circulate water through the collector. This make the use of an electric pump to circulate the water through the collector unnecessary, and thus the naming, passive systems. The only components visible for an observer outside the dwelling would be the usually glass covered black collector panel.

In contrast, close-coupled solar water heating systems usually displays the complete system to the external observer. Where such systems are mounted on north facing pitched roofs, both the flat plate collector and the horizontal storage tank is clearly visible as shown in Figure 2-2. Water circulation through the collector is invariably by the thermosiphon effect making these passive systems.

Figure 2-2: A pair of close-coupled systems on pitched roof

Close-coupled systems are usually of unitary construction. This makes them suitable for mounting on any readily available or simple structure if the dwelling roof is deemed not suitable for supporting it. Figure 2-3 shows a pair of close-coupled solar water heaters by the South African company *SOLAR HEAT* mounted on a wooden structure adjacent to a thatched roof dwelling. The close-coupled systems on offer in Southern Africa are mostly of the direct heating type and should not be installed in potential freezing areas.

Figure 2-3: A pair of *SOLAR HEAT* close-coupled systems on separate structure

SOLAR HEAT also offers what is described as an affordable hybrid ICS solar water heater as shown mounted to the pitched roof of a small dwelling in Figure 2-4. The unit has a water capacity of 70 litres, and the collector and additional water storage bulge are unitary moulded in UV stabilised polyethylene using the rotational moulding process. This collector tank unit is then installed in an insulated galvanised steel plate housing for mounting in a suitable location. It ideally still needs a piped water supply, but is essentially an open non-pressurised batch heating system. A sectional view of this system is shown in Figure 2-5. Of note is that ICS solar heating systems are inherently direct heating and passive.

Figure 2-4: *SOLAR HEAT* ICS system mounted on small dwelling roof

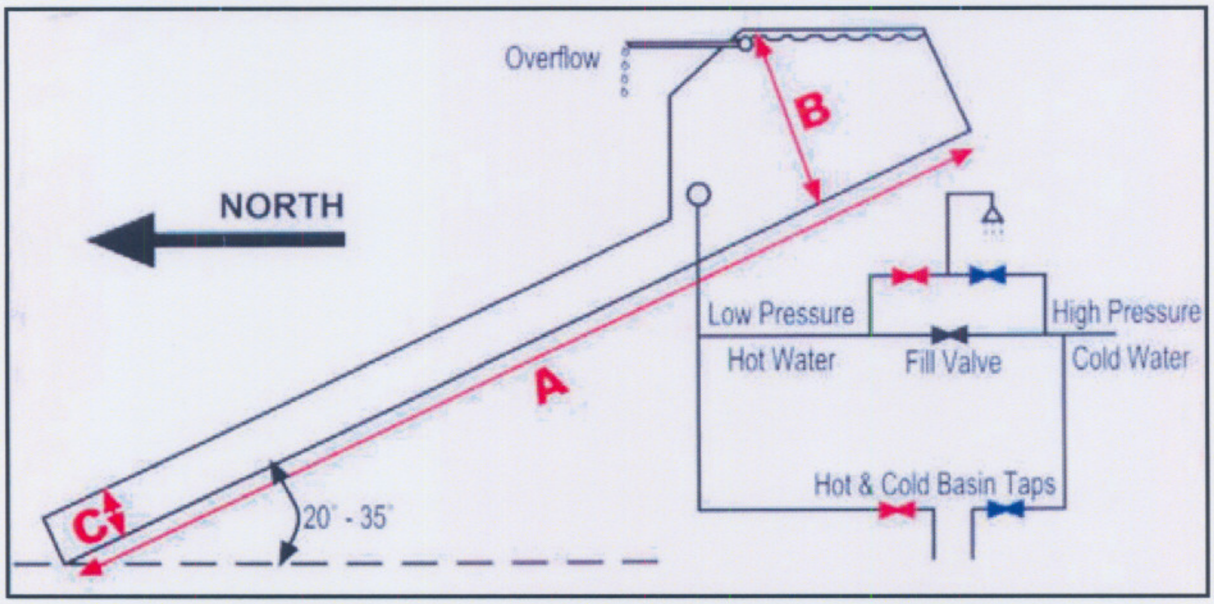

Figure 2-5: Schematic of *SOLAR HEAT* ICS system

Another ICS solar water heating system offered in Southern Africa by the Australian based company *SOLCO* is almost similar to the *SOLAR HEAT* system. The main difference is that the housing is also manufactured from polyethylene. This unit is shown in Figure 2-6.

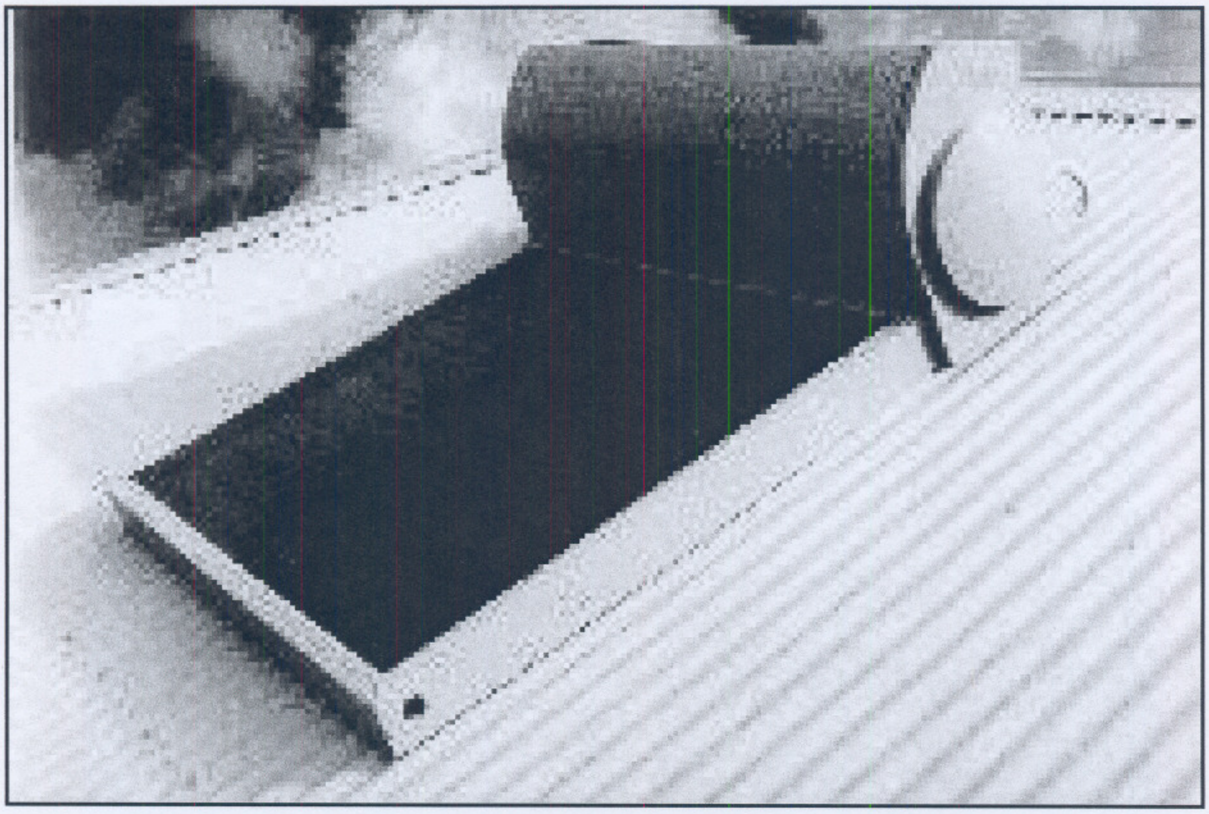

Figure 2-6: SOLCO ICS system mounted on roof

In a 2002 pilot project close to Durban, low-cost solar water heating units were offered at half their normal retail price to the inhabitants of low-cost houses (SES, 2002). The project was funded by USAID. A brochure distributed to the community showed two solar water heaters of interest being available.

Both systems have the ability to heat approximately 25 litres of water in two hours during midday. Both are close-coupled flat plate collector systems, with the roof mounted model shown on the left in Figure 2-7 offering an insulated storage tank. The mobile unit shown on the right in Figure 2-7 offers a non-insulated plastic storage tank. Neither have a back-up heating system.

Figure 2-7: Low cost close-coupled solar water heaters offered in SA rural pilot project (SES)

The brochure gives the retail price of the roof-mounted model as R 1600. The dwelling will require a piped supply of water for filling and using of the hot water. The price for the mobile unit is R 980. It is filled by hand and has a tap for drawing hot water from the storage tank. The wheels of this unit are of adequate size to ensure reasonable mobility over unpaved surfaces.

Faiman *et al* (2001) of the Ben-Gurion University in Israel, in association with the company *SOLTECH*, studied a prototype mobile ICS type solar water heater designed specifically to reduce the night-time radiation and convection losses[1]. This is potentially the biggest drawback of ICS units in that excessive heat loss from the exposed collector cause a large drop in the stored water temperature during the nocturnal hours.

The SOLTECH 1000™ unit has a water capacity of 120 litres and a collector area of 1.15 m^2. It is conventionally isolated on the back and sides. The complete unit is

[1] The specifics of this feature is discussed in paragraph 2.3.3 of this dissertation.

manufactured in polymeric materials. Filling of the unit is by hand, and it has token wheels that at best can assist in changing the orientation of the unit (Figure 2-8).

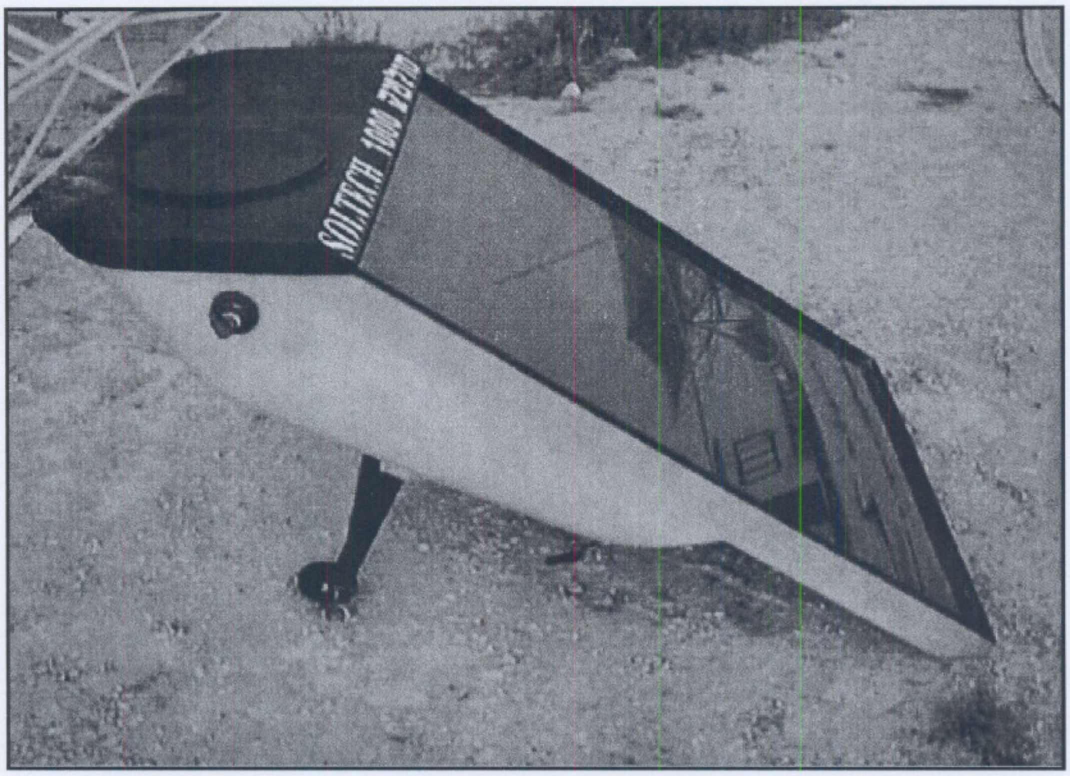

Figure 2-8: The SOLTECH 1000™ ICS solar water heater (Faiman *et al*)

2.1.2 Standards for solar domestic water heaters

When a technology field becomes mature, the commercial systems emanating from such a technology are usually regulated by national and/or international standards.

The recently updated South African National Standard SANS 1307 (2003) regulates solar domestic water heaters marketed in South Africa. This standard is specifically written to cover the requirements for the testing of the three types of SDWH mentioned in paragraph 2.1.1 of this dissertation. Important characteristics covered are:

- Thermal performance of the solar water heater, where the minimum acceptable daily heat output shall not be less than 9 MJ/m^2.
- Water storage tank requirements in terms of heat loss coefficients and mixing factors, similar to those of electrical domestic water heating systems.

- Construction methods and material selection requirements.
- Requirements to prevent collector damage during stagnation.
- Structural requirements for protection against rain, hail, freezing, and system water pressure.
- Product and performance marking of the unit, and instructional leaflets to be included for consumer information.

It then specifies the test methods to be used to verify specific characteristics. These test methods are described in two additional South African Standard Methods namely:

- SABS SM 1210 (1992) for mechanical qualification testing of:
  - collector damage resistance during stagnation
  - mechanical strength and damage resistance
  - corrosion and dezincification resistance of metallic components, and
  - water absorption of polymeric and composite materials
- SABS SM 1211 (1992) for thermal performance tests specifying:
  - system installation parameters for the testing
  - instrumentation to be used and its accuracy, and
  - details of the actual performance tests

The thermal performance test results include the daily heat output of the system for six different values of daily solar irradiation, and average ambient air and cold water inlet temperatures. According to the standard, the performance of a SDWH system can be represented by the following empirical equation:

$$Q = \alpha_1 H + \alpha_2 (T_{aav} - T_{cav}) + \alpha_3 \qquad (2.1)$$

where

Q is the daily heat (or energy) output of the system ($MJ/m^2/day$)

α_1 , α_2 and α_3 are constants for a system, determined from the test results

H is the daily solar irradiation at the collector aperture ($MJ/m^2/day$)

T_{aav} is the average ambient air temperature (°C)

T_{cav} is the average cold water inlet temperature (°C).

By performing a series of experiments over six days with different climatic conditions as described in the standard, the constants of equation (2.1) can be evaluated.

Additional tests are prescribed to determine the draw-off mixing profile and the heat loss coefficient of the storage tank. A volume of water equal to three times the storage tank volume is drawn off the system during the draw-off mixing profile tests. The temperature is measured for each increment of water equal to $^1/_{10}$ of the storage tank volume. The results are plotted on a graph, and this is the draw-off mixing profile. It shows the amount of mixing between the hot water in the tank and cold water entering the tank.

The overnight heat loss coefficient of the hot water storage system is determined by measuring the temperature loss of the water during a 12 hour nocturnal period. The formula used is:

$$U_s = (C_s / t) \ln [(T_{init})(T_{aav}) / (T_{fin} - T_{aav})] \quad (2.2)$$

where

U_s is the heat loss coefficient (W/K).

C_s is the total heat capacity of the hot water mass in the storage tank (J/K)

t is the test period (seconds)

T_{init} is the initial temperature (higher than 60°C) of the water in the tank (°C)

T_{fin} is the final temperature of the water (after mixing) in the tank (°C)

The International Standards Organization (ISO) has also produced a number of standards dealing with the performance testing of solar collectors and systems. One is ISO 9488 (1999) dealing with the vocabulary of solar energy.

On a more technical note, the standard ISO 9459-2 (1995) deals with outdoor test methods for system performance characterization and yearly performance prediction of solar-only systems. The ISO Technical Committee for Solar Energy (ISO/TC 180) generated this standard. Both SABS SM 1210 (1992) and SABS SM 1211 (1992) are also based on the recommendations of ISO/TC 180.

Over and above the tests of SABS SM 1211 (1992), ISO 9459-2 (1995) describes additional tests, and gives the algorithm as well as the listing of the modelling programs used to predict the long-term system performance under any given climatic and operating conditions, based on the experimental results.

The data required to perform long-term performance prediction according to this standard are of three types: test results, climatic data, and system usage data as follows:

- the coefficients a_1, a_2 and a_3 of equation (2.1)
- two draw-off normalized temperature profiles expressed as a function of the volume for two values of radiation level as required by the standard (this is additional to SABS SM 1211, 1992)
- the mixing draw-off normalized profile expressed as a function of the volume
- the heat loss coefficient of the storage tank, U_s to equation (2.2)
- various climatic data such as the daily insolance on the collector plane, the average ambient temperature during the day and the average ambient temperature during the night, and
- system usage data required, i.e. volume of the daily hot water consumption and the mean cold water inlet temperature for each day.

One comment on both SABS SM 1211 (1992) and ISO 9459-2 (1995) is that they provide well for the testing of solar water heating systems that are permanently plumbed into the running water system. Batch heating type solar water heaters in general, and specifically of the ICS type, are however not adequately addressed. It will be addressed in the following paragraph.

2.2 Design and construction of solar domestic water heaters

2.2.1 Design of collectors

The main purpose of the collector of a solar water heater is to transform the solar insolance into useful energy to be stored in the form of hot water. The success with which this function is performed is simply the efficiency of the collector.

According to ASHRAE (2000) the useful energy delivered by a solar collector is equal to the energy absorbed by the heat transfer fluid minus the direct and indirect losses from the surface to the surroundings, or in the form of an equation:

$$Q_u = A\,[I\tau\alpha - U_L(T_{pav} - T_a)] \tag{2.3}$$

where

Q_u is the useful energy delivered by collector to the working fluid (W)

A is the collector aperture area (m^2)

I is the solar energy incident on the collector surface (W/m^2)

τ is the glazing transmissivity (dimensionless)

α is the absorptivity of the collector surface (dimensionless)

U_L is the overall heat loss coefficient (W/m^2K)

T_{pav} is the average temperature of collector plate surface (°C)

T_a is the ambient air temperature (°C)

By introducing a collector heat removal efficiency factor with a value of less than 1.0, equation (2.3) can be modified by substituting the inlet fluid temperature for the average plate temperature. The equation then becomes

$$Q_u = F_R A\,[I\tau\alpha - U_L(T_{in} - T_a)] \tag{2.4}$$

where

F_R is the collector heat removal efficiency factor, a value smaller than 1.0

T_{in} is the working fluid inlet temperature (°C)

This equation is also well-suited to simulation models (Varley, 1995) when used in combination with:

$$Q_u = \rho\, C_P\, V'\,(T_{out} - T_{in}) \tag{2.5}$$

where

ρ is the density of the working fluid in the collector (kg/m^3)

C_P is the specific heat capacity of the working fluid (J/kg.K)

V' is the volume flow of water through the collector (m^3/s)

T_{out} is the outlet fluid temperature from the collector (°C)

Equation (2.4) may be rewritten in a dimensionless efficiency of total solar radiation collected by dividing both sides of the equation by IA, resulting in

$$\eta = F_R \tau\alpha - F_R U_L (T_{in} - T_a) / I \qquad (2.6)$$

where η is the collector efficiency to ASHRAE.

Equation (2.6) is also known as the Hottel-Whillier equation for solar collector efficiency (Duffie & Beckman, 1980), and plots as a straight line on a graph of efficiency versus the heat loss parameter $(T_{in} - T_a) / I$. The intercept of the graph equals $F_R \tau\alpha$. The slope of the line equals $-F_R U_L$. At the intersection of the line with the horizontal axis, collection efficiency is zero. It is the result of either such a low insolance or such a high fluid inlet temperature that the heat losses equal solar absorption, and is called stagnation of the collector.

Faiman *et al* (2001), however, argues that because of the large thermal mass of the water resident in an ICS solar water heater, the system cannot achieve thermodynamic steady state conditions as found in standard low mass flow flat plate collectors. The ASHRAE test method for standard flat plate solar collectors, where only the collector is evaluated, is thus not fully applicable. They have reported on a 1984 paper by themselves where they have developed a test method that showed that the 'maximum useful efficiency' of an ICS solar water heater could be cast in a mathematical form similar to the Hottel-Whillier equation for a flat plate collector, but where the variables take on time averaged values. Note that the working fluid is implicitly defined as water for ICS solar water heaters.

This maximum useful efficiency, or MUE, is then further defined as

$$\mu = M_w C_w (T_{mav} - T_{inav}) / A \int I(t) dt \qquad (2.7)$$

where

μ is the maximum useful efficiency, or MUE (dimensionless)

M_w is the mass of the water contained in the ICS SWH (kg)

C_w is the specific heat capacity of water (J/kg.K)

T_{mav} is the averaged maximum temperature reached by the water (°C)

T_{inav} is the averaged starting temperature of water at sunrise, or at filling (°C)

A is the collector aperture area (m^2)

I is the solar energy incident on the collector surface (W/m^2)

t is time in seconds

The integral $\int I(t)dt$ in equation (7) is that of the solar energy incident on the collector surface taken over the time from sunrise, or from filling of the heater with water, until the water reaches its averaged maximum temperature.

This averaged maximum water temperature can then also be defined as the stagnation of the ICS solar water heater that is still filled with water. Mathews and Rossouw (1997), however, defines another stagnation point for an ICS solar water heater, namely the steady state temperature of the collector surface when there is no water inside. This definition is useful to determine the maximum temperature that the collector will reach when no water is resident to remove energy from it, especially if the collector is made from polymer materials that may be damaged by such temperatures.

2.2.2 Collector materials

The usual materials that solar heating flat plate collectors are manufactured from are high conductivity metals such as copper, aluminium, steel, and combinations thereof (ASHRAE, 2000). Polymer materials such as polyethylene (PE) and ethylene-propylene-diene terpolymer (EPDM) are traditionally only used for low temperature collectors for swimming pools. Collectors normally have a flat black, but spectrally nonselective, coating. This coating is either painted on for metal collectors, or is the inherent colour of the polymer used by virtue of its carbon black fillers.

Considerable effort goes into increasing the efficiency of the metal absorbers for high efficiency installations. One of the methods employed is to increase its absorptivity for short wavelength radiation in the visible light range by the application of spectrally selective coatings (ASHRAE, 2000). These coatings often also decrease its emmisivity in the longer wavelength infrared range. The best of these is a chromium compound known by the trademark *ChromOnyx*, which has a visible absorptivity of 0.92 and an infra-red emissivity of 0.085 when applied to a dull nickel surface (Varley, 1995). Black chrome, black nickel, and copper oxide coatings are almost as good with similar absorptivity but higher emissivity of approximately 0.2. This is still better than the standard flat black paint emissivity of between 0.7 and 0.95. (ASHRAE, 2000) These special coatings, however, increases the cost of the collector considerably, and cannot be applied to polymer collectors.

In an effort to reduce the cost of solar water heating, several researchers actively pursue the use of polymer materials for complete collectors, especially for application in ICS solar water heaters (Cristofari *et al,* 2002; Faiman *et al,* 2001; Mathews & Rossouw, 1997). The advantages of polymer materials used for collectors in general, and ICS in particular, are reduced scaling, very high corrosion resistance, better freezing resistance, and integrated manufacturing of the collector storage unit using moulding processes. Disadvantages compared to metal absorbers are lower temperature limitations, lower thermal conductivity, and that even with UV protection fillers the polymers tend to deteriorate faster over long periods of UV exposure.

These ICS units are, however, limited to low pressure use. Other researchers follow the route of round polymer tubes semi-enclosed in low cost metal sheeting for hybrid collectors to, amongst other reasons, increase the useable working pressures.

Bartelsen *et al* (1999) believes that the wall thickness of the polymer tubes used should be thin, that the tubes should have as large as possible a diameter, and that the low thermal conductivity of standard elastomers have to be increased. They pursued this route and developed special formulations of EPDM, where some of the carbon black fillers were substituted with graphite and aluminium powder. The resultant materials are up to 100% stronger in tensile strength, while the thermal conductivity increased from 0.25 W/mK to between 0.7 and 1.0 W/mK.

In contrast, Van Niekerk *et al* (1996) came to the conclusion that the efficiency of their collector is only slightly dependant on the wall thickness, and thus the thermal resistance, and the diameter of the polymer tubing. They believe that the resistance of the hydrodynamic boundary layer of water inside the tube forms a significant part of the total heat transfer resistance to the water. They correlated this by using copper tubes with negligible thermal resistance when compared to the polymer tubes. This increased the collector efficiency by only 3.5 percentage points (61.5% to 65%) compared to a 3mm wall thickness polymer tube. The increase was 0.5 percentage points when compared to a 0.5mm wall thickness polymer tube. This viewpoint is supported by the results of tests performed by Mathews and Rossouw (1997) on the thickness of an ICS storage unit's polymer collector plate. Cristofari *et al* (2002) also found similar efficiencies in their comparative tests between polymer and metal absorbers.

2.2.3 Glazing materials

The glazing of a solar water heater collector is an important factor in increasing the collector efficiency. By creating an air gap between the hot collector surface and the ambient air, some limitation of convective losses occur in no wind conditions. The biggest advantage of glazing is, however, the limitation of convective losses when the wind is blowing (Kumar *et al,* 1997; Mathews & Rossouw, 1997; Nabilek *et al,* 1999; Kalogirou *et al,* 1999; Chaurasia & Twidell, 2001). Single glazing is usually used in all but very cold climates, where double glazing is needed to reduce the losses to acceptable levels.

The ideal glazing materials for solar water heater collectors have:

- high transmissivity in the short wavelength light range to allow as much as possible of the incoming light to reach the collector
- low transmissivity of radiation in the longer wavelength infrared range to limit radiation losses from the collector
- good insulation properties to limit the convective losses from the collector
- high mechanical resistance to damage from hail, vandalism and other forms of damage
- high resistance to deterioration of its properties by UV and light radiation
- good formability to allow for shaping of the glazing when required
- low mass, and
- as always, low cost.

Not one single glazing fulfils all these requirements. Glass, specifically tempered low-iron glass, fulfil both transmissivity requirements, and the deterioration and relatively low cost requirements (ASHRAE, 2000). It is, however, prone to damage other than for good scratch resistance. It does not isolate well, has mass penalties and practically limits the designer to flat sheets.

Polymer sheeting such as polycarbonate (PC) and polyethylene terephthalate (PET) meets the damage requirements other than for scratching, where PC perform better than PET (ASHRAE, 2000; Gombert *et al,* 2000). Both meet the light transmissivity, mass and formability requirements. In sufficient thickness, the insulation properties are better than that of glass, but the cost is higher by a factor of up to ten times. Both also exhibit a slight deterioration in its properties from prolonged exposure to UV and light.

Gombert *et al* (2000) developed a special coating for glass and polymer glazing that increase the transmissivity by up to 6 percentage points, from 91% to 97% for glass and slightly lower for polymers, for a normal incidence. These coatings work especially well for light striking the glazing at incidence angles away from normal, where the improvement in transmittance are even higher due to less reflection from the glazing surface.

2.2.4 Storage tank design and insulation

Once water has been heated for domestic use, it is useful to store this water at temperature for use when required. Well isolated tanks are normally used in similar cylindrical form for two component and close-coupled solar water heaters on the one hand, and electric domestic water heaters on the other. If reverse thermosiphon water circulation through the collector are prevented, heat losses for these types of solar heater storage tanks during night time are minimal. The design and insulation of these tanks are well defined by ASHRAE (2000) and others.

The insulation of ICS solar water heaters are however not as easy. It is usually not possible to optimise the tank shapes with respect to volume and surface area. Even with good insulation, the relative losses through the insulation remains larger than for optimised cylindrical storage tanks.

The relatively large collector surface also remains substantially open to ambient conditions even with glazing, with large resulting heat losses. These are mainly convective losses from the hot collector surface through the glazing, and radiation losses especially at night when the sky temperature is low. As a result, the water temperature drops by a considerable amount overnight, leaving little, if any, useful energy the next morning (Faiman *et al,* 2001; Cristofari *et al,* 2002; Mathews & Rossouw, 1997; Chaurasia & Twidell, 2001; Kalogirou *et al* 1999).

Specialised isolating glazing in the form of a double wall honeycomb PC structure was investigated by Chaurasia and Twidell (2001) for application with ICS solar water heaters. This transparent insulation material, or TIM, reduced the heat loss factor of the collector surface from 7.1 W/m^2 K to 1.0 W/m^2 K, resulting in a solar water heater storage efficiency of 40% versus 15% for the same heater with conventional single glass glazing. The cost of this material is not reported.

2.2.5 Suitability of ICS SWH for Southern Africa

Fasulo *et al* (2001) investigated the cost and performance of fixed ICS solar water heaters and compared it to that of the classical flat plate collector thermosiphon systems. Both systems had a hot water delivery of 300 litres per day. Their study was done in the city of San Luis, Argentina, which at 33.3° S is similar to that of the Southern Cape and Southern Karoo regions of South Africa. They found that:

- It is feasible to obtain domestic hot water by means of simple ICS solar water heaters, which are cheaper than the classical flat plate collector variety, in relatively dry regions with abundant solar radiation.
- The ICS system performs better, and for a lower initial cost, than classical systems for 10 months of the year.
- Transparent thermal insulation of the collector surface must be improved in order to succeed in making the ICS systems competitive all year round.

ASHRAE (2000) also states that ICS solar water heaters are suitable for solar domestic hot water service but only in regions with mild climates and high insolance. This is also the opinion of Chaurasia and Twidell (2001) who performed their studies on the Indian sub-continent. The reason is again the excessive heat loss through the collector surface at night in colder climates. Although feasible, temporary isolating covers for the collector aperture are difficult and cumbersome to fit during night-time where ICS solar water heaters are fixed roof-mounted units. (Smyth *et al,* 1999; Chaurasia & Twidell, 2001).

It is, however, a viable option for the low cost mobile solar water heaters considered under this study. The isolating covers can be made from proper insulation materials, or can be as simple as covering the aperture with a thick blanket or a few layers of cardboard. Bringing mobile solar water heaters indoors during night time will of course also reduce the heat losses due to the absence of the low sky temperature.

The ambient temperature inside a dwelling is also usually higher than the outside temperature.

2.3 Factors influencing ICS SWH performance

Significant factors influencing the performance of solar water heaters in general, and ICS solar water heaters in particular, are examined here.

2.3.1 Inclination and orientation

The inclination and orientation of a solar water heater has one of the largest roles to play in its performance. Inclination is defined as the solar water heater collector angle from horizontal, where horizontal is when the collector faces vertically upwards. Orientation is defined as the direction in which this inclined collector faces.

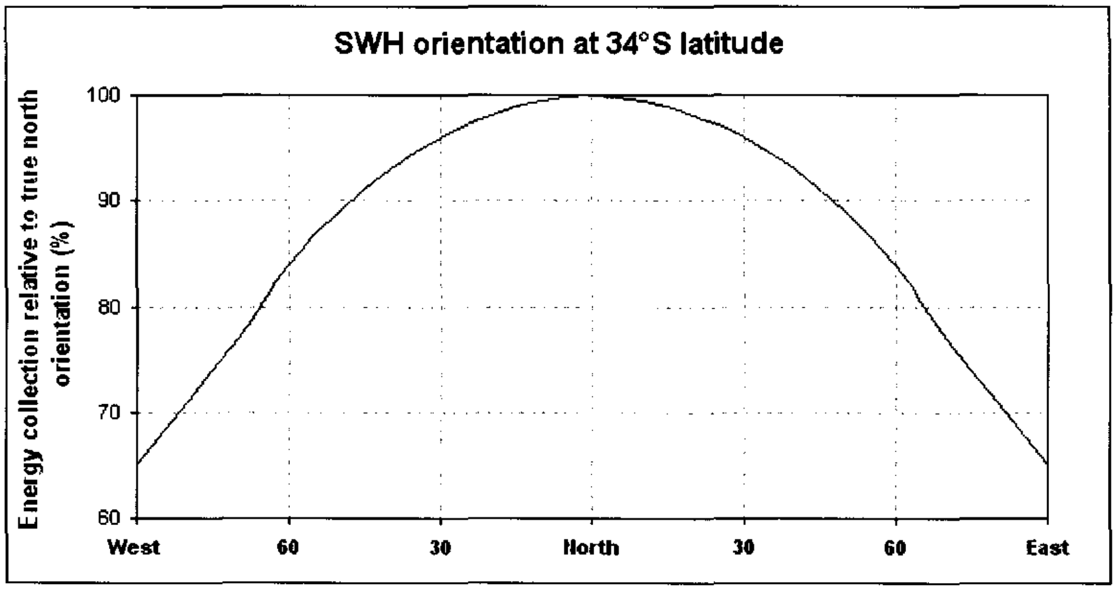

Figure 2-9: Effect of orientation deviation from North on SWH collector energy collection (NBRI)

Two figures by the NBRI (1978), an institute of the CSIR, graphically demonstrates this effect. The reduction in insolance for a fixed solar collector orientation between east and west via north for a southern latitude is shown in Figure 2-9. The energy collection reduces to approximately 66% of the potential for a collector facing directly east or west.

The optimum orientation for a fixed installation in the southern hemisphere is of course directly north due to the northern track of the sun, especially in winter. Only north of the Tropic of Capricorn does the sun have a brief southern track in summer. This situation is reversed in the northern hemisphere, where the optimum orientation will be to the south.

The inclination of a solar collector serves two purposes. The first is to balance the available total insolance between summer and winter to enable a good year round performance. Figure 2-10 shows the effect of the angle of inclination on the annual variation of total solar radiation on horizontal and tilted surfaces for Pretoria. The optimum inclination, again for a fixed collector, is of the order of the latitude +10°, in this case 35° facing north. Of note though is that even for a horizontal collector, the total solar radiation is still nearly 14 MJ/m^2.day.

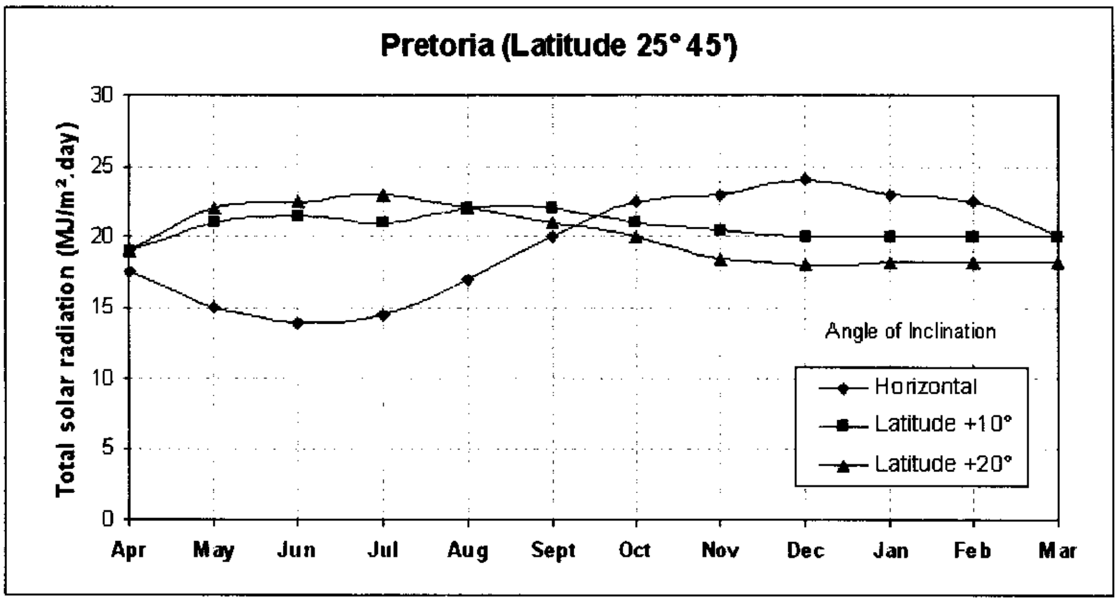

Figure 2-10: Annual variation of total solar radiation on horizontal and tilted surfaces for Pretoria (NBRI)

The second purpose of the inclination of a solar water heater collector is the thermosiphon effect created by the density difference between cold and hot water. This ensures that, for passive type solar water heaters, the water circulates unassisted through suitably designed split and close-coupled systems, and help to mix the water through convective thermosiphon flow in ICS solar water heaters.

Mathews and Rossouw (1997) demonstrated the effect of inclination with tests of an ICS system at a fixed inclination and orientation in Pretoria. For mid-winter, the difference between a unit inclined at 35° and a horizontal unit is approximately 15°C. This is shown graphically in Figure 2-11.

Sharia *et al* (2002) studied the optimum angle of inclination for solar water heater collectors in Jordan. They found that even better year round performance could be extracted for a system inclined 5° to 8° more than the generally recommended latitude +10° angle. Their work were, however, performed on a system with a relatively large collector surface aperture of 3m^2. This caused the solar collector to deliver more useful energy in summer than required by the usage profile. The system could thus tolerate a less than optimum summer efficiency and still fulfil in the user requirement for hot water.

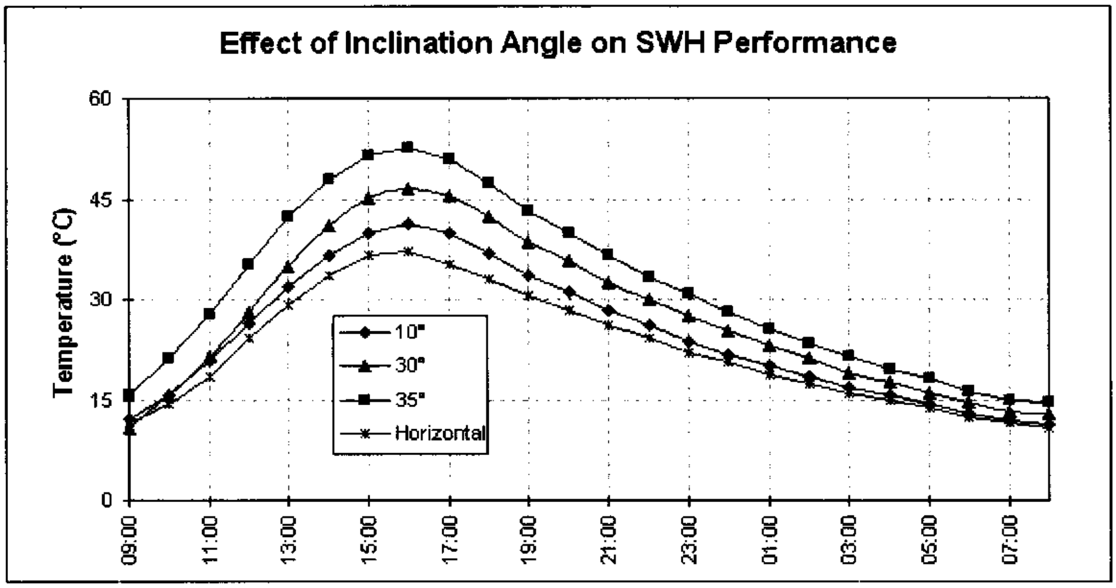

Figure 2-11: SWH model performance based on inclination angle (Mathews & Rossouw)

Several researchers also investigated the gain in useful energy delivered by a solar collector if it could track the sun in both a daily east – west direction, and seasonally in inclination. Hove (2000) studied the two axes of tracking independently for flat plate collectors. He found that in all cases a single axis north – south tracker, adjusted daily, collected more than 93% of the solar radiation that an optimal two axis tracker could collect. The useful energy collection of a single axis east – west tracker were about 25% worse than a single axis north – south tracker, and only marginally better than a fixed collector.

Nijegorodov and Jain (1997) investigated the optimal strategy for maximising the output of photo-voltaic (PV) panels in Botswana. Their dependence on maximal solar radiation for delivering optimised, useful electrical energy is equivalent to that of solar water heaters. These panels are used to power rural telecommunication equipment, and were all installed at a 30° inclination throughout Botswana. The researchers recommended optimising the inclination of the panels for each location, and then to manually track the sun in a single north – south axis strategy performed only once a month. The electrical output could be boosted in all cases by between 20% and 25% at only the cost of the hand-adjustable mounting for the tracking. This result confirms the potential north – south tracking gain for solar water heaters as reported by Hove (2000).

2.3.2 Insulation and wind

The effect of insulation on the storage tank of a solar water heater is quite dramatic. Even during daytime, while collecting energy from the sun on the collector, the losses from the walls of a non-insulated solar heater storage tank can limit the system performance to a mediocre level.

Mathews and Rossouw (1997) demonstrated this by testing an ICS system with different insulation schemes. This is graphically reproduced in Figure 2-12. Without insulation the water temperature barely reaches 40°C on a sunny winter day. With full insulation on the non-collecting surfaces the water temperature exceeds 65°C under the same conditions. Even omitting insulation from just the relatively shallow sidewalls of the storage volume, the maximum temperature was limited to below 55°C.

Typical insulation materials used are glass and mineral wools, and materials like polystyrene and poly-isocyanurate foam (ASHRAE, 2000). Glass wools have a typical heat conduction of 0.037 W/mK (Faiman *et al* 2001), but this can drastically increase if it becomes wet. ASHRAE (2000) warns against this and recommends that insulated spaces must be vented at least to allow the wool to dry at the earliest opportunity. Their argument is that moisture will always find a way into a unit exposed to the elements, regardless of sealing attempts. This is a very practical standpoint indeed.

In a recent study, Holck *et al* (2003) came to the same conclusion in that the hygroscopic behaviour of insulation material, and proper ventilation of the solar collector isolated space are both important for the durability of solar collectors with respect to moisture. Optimising the influence of the insulation materials and the ventilation rate of solar collectors can reduce the relative humidity and the formation of condensation inside the collector. They showed that the optimised ventilation rate is in the region of 60 litres / hour.Pa for a 2 m^2 collector. The ventilation rate is given for a pressure difference between ambient pressure and the air gap pressure in the collector caused by thermal buoyancy, wind or gusts.

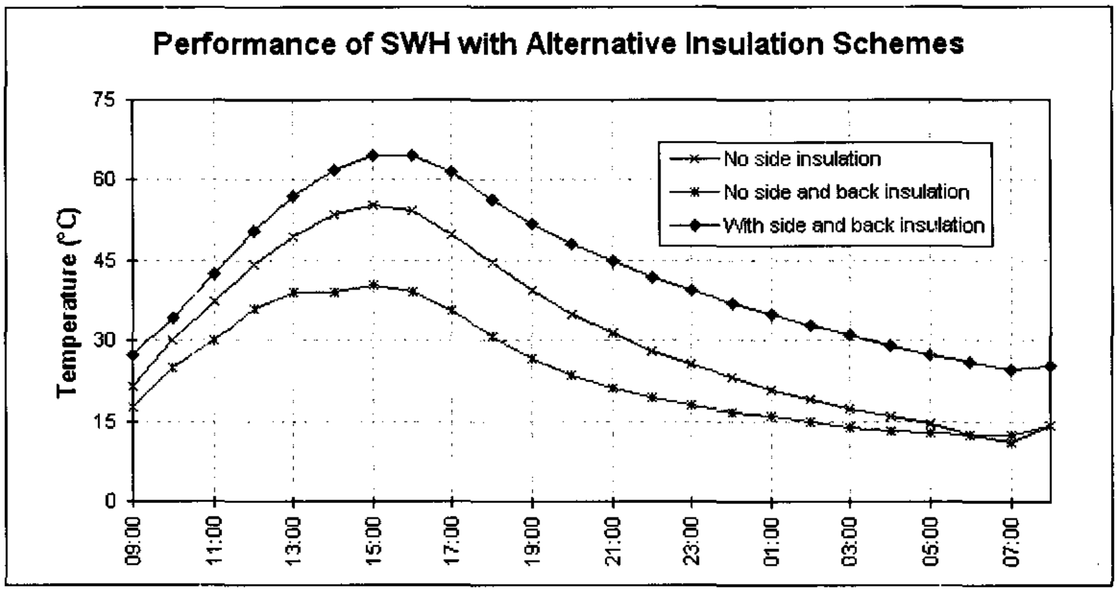

Figure 2-12: Thermal performance of SWH with alternative insulation (Mathews & Rossouw)

Polystyrene blocks do not absorb moisture, but are often placed as loose blocks in the housing around a storage unit. This may allow water and moisture to get between the insulation and the tank, with high evaporative losses until the space is dry again. Poly-isocyanurate foam, also called polyurethane foam, can be bought as a two component fluid. Mixing it on site and allowing it to expand in the space to be insulated creates insulation materials with excellent adherence to most surfaces. If contained correctly during the expansion period, the foam has a closed cell structure highly resistant to water absorption. The heat conductivity is in the order of 0.022 W/mK at a density of 80 kg/m^3 (Cristofari *et al*, 2002).

One mechanism of heat loss from a non-insulated tank but with a spaced cover around it is by the convective flow of the air through it. Smythe *et al* (1999) studied this effect amongst others, and reduced the heat loss by 20% by limiting this airflow with sleeves in the applicable spaces. The outside cover in this case also drastically reduced the heat loss from the storage tank due to wind.

An unglazed ICS solar water heater is very susceptible to the increase in convective heat losses from the collector when the wind blows. Even low wind speeds can limit the useful energy gain as demonstrated by Mathews and Rossouw (1997) in Figure 2-13, and confirmed by Nabilek *et al* (1999). The effect of a wind speed of only 2.3 m/s, or less than 10 km/h, is almost the same as if the storage tank has no insulation. This is one of the important reasons for glazing on solar water heater collectors in general.

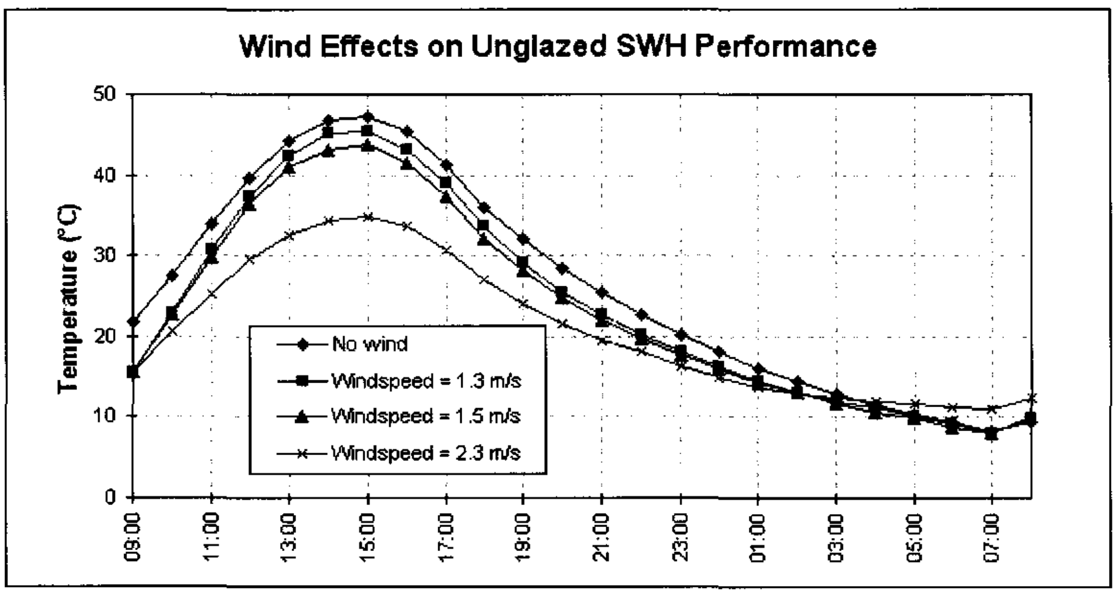

Figure 2-13: Effect of wind on non-glazed SWH (Mathews & Rossouw)

Kumar *et al* (1997) experimented to find a correlation between wind speed and the convective losses from the glazing surface of flat plate solar collectors used in both solar water heaters and solar cookers. They found a linear relationship of the convective heat transfer coefficient with the wind speed to the equation

$$H_w = 10.03 + 4.687\ V_w \qquad (2.8)$$

where

H_w is the convective heat transfer coefficient (W/m^2K)

V_w is the wind speed (m/s)

They also report on the correlations of two other authors. McAdams (1954) are reported to have found the correlation

$$H_w = 5.7 + 3.8\ V_w \qquad (2.9)$$

and Test *et al* (1981) as

$$H_w = 8.55 + 2.56\ V_w \qquad (2.10)$$

Though the differences between these correlations are relatively large, all have a starting point at no wind not too far from those reported by researchers in paragraph 2.3.3 of this dissertation.

2.3.3 <u>Nocturnal losses</u>

No matter how well insulated the rear and sides of the storage tank of an ICS solar water heater might be, its collector face, especially with single glazing, constitutes a significant source of night time heat loss, reported at between 6.8 W/m^2K (Faiman *et al*, 2001) and 7.1 W/m^2K (Chaurasia & Twidell, 2001). The losses are mainly due to convective effects between the collector surface and the glazing, as well as by radiation from the collector to the lower sky temperature. In an interesting study, Khedari *et al* (2000) utilised this radiation component in radiators similar to collectors to produce night-time cooling of water to temperatures lower than ambient.

Faiman *et al* (2001) shows how, from a starting water temperature of 60°C, a typical isolated cylindrical storage tank will still have water at 55°C the next morning, while for a similarly sized ICS solar water heater the temperature will drop to below 40°C. The night temperature is 10°C, and the insulation is 50 mm glass wool.

They then describe the SOLTECH 1000™ ICS solar water heater that has beneath the collector plate, and parallel to it, a plate made of insulated material. It is positioned to permit thermosiphon flow of a sheet of water between the two planes during the day. At the onset of reverse thermosiphon flow i.e. cooling, a mechanical flap valve closes to prevent movement of the water between the absorber and insulated planes. Figure 2-14 shows a schematic vertical cross-section through the unit to illustrate these ideas. The layer of stagnant water, together with its underlying insulated support plane, automatically reduce the collector loss coefficient from 6.8 to 2.4 W/m^{2}K at night.

Mathews and Rossouw (1997) also performed tests on a simple ICS solar water heater and found that the addition of a 50mm polystyrene insulation sheet on the collector leads to considerably better storage performance of the system. From a lowly 35°C water temperature at nightfall, and for a night temperature of 10°C, the water temperature dropped to ambient at sunrise. With the isolating cover, the sunrise temperature of the water was 20°C.

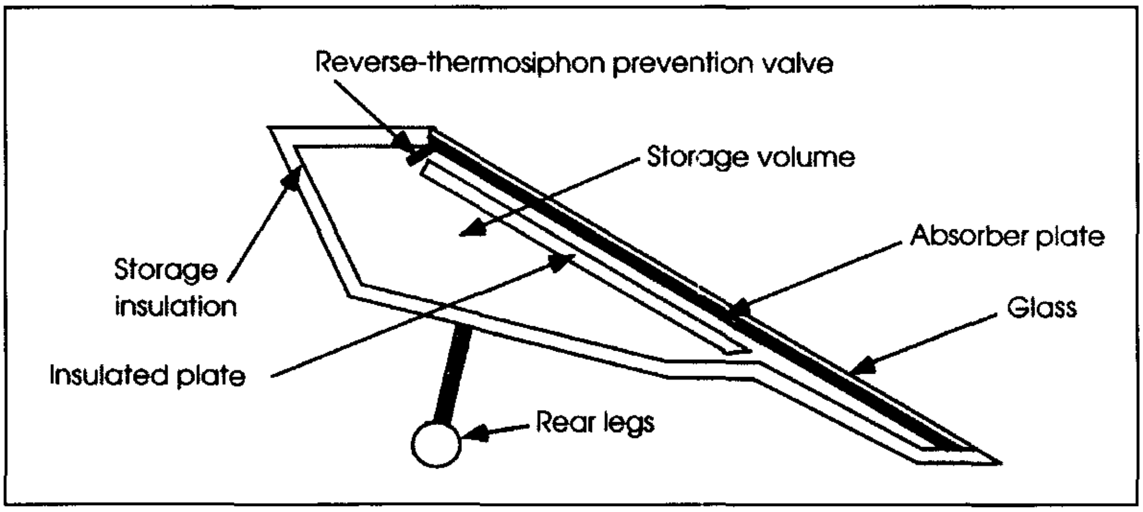

Figure 2-14: Schematic cross-section through SOLTECH 1000™ solar water heater (Faiman *et al*)

2.3.4 Collector material and thickness

The merits of a polymer as collector for an ICS solar water heater was described in paragraph 2.2.1 of this dissertation. Though limited in pressure containment at temperature, the fact that the SWH under consideration here will be a mobile ICS unit not pressurised by a water reticulation system, made it possible to mould the collector-storage unit as a single polymer component.

Only a few polymers are worthwhile considering though. Cristofari *et al* (2002) selected polycarbonate as a collector-storage unit material in their study. This polymer has superior strength and temperature resistance, and a thermal conductivity of 0.7 – 0.85 W/mK. Their aim was, however, to create a high performance unit with as low as possible a mass, and the relatively high cost of PC was justified on these grounds. The specially formulated EPDM materials developed by Bartelsen *et al* (1999), also with a thermal conductivity in the range of polycarbonate, are not available to the general trade and can thus not be considered.

The ease of creating complex containers in relatively small prototype numbers by using the rotational moulding process, make low density polyethylene (LDPE) an attractive option. Prototype tooling for this process is relatively cheap compared to other processing techniques. Control of the wall thickness is not very accurate though, and even with UV protection additives, the material will deteriorate in prolonged exposure to sunlight. This may cause premature failure of the collector where the wall thickness is insufficient due to process limitations.

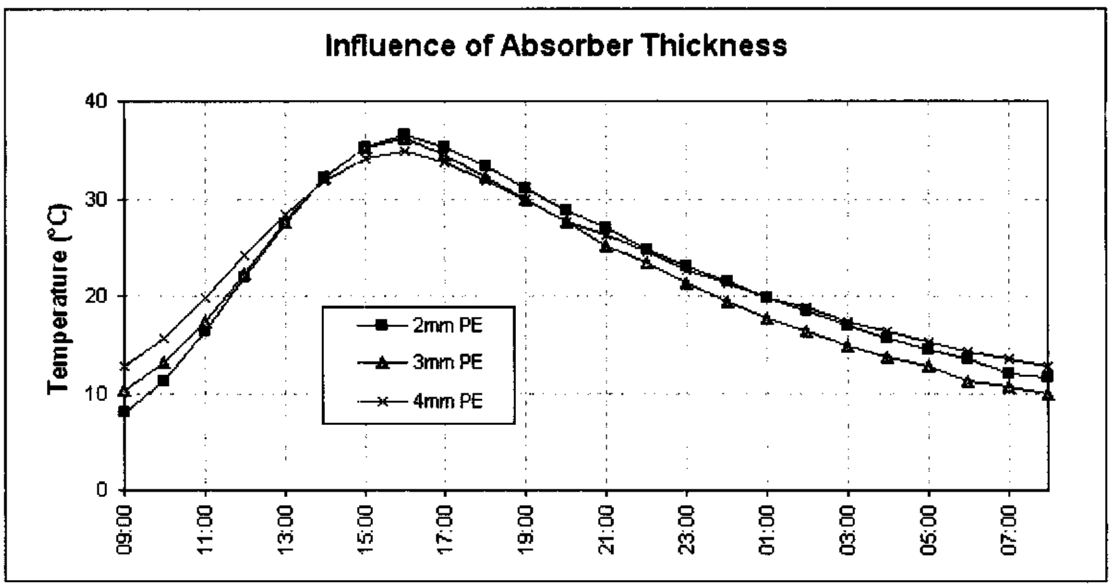

Figure 2-15: Effect of the absorber thickness on the SWH performance (Mathews & Rossouw)

Temperature limits for this material at around 80°C is also close to the expected working point of the collector surface. Typical thermal conductivity of 0.25 W/mK, and absorptance of 0.87 – 0.94 at incidence angles of up to 45°, is quoted by Bartelsen *et* *al* (1999) and Nabilek *et al* (1999). No firm figure for emissivity could be established from literature, but it is not expected to be better than standard flat black painted surfaces.

Though some authors prefer higher conductivity for polymer materials used in solar collectors, Van Niekerk *et al* (1996) found that this is not necessary as described in paragraph 2.2.1 of this dissertation. They also found that the wall thickness of the material has a small influence on the efficiency of the collector. This is confirmed by Mathews and Rossouw (1997) for polyethylene, and illustrated graphically in Figure 2-15.

Other suitable materials for the collector-storage unit under consideration are high-density polyethylene (HDPE) and polyethylene terephthalate (PET). The preferred processing method to manufacture closed containers in both these materials is blow moulding. The size of the component will, however, cause the tooling cost to be prohibitive for small numbers of prototypes. It will be suitable for reliably producing high quality components in large numbers, and must be seriously considered as a large-scale production option.

2.3.5 Glazing material and transmittance

The cheapest high transmissivity glazing for solar water heater collectors is glass with a transmittance of up to 90% (ASHRAE, 2000). This material is, however, not considered suitable for the glazing of mobile solar water heaters of any type due to its low impact resistance.

Polycarbonate proved to be a good material for collector glazing, mainly because of its good transmittance of around 90%, resistance to scratching, and impact resistance (ASHRAE, 2000; Fasulo *et al*, 2001; Chaurasia & Twidell, 2001). It does, however, exhibit a slight deterioration in characteristics under prolonged exposure to UV. Another material promoted by Gombert *et al* (2000), is clear PET, similar to that from which clear plastic soft drink bottles are made. Its scratch resistance is slightly lower than that of PC, but it has a measured transmittance of up to 95% for thin films up to 0.35 mm.

Scratching of glazing does influence the transmissivity of glazing, though not by as much as one would expect. Mathews and Rossouw (1997) intentionally sanded the full surface of their acrylic solar collector glazing with sandpaper. Their results shown in Figure 2-16 show only a 5°C reduction in the maximum water temperature achieved in the solar water heater.

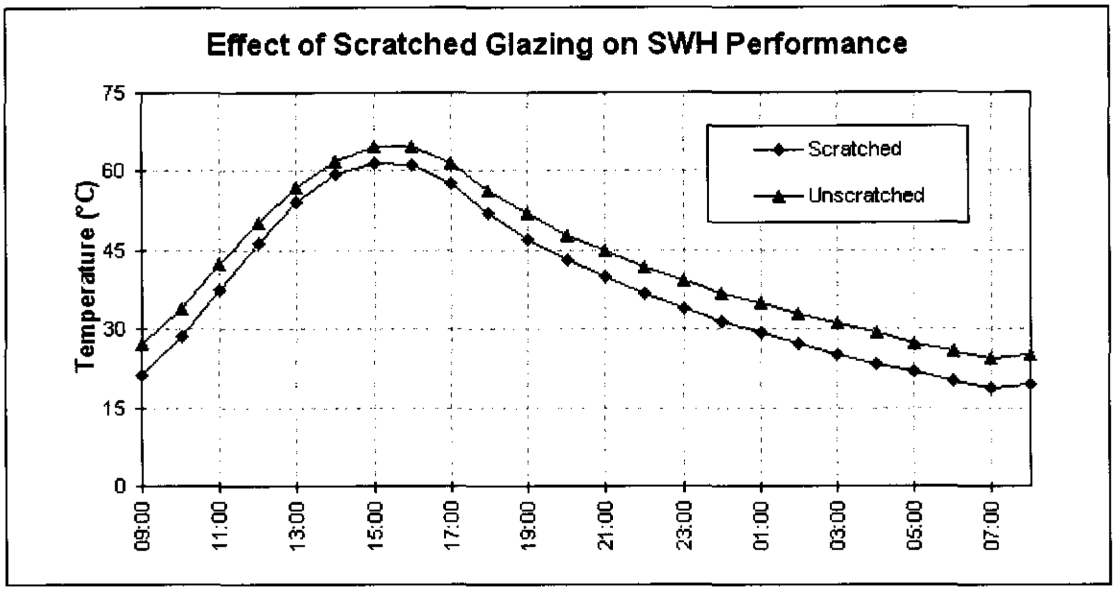

Figure 2-16: Effect of scratched glazing on SWH thermal performance (Mathews & Rossouw)

The incidence angle of light on glazing can reduce the transmissivity because a percentage of light is reflected from the surface. For all the glazings considered it is, however, assumed that the performance will not be worse than that of window glass. Karlsson *et al* (2000) showed that the transmittance of glass is nearly constant up to an incident angle of 45°, hereafter it rapidly deteriorates to zero at 90°. This is graphically represented in Figure 2-17.

Solar panel glazing, like the windows of a house, gets dirty. Dust settles on it, and reduces its transmissivity. Hegazy (2001) published experimental values for this effect on glass at different angles of inclination as shown in Figure 2-18. At typical solar collector angles of 30° – 40° the reduction in transmissivity can be as much as 15 – 18% after 30 days. Mastekbayeva and Kumar (2000) published similar figures with similar results for LDPE sheet at 15° inclination as used in solar hothouse applications (Figure 2-19). It can be expected with reasonable certainty that the polymer glazings for solar water heaters considered here will exhibit similar behaviour to glass and polyethylene sheet.

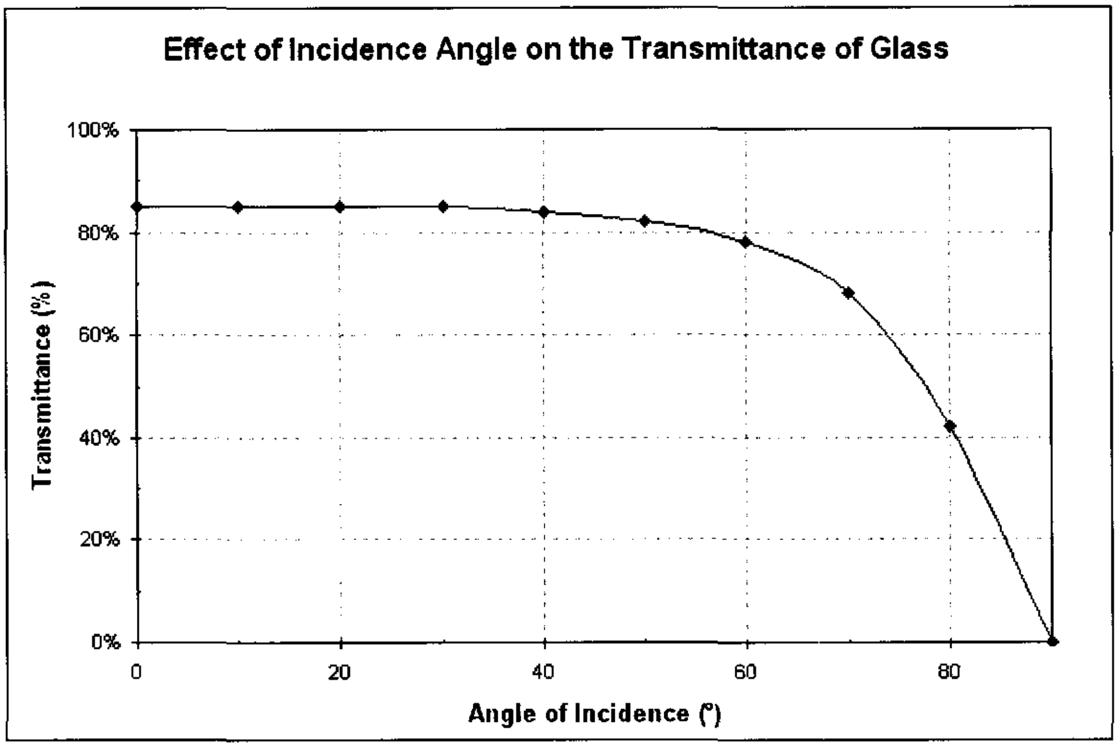

Figure 2-17: Effect of the incidence angle of light on the transmittance of glass (Karlsson *et al*)

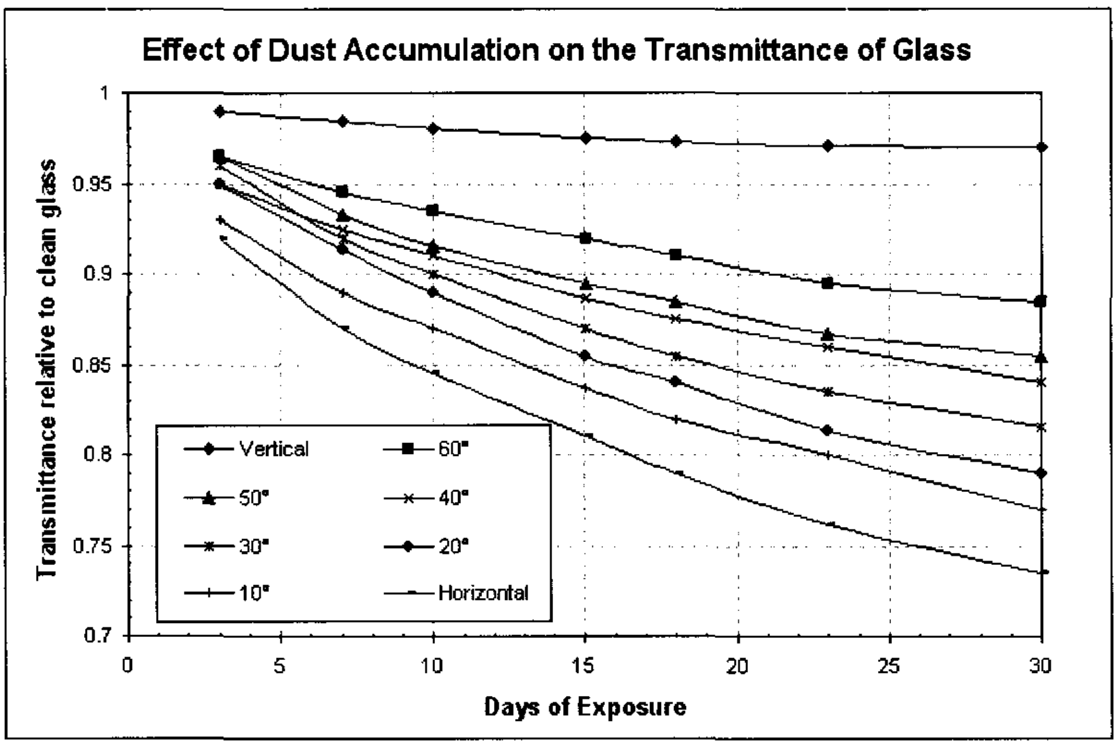

Figure 2-18: Effect of atmospheric dust accumulation on the transmittance of glass (Hegazy)

Condensation on the glazing of solar water heaters cause a surprising difference on the transmissivity of glass and polymers. Pollet *et al* (2002) experimented with glass and LDPE sheets. Their results are shown in Figure 2-20. Both sheets when dry exhibit similar performance in transmittance when measured against the incidence angle of light on its surface. When wet, glass start at the same value as when dry for a normal incidence, or vertical, but its transmittance then start to deteriorate by up to 15% for an incidence angle of 60°. Wet LDPE sheet on the other hand start off at a 21% lower transmittance at normal incidence, but retain this value up to 50° incidence.

The difference in behaviour between wet glass and LDPE is explained by the different droplet forms on the two materials. The droplets on glass are flatter than those on LDPE due to a higher surface tension difference between it and water. It would be prudent to assume that the polymer materials considered for glazing here behave like the LDPE sheet.

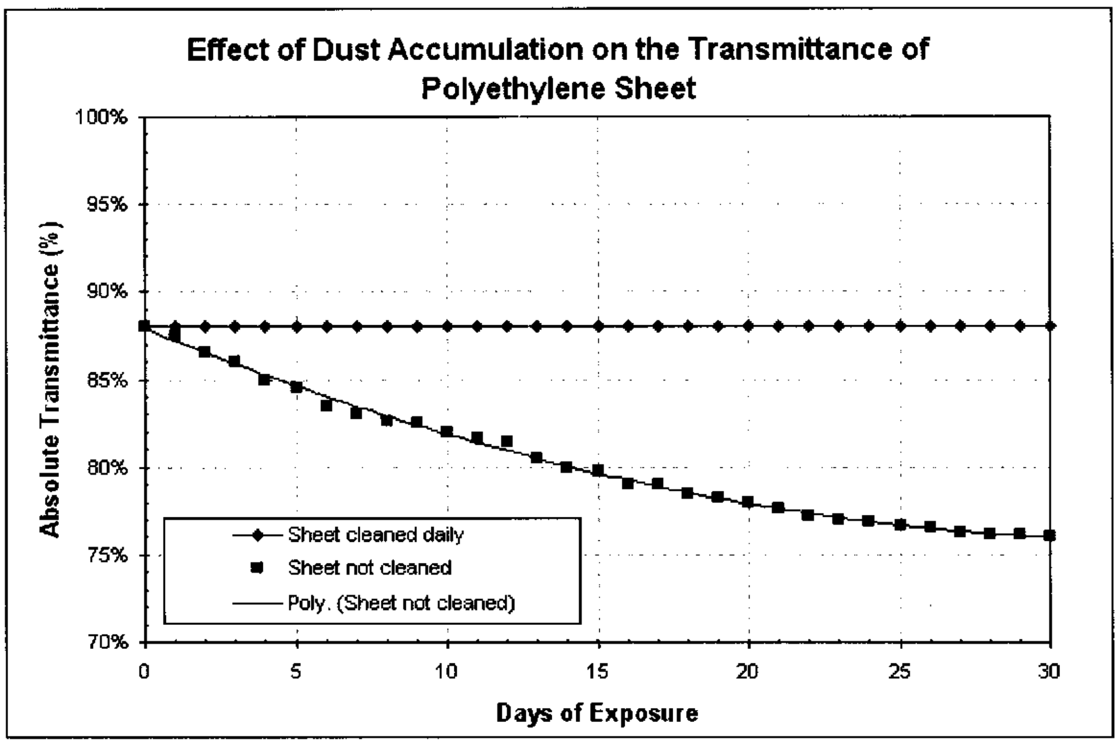

Figure 2-19: Effect of dust on the transmittance of LDPE sheet at 15° inclination (Mastekbayeva & Kumar)

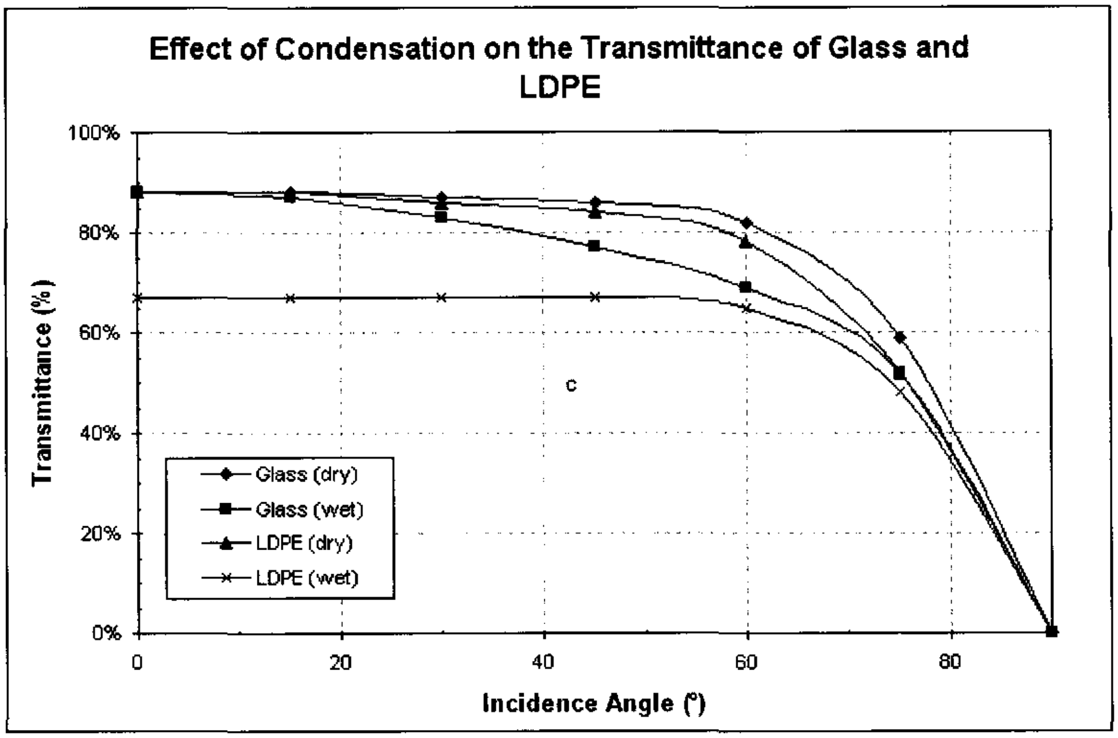

Figure 2-20: Effect of condensation on the transmittance of visible radiation for glass and LDPE sheet (Pollet *et al*)

2.4 Definition of SWH device for this study

The main lesson learned from the preceding study was that, for the Southern African market, a less than optimum solar heating efficiency would be sufficient. The mobility factor could dictate some parameters of the device without distracting from its use-ability. The fact that people can actually clean and orientate the device would then make up for most of the efficiency loss.

There was now sufficient information available to specify the main parameters of a mobile solar water heater to be developed for this study.

2.4.1 <u>Type</u>

The integrated collector storage (ICS) solar water heater was the natural choice for the SWH to be developed for this study. It is suitable for use in Southern Africa with its mild sunny climate, and is the simplest form of solar water heater from a manufacturing point of view. It is also the easiest to package in an acceptable form for a highly mobile appliance.

2.4.2 Mobility

The solar water heater would be made mobile similar to a standard wheelbarrow to enable people to fetch water from communal sources. The wheelbarrow layout has been for many years, and remains, the yardstick of human powered push propelled transport equipment. The single wheel layout is easier to push and directionally stable over any type of terrain. The other two wheel mobile solar water heater concepts shown in paragraph 2.1.1 of this dissertation is unstable when pushed. This is simply because a disturbing force on any one of the two wheels will cause the unit to steer such as to increase the disturbance.

One improvement made is to reduce the rolling resistance of the wheel of this device over soft terrain. Copying from experience with farm implements like ploughs that are used on soft ground, a wide wheel made with a soft sponge-centred rubber tyre in the form of a partial sphere will reduce the effort to propel this device over soft terrain.

Stability of the unit when placed stationary for heating should also not be a problem. Standard wheelbarrow type supports would be incorporated to create a stable triangular support layout.

2.4.3 Volume, mass and size

As defined in paragraph 1.1.3 of this dissertation, every person needs at least 10 litres of hot water per day as a minimum for hygienic use. If we further define that a young, often pre-teen, child must be able to help with the household chores by fetching water, the total mass of the unit should not exceed 35 – 40 kg. By allowing 10 - 15 kg for the mass of the unit itself, the water volume of the ICS solar water heater cum wheelbarrow, or *Solar Heat Barrow* (*SHB*) for lack of a better name, was limited to approximately 25 litres. This provides in the basic needs of two people.

ASHREA (2000) recommends, as a guideline for general purpose solar water heaters, a hot water storage capacity of 40 – 80 litres per square meter collector aperture area. A solar collector area of around 0.5 m^2 should thus be able to provide sufficient useful energy to heat the contents of the *SHB* in a reasonable time.

Many low cost dwellings in rural areas have doors not much wider than the minimum usable 600 mm for humans. It would thus be prudent to limit the width of the complete *SHB* to this value to allow for easy appliance access into and out of the dwelling.

2.4.4 Materials of construction

The preferred materials for general construction of the *SHB* are polymers. For cost reasons the storage-collector of the prototypes of the *SHB* would be roto-moulded in black UV stabilised LDPE using low cost sheet metal moulds. A material thickness of 3 – 4 mm was specified, but consistent quality with the prototype tooling was difficult to maintain. The choice of material should, however, be reconsidered for production of consistently high quality components at the required rates of manufacture. Blow moulded HDPE or PET is the more preferred option.

Because of its low prototyping cost and mechanical robustness, roto-moulded LDPE was also chosen to manufacture the outside body around the collector. The housing body could be coloured to a variety of bright and not so bright hues.

The collector glazing for the *SHB* prototypes should be a polymeric material to meet the robustness requirements. Clear polycarbonate sheet, though expensive in small quantities, is a readily available and suitable material, and was thus selected for the prototype units. PET may, however, be a more cost effective material for production.

The manufacturing of special wheels for the *SHB* would be too expensive for the available funds. The wheel of the prototype units was thus selected at an early design stage to be a standard, off the shelf, wheelbarrow wheel.

2.4.5 Insulation

The polymer components of the *SHB* would be relatively flexible due to the low modulus of the material used. In order to obtain an assembly with an acceptable rigidity for general use, the insulation material should preferably be poly-isocyanurate foam expanded in the cavity between the housing and the storage-collector. The bonding of the foam to the polyethylene components then forms a rigid compound structure able to withstand the use and abuse to which the unit will be subjected to.

A preliminary sizing of the storage-collector and housing for the parameters of paragraph 2.4.3 of this dissertation, showed that an insulation thickness of approximately 25 mm could be fitted around the unit without exceeding the physical limits. This also corresponds to the optimal thickness of 20 mm of the same material as reported by Chaurasia and Twidell (2000) for the ICS solar water heater they have studied. The goal of this insulation has to be kept in mind, i.e. to maintain a bathwater temperature of 40°C until at least 20:00 at night.

Rough prototype tooling were again used here, but relatively expensive tooling will be required for production to ensure that the foam meets the density, and thus closed cell, requirements for high quality insulation. Allowing the poly-isocyanurate foam to over expand allows it to form a partial open-cell structure that reduces the insulation effectiveness, especially in the presence of moisture.

2.4.6 Cost target

The cost of the *SHB* would have to be very low for the product to be a success on pure commercial grounds. It would be ideal to actually sell such a unit for the same price as a standard wheelbarrow, which can be bought for less than R200 at larger outlets all over South Africa. It quickly proved near impossible due to the cost of the locally produced, but internationally priced, polymers of the storage-collector and housing units. The polycarbonate glazing and the poly-isocyanurate foam are fully imported and as such are relatively high cost components.

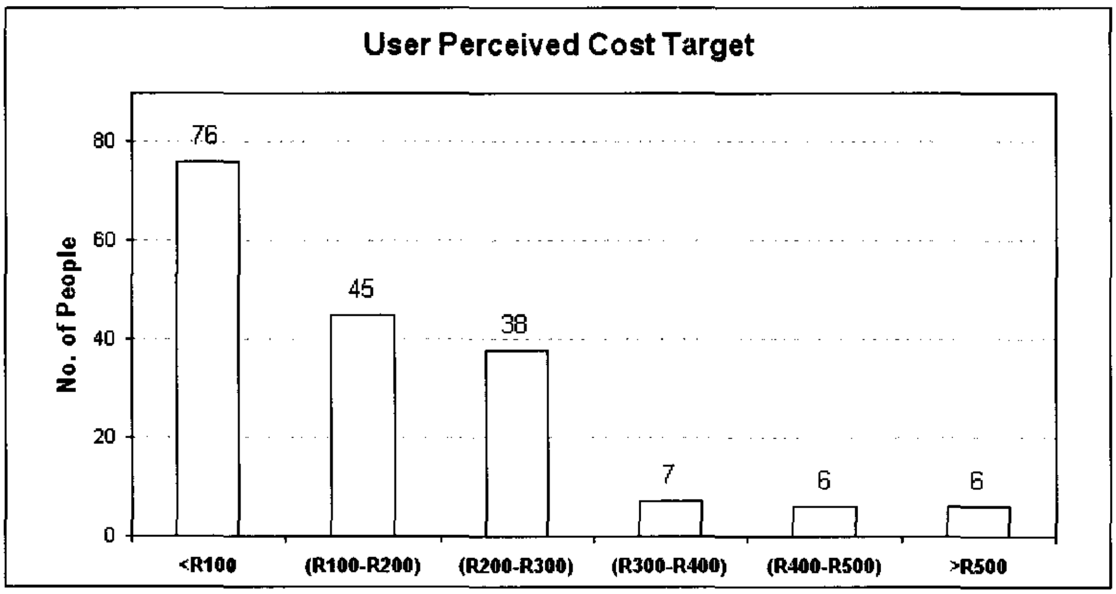

Figure 2-21: User perception of what the cost for SWH device should be (adapted from Taylor)

In his survey reported in paragraph 1.1 of this dissertation, Taylor (2001) asked participants in the informal settlements around Pretoria what they could afford to pay for a product such as the *SHB*. As shown in Figure 2-21 very few people could afford, or were willing, to pay a price of around R500. This is equivalent to the price of a portable black and white television set. The unit will have to sell for about R300 to achieve any reasonable market penetration of around 15%. This is based on the assumption that half of the people that indicated a willingness to pay between R200 and R300, and 75% of those willing to pay more, actually buy a *Solar Heat Barrow.*

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CHAPTER 3: WATER DISINFECTION

3.1 Modern practice

3.1.1 History

In the old days, natural watercourses and wells provided adequate water for human consumption. As populations increased, domestic water needs for drinking, cooking, and hygiene stimulated demand for more and a higher quality of water. Modern water-supply systems were conceived at a time when public health ideas blamed disease transmission on filth, decaying matter, foul smells, and 'bad air', or so called miasmas (Melosi, 2000). The fear of epidemics was a particularly great motivator for change, and increased public pressure for improved water supplies. Ralph Waldo Emerson observed that cholera killed 5 to 15 % of the US population in an 1833 epidemic (USPC, 2002).

Melosi (2000) reports that Edwin Chadwick, in his 1832 *Sanitary Report,* linked filth with disease. This notion turned attention to controlling environmental factors. Engineers, among others, linked the structure of sanitary systems and their functions to the goals of environmental sanitation, utilising sensory tests of purity to deliver a product that would be free from known diseases and would remove wastes from direct human contact. At the time, daily consumption of water in US cities probably averaged between 10 and 20 liters per capita, however, the new water systems did not provide for equity of service (Melosi, 2000).

During the mid-nineteenth century, some waterworks employed sedimentation to clarify muddy water, and others used 'natural' filtration in the form of wetlands, reeds and dunes. The first means of water purification readily available in the late nineteenth century was filtration through sand or gravel to improve clarity, odour, and colour (Melosi, 2000). Complicating the search for pure water was the inability to accurately determine what constituted a contaminated supply.

The idea of disinfecting water was discovered well before the twentieth century. Even before chlorination of water became popular, sewage had been chlorinated in

England, France, and in the United States. One of the first known uses of chlorine for water disinfection was by John Snow in 1850, when he attempted to disinfect a water supply in London after an outbreak of cholera (Christman, 1998). Nobody was immune against these diseases. Prince Albert, husband of Queen Victoria of Great Britain, died in 1861 of typhoid spread through the water of Windsor Castle. Peter Ilich Tchaikovsky, the great composer, died in 1893 from drinking a glass of unboiled water during a cholera epidemic in St. Petersburg, Russia (USPC, 2002).

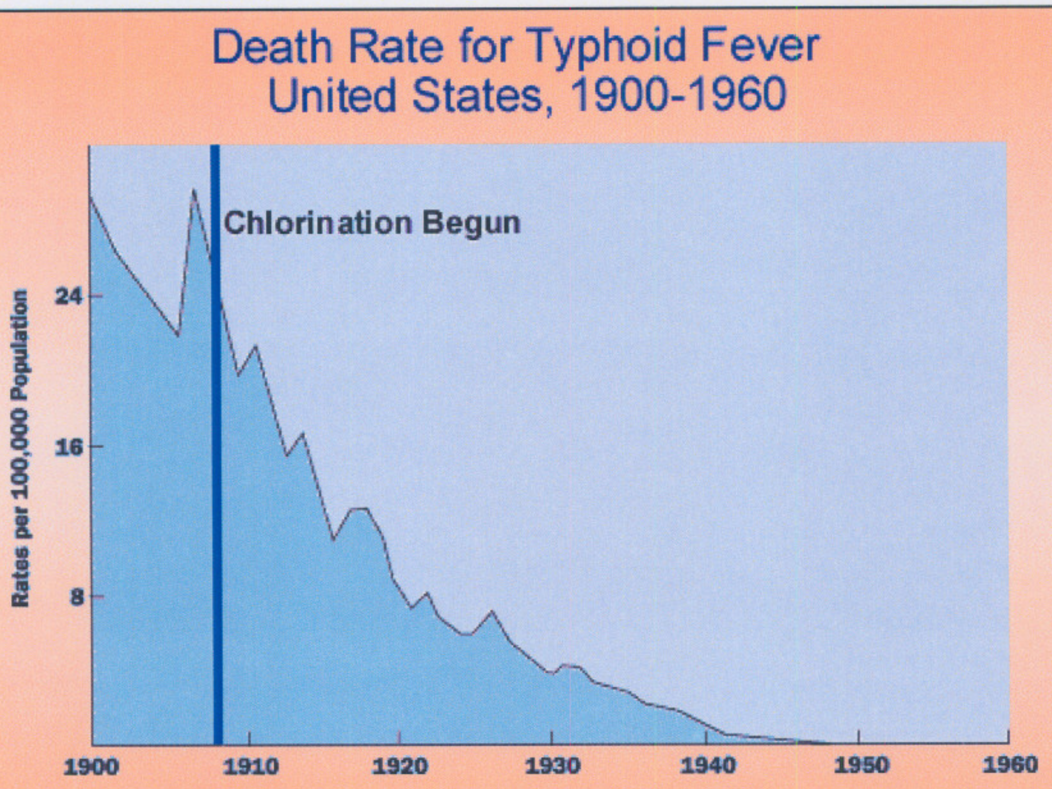
In 1896, sanitary engineers introduced bleaching powder in Austria. In 1897, Sims Woodhead used 'bleach solution' as a temporary measure to sterilize potable water distribution mains at Maidstone, Kent (England) following a typhoid outbreak (Christman, 1998).

Water treatment however made important strides in the first decade of the twentieth century. Continuous chlorination of drinking water began in the early years of this century in Great Britain, where its application sharply reduced typhoid deaths (Christman, 1998). Several cities added chlorine to their water. In 1909, chemists produced liquid chlorine, which offered a much easier method of dispersal (Melosi, 2000).

A dramatic decline in typhoid fever rates followed the use of chlorine in many locations (Melosi, 2000; Christman, 1998). Of the 20 countries surveyed in 1932, the United States was ranked 11th in the lowest typhoid rate, one place higher than France, and substantially better than South Africa in 20th place (Melosi, 2000). The dramatic decline of typhoid fever in the USA is graphically illustrated in Figure 3-1.

Despite the optimistic reports, there remained some concern among populations about the 'doping' of water with chemicals. Even the widely adopted practice of chlorination attracted doubters. This fear arose before the turn of the twentieth century (Melosi, 2000), and it still has not completely died out.

Until the mid-twentieth century, engineers and medical and public health experts paid greater attention to biological forms of pollution linked to epidemic diseases than to industrial and other chemical pollutants. Water pollution at the source, however, emerged as an issue (WHO, 1993[b]), and attention to water pollution broadened considerably from the focus on biological contaminants to a wide variety of chemical contaminants (Melosi, 2000). Runoff into watercourses contained asbestos, heavy metals, oil and grease, salts, manures, pesticides and herbicides, construction-site pollutants, bacterial and viral contaminants, hydrocarbons and topsoil (WHO, 1993[b]).



Source: U.S. Centers for Disease Control and Prevention, Summary of Notifiable Diseases, 1997.

Figure 3-1: Reduction in US death rate due to *Salmonella typhi* ascribed to chlorination (CDC as in CCC)

One important reason for the change in awareness was the substantial decline in a number of water-borne diseases, and confidence in available methods and technologies in combating those that remained. Diseases such as cholera and typhoid fever had been virtually eliminated from the industrialised first world due to a change in the environmental paradigm from miasmas to bacteria.

3.1.2 Guidelines for water acceptability

Consumers have no means of judging the safety of their potable water themselves. Their attitude towards their water supply will, however, be affected to a considerable extent by the aspects of water quality that they are able to perceive with their own senses. It is natural for consumers to regard water that appears dirty or discoloured, or that has an unpleasant taste or smell, with suspicion. These characteristics may not in themselves be of any direct consequence to health (WHO, 1993[b]).

Many potential water problems can be prevented by safeguarding the integrity of a raw water source and its watershed, (WHO, 1993[b]; EPA in CCC, 1997). It should be protected from human activities, surface drainage and flooding.

Protection of open surface water is a problem. It may be possible to protect a reservoir or dam from major human activity. In the case of a river, however, protection may be possible only over a limited reach, if at all. It is often necessary to accept existing and historical uses of a river and to design the water treatment accordingly (WHO, 1993[a]).

Indicators

The common procedure to determine the safety of water is to test it for bacterial indicators of faecal pollution. There are two groups of indicators that are used. The first is the general coliform bacteria that may come from faeces or from plants.

Among the coliform bacteria is the important second indicator, *Escherichia coli*. This bacterium is present in large numbers in human faeces (approximately 100 million per gram of faeces) and that of other mammals. A water source containing 100 individual *E. coli* bacteria per 100 millilitres poses a substantial risk of disease (Metcalf, 2002). The World Health Organisation recommends coliform and *E. coli* concentrations of less than 1 per 100 ml. This should be readily achievable through good water management practices (WHO, 1979[a]).

The standard method of testing water for the presence of coliforms and *E. coli* requires trained personnel and a good laboratory facility or field unit, which are usually not present in developing countries (WHO, 1979[a]). Thus, rural water supplies are almost never tested (Metcalf, 2002).

The efficiency of any disinfection process depends upon the water being treated beforehand to a high degree of purity, as disinfectants will be neutralized to a greater or lesser extent by organic matter and readily oxidizable compounds in water (WHO, 1993[a]).

Turbidity

Turbidity in drinking water is caused by particulate matter that may be present as a consequence of inadequate treatment or from resuspension of sediment in the source. It may also be due to the presence of inorganic particulate matter in some ground waters (WHO, 2000).

Micro-organisms that are gathered or adsorbed to particulate matter will also be partly protected from disinfection. There are instances of disinfection failing to destroy waterborne pathogens and faecal bacteria when the turbidity was greater than 5 nephelometric turbidity units (NTU). It is therefore essential that the treatment process preceding disinfection produce water with a median turbidity not exceeding 1 NTU and not exceeding 5 NTU in any single sample. Values well below these levels will regularly be attained with a properly managed plant (WHO, 1993[a]).

pH

Although pH usually has no direct impact on consumers, it is one of the most important operational water quality parameters. Careful attention to pH control is necessary at all stages of water treatment to ensure satisfactory water clarification and disinfection. For effective disinfection with chlorine, the pH should preferably be between 6.5 and 8 (WHO, 2000).

Temperature

In general, disinfection is aided by increased temperature. The majority of the available data relate to chlorination. Working with *Escherichia coli*, Ames and Whitney-Smith (as reported in Health Canada, 1979[c]) found a nine-fold increase in effectiveness between 8°C and 40°C. Similar results have been obtained with viruses.

An aesthetic objective of less than 15°C has been established for the temperature of drinking water. From the user's viewpoint, cool drinking water with a temperature of around 10°C is usually satisfactory (WHO, 1993[a]). The figure of 19°C is often quoted as a limit above which most consumers complain (Health Canada, 1979[c]).

The temperature of water also plays a role in its taste and odour.

Taste and Odour

As taste and odour cannot be measured objectively their limits are set mainly on the basis of aesthetic considerations.

Non-specific taste and odour problems are usually associated with high concentrations of colour and turbidity in water. High densities of nuisance organisms in water can result in unacceptable tastes and odours because of the production of low concentrations of metabolic products (Health Canada, 1979[a]; Health Canada, 1979[b]).

The parameter that has been most closely related to taste is 'total dissolved solids' (TDS). The maximum recommended TDS levels, 500 to 1000 mg/L, have traditionally been set largely on the basis of taste thresholds for the major anions and cat ions of water (Health Canada, 1979[b]).

Odour in water is usually measured in terms of its 'threshold odour number' (TON), the number of times a sample must be diluted with an equal volume of distilled water to become only just detectable by 50% of a panel of judges (Health Canada, 1979[a]).

No direct relationship appears to exist between taste and odour in drinking water and the presence of coliform organisms and related pathogens. Some organic odours may, however, be indirectly due to the dumping of raw sewage into the aquatic environment. This enhances biological growth and consequently odours (Health Canada, 1979[a]; Health Canada, 1979[b]; WHO, 1993[a]).

Unfortunately, the absence of offensive odours and taste provides no assurance that water is free of pathogens.

3.1.3 Disinfection practice

The fundamental purpose of water treatment is to protect the water consumer from pathogens and impurities in the water that may be detrimental to human health. Urban treatment of water usually consists of

- reservoir storage or pre-disinfection,
- coagulation, flocculation, sedimentation and flotation,
- filtration, and
- disinfection.

Urban water treatment is, in effect, a four-stage multiple-barrier system for the removal of contamination (WHO, 1993[a]).

Storage and sedimentation

Surface waters may be either stored in reservoirs or disinfected before treatment. During impoundment in dams or reservoirs, the microbiological quality improves considerably as a result of sedimentation, the effect of the ultraviolet content of sunlight in surface layers of water, starvation, and predation by other micro-organisms. Reductions of faecal indicator bacteria, salmonella, and enteroviruses are about 99% with residence periods of the order of 3–4 weeks (WHO, 1993[a]).

The typical settling time of matter in a reservoir of water is summarised in Table 3-1 (USPC, 2002; Burch & Thomas, 1998).

Table 3-1: ORDER OF TIME REQUIRED FOR MATTER TO SETTLE IN WATER

Matter	Approximate Size	Settling time order
Sand	1mm	seconds
Fine sand, algae, helminths	100 µm	minutes
Silt, bacteria, oocysts	10 µm	hours
Clay, small bacteria	1 µm	days
Colour particle	0.1 µm	years
Colloid, virus	0.01 µm	practically never

The settlement of particles in water does so in accordance with Stokes Law, which is:

$$u_s = D_p^2 g(\rho_s - \rho_w) / 18\eta_w \qquad (3.1)$$

where

u_s is the settling velocity (m/s)

D_p is the diameter of particle (m)

ρ_w is the water density (kg/m^3)

ρ_s is the solid density (kg/m^3)

g is the gravitation constant (9.81 m/s^2)

η_w is the dynamic viscosity of the water (Pa.s)

Slow sand filtration

Slow sand filtration is particularly suitable for developing countries and small rural systems, but it is applicable only if sufficient land is available.

When correctly loaded, slow sand filtration brings about the greatest improvement in water quality of any single conventional water treatment process. Bacterial removal will be 98–99.5% or more. *E. coli* will be reduced by a factor of 1000, and virus removal will be even greater. A slow sand filter is also very efficient in removing parasitic protozoa. Nevertheless, the effluent from a slow sand filter might well contain a few *E. coli* and viruses. (WHO, 1993[a])

The movement of water through slow sand filtration in a packed bed follows the Ergun equation (USPC, 2002). Only the laminar Blake-Kozensky term of the equation applies to slow sand filtration (Subramanian, 2003), and it can be written (in SI units) as:

$$\Delta p = 150\, L\, (1 - \Phi)^2\, v_s\, \eta_w / \Phi^3 D_b^2 \qquad (3.2)$$

where

Δp is pressure drop across the filter bed (Pa)

L is the thickness of bed (m)

Φ is the void fraction in bed

v_s is the superficial flow velocity (m/s)

η_w is the dynamic viscosity of the water (Pa.s)

D_b is the diameter of filter bed particles (m)

Terminal disinfection of potable water supplies is of paramount importance as it is the final barrier to the transmission of waterborne bacterial and viral diseases. Although chlorine and hypochlorite are most often used, water may also be disinfected with chlorinated isocyanurates, ozone, and ultraviolet irradiation (WHO, 1993[a]; USPC, 2002; Burch & Thomas, 1998).

Chlorination

Chlorination is usually in the form of chlorine gas or sodium or calcium hypochlorite. (WHO, 1993[a]) The benefits of water disinfection with chlorine are that it is a potent germicide and has residual qualities (the presence of a sustained residual maintains the quality of the finished water). It also helps to control taste, odour and biological growth such as algae. (CCC, 1997)

When chlorine gas or hypochlorite is added to water, hypochlorous acid (HOCl) is formed as follows (WHO, 2000; Pinto & Rohrig, 2003; USPC, 2002).

$$Cl_2 + H_2O \leftrightarrow HOCl + HCl \qquad (3.3)$$

and

$$NaOCl + H_2O \leftrightarrow HOCl + NaOH \qquad (3.4)$$

Hypochlorous acid dissociates in water into its constituents H^+ and OCl^- (hypochlorite ion), as follows:

$$HOCl \leftrightarrow H^+ + OCl^- \qquad (3.5)$$

Together, hypochlorous acid and OCl^- are referred to as free chlorine. The degree of dissociation depends on pH and temperature. Dissociation is poor at pH levels below 6. At pH levels of 6.5–8.5, a change occurs from undissociated hypochlorous acid to nearly complete dissociation. Both species are necessary for good disinfection, and control of pH is therefore very important (WHO, 1993[a]; Pinto & Rohrig, 2003).

At a given pH, higher temperature leads to greater dissociation of hypochlorous acid. At pH 8, for example, hypochlorous acid concentration decreases by nearly 30% in the temperature range 0°C to 20°C. The magnitude of this effect on the germicidal efficiency of chlorinated water is, however, of secondary importance to the larger, and opposite, effect of increased germicidal action at higher temperatures (Health Canada, 1979[c]).

The terms to define the sodium hypochlorite strength commonly used in water disinfection are 'grams per litre of available chlorine' (gpl). This is the weight of available chlorine in grams in one litre of sodium hypochlorite solution. Another term commonly used is 'trade percent of available chlorine' (%), often used to define the strength of commercial bleaches. It is identical to grams per litre of available chlorine except the unit of volume is 100 millilitres, not one litre (Powell, 2002). Therefore the numerical value of percentage is one tenth of the numerical value of grams per litre for the same sample

The World Health Organisation's (WHO, 1993[a]) recommendations for disinfection with chlorine are:

- an initial chlorine dose of 5 mg per litre (0.0005%),
- a free residual chlorine of 0.5 mg per litre (0.00005%),
- water turbidity of less than 1 NTU,
- pH between 6.5 and 8.0, and
- at least 30 minutes contact

For these conditions over 99% of *E. coli* and certain viruses, but not all of the oocysts of parasitic protozoa, will be destroyed.

A little bit of chlorine, such as the levels used in drinking water, kills relatively simple micro-organisms very effectively. However, at these levels the food and the matter normally present in the stomach and intestinal tract of humans quickly neutralise the chlorine. At much higher concentrations, chlorine would also harm people (Calomiris & Christman, 1998).

The minor decomposition pathway of sodium hypochlorite is as follows:

$$2NaOCl \rightarrow 2NaCl + O_2 \qquad (3.6)$$

Increasing strength, temperature, decreasing pH, and exposure to light will increase the rate of this pathway and a loss of sodium hypochlorite. Contact with metals in particular will result in large amounts of product decomposition and oxygen formation, and may create and explosive hazard. All hypochlorites and hypochlorite forming materials must thus only be stored in plastic, preferably polyethylene, containers (Powell, 2002).

Chloroisocyanurates

The chlorinated isocyanurate compounds are white crystalline compounds with a slight chlorine-type odour that provide free chlorine (HOCl) when dissolved in water. For Sodium dichloroisocyanurate (NaDCC) this is (Pinto & Rohrig; 2003):

$$C_3Cl_2N_3O_3Na + 2H_2O \rightarrow C_3H_3N_3O_3 + Na^+ + OCl^- + HOCl \quad (3.7)$$

and for Trichloroisocyanuric acid (TCC):

$$C_3Cl_3N_3O_3 + 3H_2O \rightarrow C_3H_3N_3O_3 + 3HOCl \quad (3.8)$$

They are an indirect source of chlorine, via an organic reserve (cyanuric acid). The relative amounts of each compound are determined by the pH and free chlorine concentration. As the disinfectant (HOCl) is used up, more chlorine is released from the chloroisocyanurates to form hypochlorous acid (WHO, 1993[b]; Pinto & Rohrig, 2003).

Chloroisocyanurates, especially TCC, is used for domestic swimming pool disinfection, but is not recommended for drinking water disinfection (WHO, 1993[b]). NaDCC are, however, used on a limited scale for drinking water disinfection, mostly in the form of tablets for purifying small batches of water (EPA, 1993; Milton, 2003).

Ultraviolet radiation

Artificial germicidal UV radiation is a plant-room treatment that purifies the circulating water, inactivating micro-organisms by photo-oxidation and disabling the DNA involved in reproduction of bacteria and viruses. UV radiation from mercury discharge lamps is produced near 250 nm, in the middle of the 'germicidal band' from 200 nm to 280 nm (WHO, 1993b; Burch & Thomas, 1998). This decreases the chlorine demand of the purified water but does not leave a disinfectant residual in the water.

For germicidal UV to be most effective, the water must be pre-treated to remove turbidity-causing particulate matter that prevents the penetration of the UV radiation or absorbs the UV energy (WHO, 1993[b]).

In recent years, the parasitic protozoans *Cryptosporidium parvum* and *Giardia lamblia* have emerged as formidable waterborne pathogens. They are remarkably resistant to chlorine disinfection. Currently, filtration is the most effective process for removing these protozoa from drinking water (Calomiris & Christman, 1998). A joint venture in the United Kingdom has proposed a UV system to inactivate the eggs (oocysts) of these protozoas in drinking water. Rather than treating the water, the system directly treats the oocysts to achieve their inactivation (CCC, 1997).

Aqua Sun International (2002) manufactures germicidal UV systems with an intensity of 160 W/m^2 or greater. They also provide the germicidal UV intensity dosage required to destroy more than 99.999% of a long list of micro-organisms. The most important ones pertinent to this study are summarised in Table 3-2. The time of exposure, and thus the total energy required, is however not given.

Table 3-2: UV INTENSITY REQUIRED TO DESTROY 99.999% OF ORGANISMS

Micro-organism	UV Intensity (W/m^2)
Salmonella typhimunum	152
Escherichia coli	70
Shigella dysenterai (Dysentery)	42
Vibrio Cholera (Cholera)	65
Hepatitis A virus	80
Rotavirus	24
Penicillum roqueforti (green)	264

3.2 Options for the Third World

High quality purified and disinfected water piped to the point of domestic use is globally the exception rather than the rule, especially in rural areas of developing nations.

3.2.1 Pre-treatment

There are a few methods that employ simple, low cost technologies that are commonly advocated for the disinfection of drinking water at the rural household level. The multiple-barrier concept can, however, be adapted for doing this. A typical series of simplified processes would include (WHO, 1993[a]; Burch & Thomas, 1998; SANDEC, 1999[a]; CDC, 2000):

- storage in available containers,
- sedimentation, or settlement, and decanting,
- straining and filtration through cloth, and
- disinfection by boiling, chemicals or solar radiation.

Water extracted from deep, well-protected boreholes are usually free from pathogenic micro-organisms, and the distribution of such untreated ground water is common practice in many rural settings. Surface water on the other hand, will usually require full treatment. In small rural communities, protection of the source of water may be the only form of treatment possible (WHO, 1993[a]).

In areas where water is turbid, pre-treatment to filter out sediment can improve the quality of water and increase the efficiency of disinfection. In some cases it may reduce the degree of microbial contamination. The simplest method of filtration promoted in the Safe Water Manual (CDC, 2000) is to filter water through locally available, inexpensive cloth. In regions with extremely turbid water, it may be difficult to adequately filter water with cloth because it can become clogged.

In such regions, it may be necessary to let water settle overnight and then decant the cleared water into a new container (CDC, 2000). Other filter systems such as slow sand filters could be considered, although cost and complexity are potential drawbacks.

Many people collect water from sources away from the point of use or store water in unsanitary conditions in the household. For these reasons, even purified water is subject to contamination in transport and the household, and this may often be the most important source of microbiological contamination.

Water to be used for drinking, processing and cooking of food, washing dishes, making any prepared drink, hand washing, and brushing the teeth, as a minimum, should be properly disinfected (EPA, 1993).

3.2.2 Temperature methods

Boiling

Both the US Environmental Protection Agency (EPA, 1993) and the World Health Organisation (WHO, 1993[b]) state that vigorous boiling for one minute will kill any disease-causing micro-organisms present in water. As water boils at a lower temperature at high altitude, a minute of extra boiling time should be added for every 1000 m above sea level.

Though the disagreeable taste of boiled water often discourages consumers, it can easily be improved by pouring it back and forth from one container to another (called aeration), by allowing it to stand for a few hours, or by adding a small pinch of salt for each litre of water boiled (EPA, 1993).

The reason boiling is recommended is to make sure that the water has reached lethal temperatures for pathogen destruction. Unless one has a thermometer it is difficult to tell what temperature heated water has reached until a roaring boil is reached.

The populations most threatened by waterborne diseases are the economically disadvantaged. Boiling sufficient water for domestic purposes, even only 10 litres of drinking water, can be too costly for most households in impoverished high-risk areas (Reiff *et al*, 1996; Metcalf, 2002). The cost to boil water also competes with the need for food, and other basic necessities (USDC, 2002).

Acra *et al* (1984), as well as Metcalf (2002), claim that to boil 1 litre of water would consumed approximately 1 kilogram of wood, coal or charcoal. This claim is probably exaggerated. The effect in that an inadequate water supply system would significantly contribute to deforestation and air pollution, is, however, clear for anyone travelling in the Southern Africa. In Africa alone, the fuel wood and charcoal consumption were estimated at 502.2 million m^3 in 1994, with an increase of 3.3% per year for the preceding decade (SANDEC, 1998).

Pasteurisation

Most milk is pasteurised at 71.7°C for only 15 seconds. Alternatively, 30 minutes at 62.8°C can also pasteurise milk (Metcalf, 2002). Some bacteria are heat resistant to these temperatures and can survive pasteurisation, but these bacteria do not cause diseases in people. They can, however, spoil the milk, so pasteurised milk must still be kept refrigerated.

Some different disease causing micro-organisms are found in water, but they are not unusually heat resistant. Figure 3-2, redrawn from Burch and Thomas (1998), shows the effect of time at temperature for various pathogens discussed in paragraph 1.1.2 of this dissertation. All but viruses are rapidly killed at temperatures of 60°C in only an hour. Of note is the relative sensitivity of *Vibrio cholerae* to heat, a weakness that may be exploited to good effect in cholera prevention during epidemics.

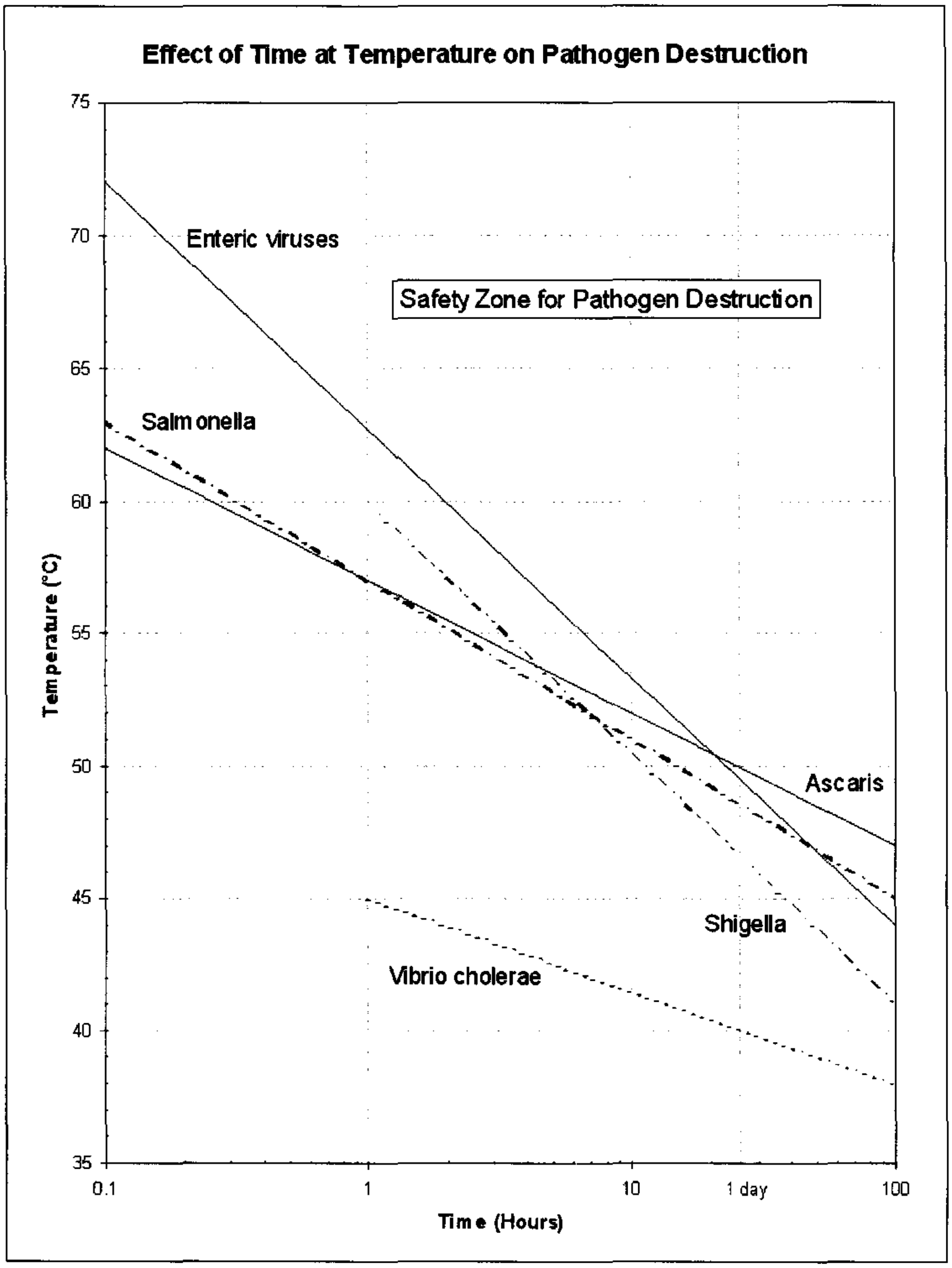


Figure 3-2: Effect of time at temperature of water pasteurisation for various pathogens (Burch & Thomas)

Pasteurising can start at temperatures as low as 50°C if sufficient exposure time is allowed. Above this, the time for pasteurisation decreases at roughly a factor of 10 for every 10°C increase in pasteurisation temperature. Ciochetti, as reported by

Metcalf (2002), also concluded that momentarily heating water to 66° C would provide enough retained heat in the water to pasteurise the water and kill the majority of disease-causing microbes. Viruses appear the hardest to kill and essentially set the boundary for acceptable time–temperature processes (Figure 3-2).

The major advantage of conventional pasteurisation is that all major pathogens of concern are killed independent of filtration, turbidity, pH, and other parameters influencing alternative methods. The major disadvantage of pasteurisation for rural populations, using conventional energy sources, is the high associated fuel cost (Burch & Thomas, 1998) and the accurate temperature measurement required to ensure that pasteurisation did indeed take place (Acra *et al*, 1984).

3.2.3 Solar methods

Several devices have been developed to utilise the energy of the sun for the small-scale disinfection of water. Most of the simple devices are not intended to 'sterilise' water, but to reduce the number of pathogens so that the water is safer for consumption.

Solar still disinfection

A solar still usually consists of a shallow pool with a flat surface of 1 to 2 m^2. The bottom surface and walls are blackened and waterproofed. Smooth glass is mounted at a slight angle above the pool. As the water is heated, it forms water vapor, which condenses on the glass. Gravity pulls the condensate to the lower edge of the pane, and drips into a trough, and then through a hose or tube into a collection jug. A 2 m^2 still produces about 10 liters of water a day in the summer, with winter production about half (Rolla, 1998).

Ward (2003) describes an interesting new solar still water purifier. A black plastic sheet, covered by a glass window, is formed into an array of interconnected square cells, which contain impure water. The unit stands at a slight angle as illustrated in Figure 3-3, and is shown orientated for use in the Southern hemisphere.

The contaminated water is heated by the sun to form water vapour. A thin sheet of purified water runs on the inside of the glass due to the heat pipe effect, to a collection trough at the lower end of the still. A feature of the design geometry is the inability of bacteria to cross over the water vapour barrier above each tray. The unit is foreseen to be used to disinfect either batches or a semi-continuous flow of water.

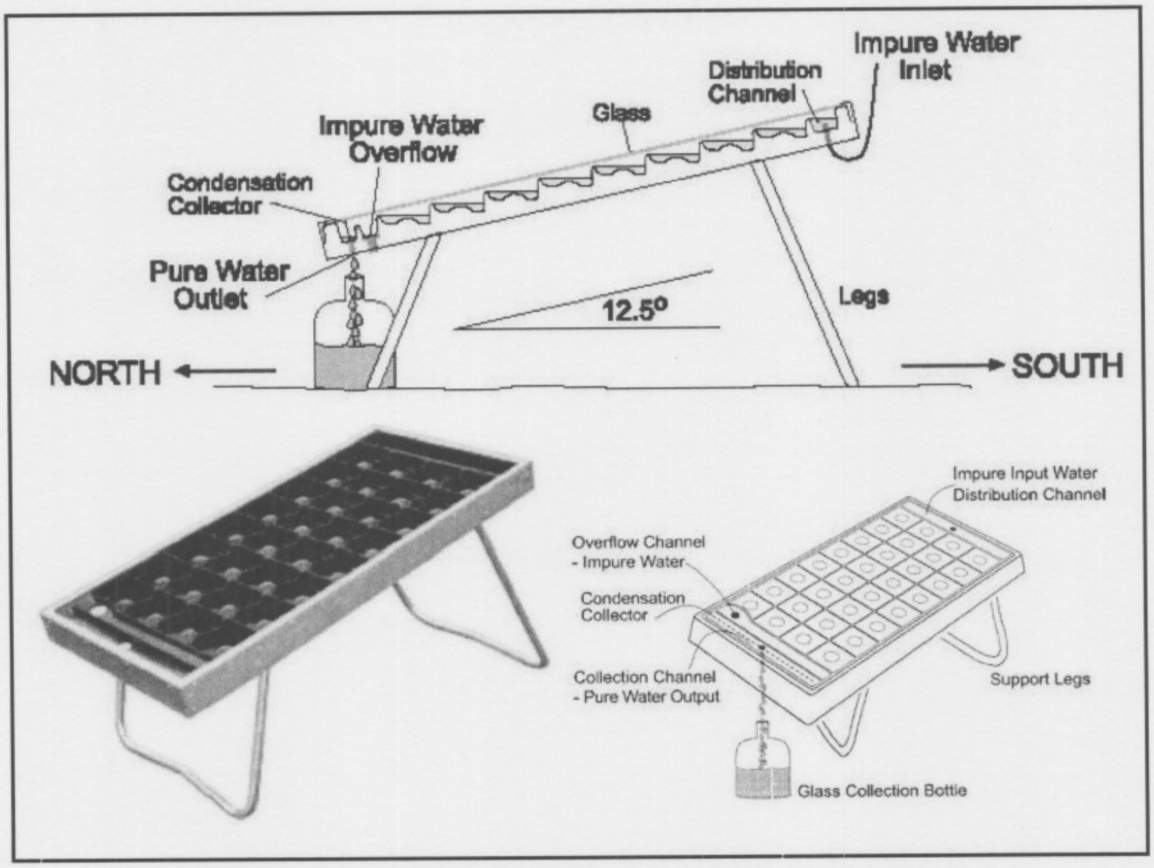


Figure 3-3: Compound picture showing new solar still (Ward)

Care must be taken with solar stills not to allow impure water to contaminate the disinfected water. This can easily happen with both devices described here. The water obtained from solar stills is in effect distilled, and may also require simple procedures for taste enhancement.

Solar pasteurisation

The relatively low water temperatures required for the pasteurisation of water (see paragraph 3.2.2 of this dissertation) can readily be achieved in standard flat plate and ICS solar water heaters (see paragraphs 2.2 and 2.3 of this dissertation). They are, however, not promoted as water pasteurisers, and the solar community tends to favour solar cookers (Metcalf, 2002; Andreatta *et al*, 1994; Saitoh & El-Ghetany,

2002) or special low-volume solar pasteurisers (Kalid-Hameed & Ahmad, 1997) for this purpose.

The biggest obstacle to solar pasteurisation is the measurement of temperature to assure that the water was hot enough for long enough. Metcalf (2002) and Andreatta *et al* (1994) describes a novel device, the so-called Water Pasteurisation Indicator (WAPI), invented in 1988 by Barrett and developed by Andreatta in the early nineties.

The WAPI is a polycarbonate tube, sealed at both ends, partially filled with a soybean fat that melts at 69°C. The WAPI is placed inside a water container with the fat at the top of the tube. A washer will keep the WAPI on the bottom of the container, which heats the slowest solar applications. If heat from the water melts the fat, the fat will move to the bottom of the WAPI, indicating water has been pasteurised. The WAPI is reusable. After the fat cools and becomes solid on the bottom, the fish line string is pulled to the other end and the washer slides to the bottom, which places the fat at the top of the tube. A sketch of the WAPI is shown in Figure 3-4.

Figure 3-4: Pasteurisation indicator (Metcalf)

Metcalf (2002) describes another pasteurisation indicator based on the expansion of a bi-metal disc that is housed in a plastic container. Devices using such ingenious techniques as automotive thermostats[1] are also reported by Rolla (1998). They only allow water out of a solar heating container once it has reached a safe temperature. A disadvantage is however that automotive thermostats usually only open above 80°C, and this may be a high temperature for a solar device to reach.

Solar UV disinfection

The ultra violet radiation coming from the sun has been in the news for several years, but more for the damage it can do to life on earth than for its positive effects.

Whereas germicidal UV radiation generated by mercury discharge lamps have a wavelength in the 'germicidal band' from 200 to 280 nm, the solar UV radiation that reaches the earth has a wavelength generally in a band between 295 and 400 nm (Acra *et al*, 1984; Burch & Thomas, 1998; Luhanga, 1995). This is largely due to absorption by ozone in the upper layers of the atmosphere. It is thus less effective per unit energy than germicidal UV radiation in disabling pathogens (Burch & Thomas, 1998), as can be seen in the graph of Figure 3-5 (Acra *et al*, 1984)

The intensity of the UV radiation from the sun is also relatively low. Luhanga (1995) measured the solar UV radiation at Gaberone, Botswana over a period of a year. He found the UV intensity to be subject to several factors, with cloudy days and the aerial dust load due to late winter winds more than halving the intensity.

His averaged measurements of the solar UV intensity for the best (January) and worst (June) months are shown in Figure 3-6. The peak for January is 160 $kJ/m^2.hr$ (44.5 W/m^2) with more than 100 $kJ.m^2.hr$ (27.8 W/m^2) available from 10:00 to 16:00 daily. For June this reduces to a peak value of 90 $kJ.m^2.hr$ (25 W/m2) with just more than 45 $kJ/m^2.hr$ (12.5 W/m2) between 10:00 and 16:00.

Several studies were done to determine the efficacy of solar UV radiation on small transparent containers filled with water. Acra *et al* (1984) performed a detail study on

[1] Thermostats are used in automotive cooling systems to regulate the flow of cooling water between the car engine and the radiator. They have a special wax pellet that expands and forces a spring loaded valve open once a pre-determined temperature has been reached. It is a very cost effective component because they are mass produced.

water in non-insulated containers in Beirut. They concluded that the rate of micro-organism destruction depends on the following factors:

- the intensity of sunlight at the time of exposure
- the kind of bacteria being exposed,
- the presence of nutritive elements capable of supporting the growth and multiplication of the various micro-organisms;
- the characteristics of the containers in which the contaminated water is kept
- clarity of the water (i.e. degree of turbidity) and its depth

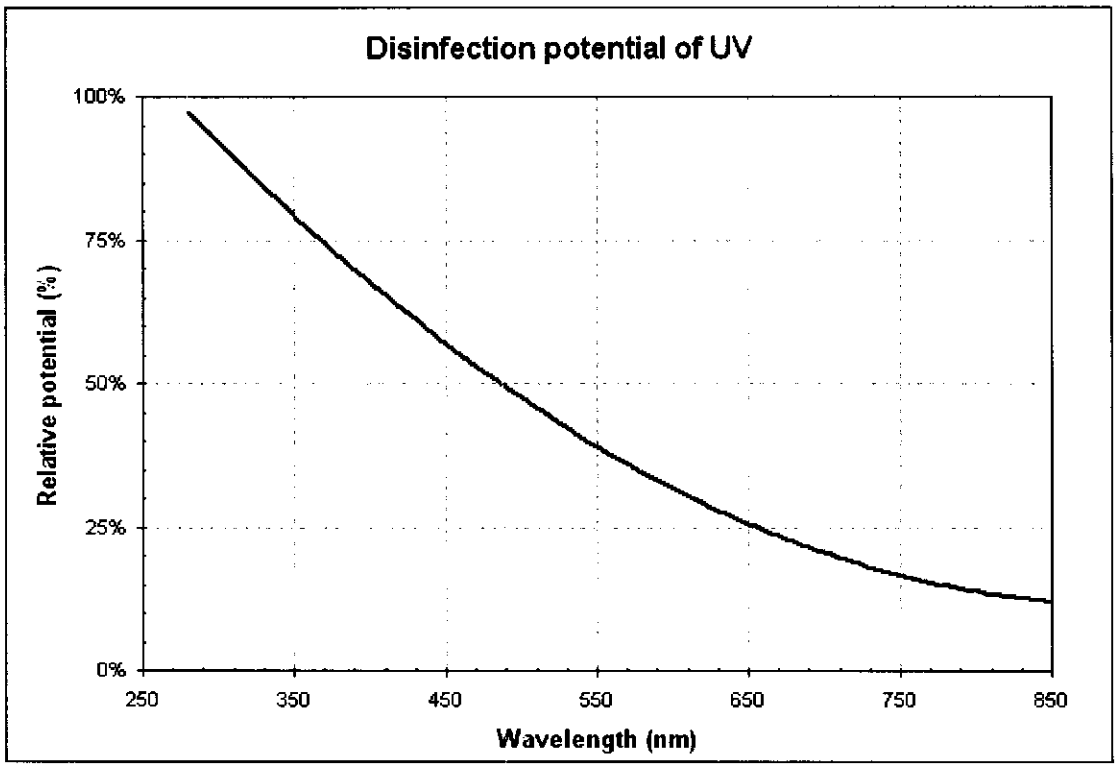


Figure 3-5: Relative disinfection potential of ultraviolet radiation spectrum (adapted from Acra *et al*)

They also noted that on hot days the water reached pasteurisation temperatures of 50 to 60°C, and that it helped in a faster rate of disinfection of the water. On cooler days, but with similar UV intensity, the water heated to approximately 30°C and disinfection times were considerably longer.

They further made an important conclusion in that the kill rate of solar UV radiation on coliform bacteria is much higher than for the complete range of bacteria present in the water. This is shown graphically in Figure 3-7.

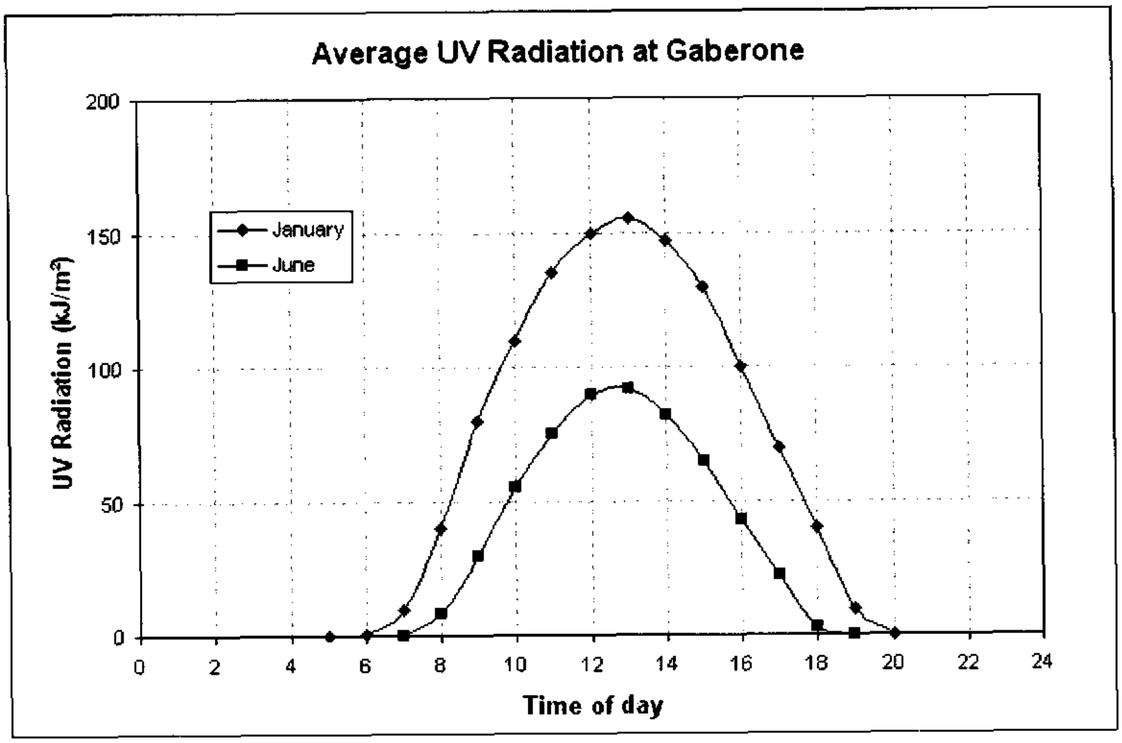


Figure 3-6: Averaged hourly variation of solar UV radiation at Gaberone, Botswana (Luhanga)

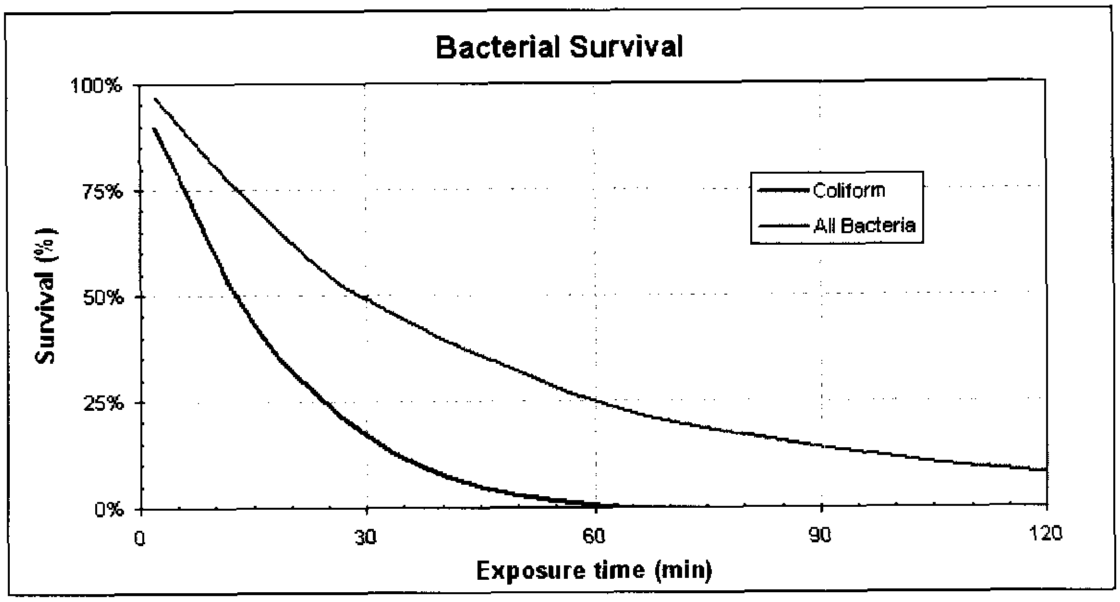


Figure 3-7: The effect of sunlight on bacterial survival (adapted from Acra *et al*)

It can also be shown that this kill rate follow an exponential decay as follows (USPC, 2002):

$$dN/dt = -kN \quad (3.9)$$

$$\Rightarrow \quad N = N_o exp(-kt) \quad (3.10)$$

where

t is the time from the start of disinfection

N is the number of micro-organisms present at any time

N_o is the initial number of bacteria present

k is a kinetic rate constant, and depends on solar UV intensity and temperature

This exponential decay in the kill rate is in fact applicable to all disinfection methods, but the kinetic rate constant differs for each method and the specific conditions during disinfection (USPC, 2002; Acra *et al*; 1984; Powell, 2002).

Rolla (1998), the Safe Water System Handbook (CDC, 2000), Kehoe *et al* (2001) and Saitoh and El-Ghetany (2002) report similar results for solar UV disinfection tests and all noted the higher disinfection rates in the presence of higher temperatures. Kehoe *et al* (2001) make an additional conclusion in that, contrary to previous believe, the agitation of sealed bottles during solar exposure is of no advantage and may actually be detrimental to the solar UV disinfection process due to the release of dissolved oxygen in the water.

The Department of Water and Sanitation in Developing Countries (SANDEC) of the Swiss Federal Institute for Environmental Science and Technology (EAWAG) promotes the solar disinfection of water with their SODIS system, primarily for the disinfection of drinking water at household level. The treatment basically consists of filling transparent PET bottles with black rear surfaces with water, and exposing them to full sunlight for about five hours. This is similar to the methods used by all the previous studies reported on in this paragraph.

Some of the SODIS promotional material (SANDEC, 1998) wrongly claimed that the disinfection is due to the solar UV action only. The figure (reproduced in Figure 3-8) supplied with this material, however, shows clearly that there is a sharp increase in the disinfection rate as the temperature of the water increases to the lower pasteurisation levels.

This claim is, however, extended to acknowledge the effect of temperature in later material published (SANDEC, 1999[a]). A larger scale SODIS installation, shown schematically in Figure 3-9, is also promoted in this publication.

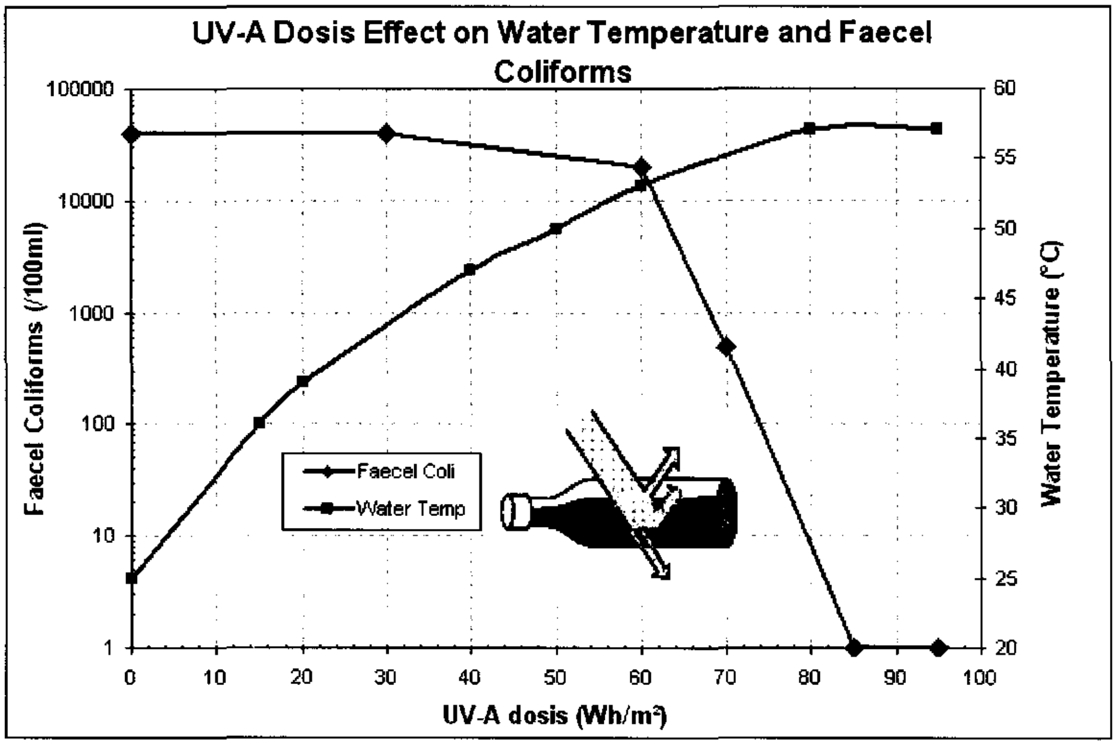


Figure 3-8: Schematic of basic SODIS principle and its claimed effectiveness (SANDEC)

3.2.4 Chemical methods

It is important to acknowledge that there is no perfect chemical water disinfectant that will work optimally under all circumstances. Reiff *et al* (1996) lists the following important characteristics to consider in selecting a chemical disinfectant. It should:

- Be reliable and effective in the inactivation of pathogens under the range of conditions likely to be encountered.
- Provide an adequate residual concentration in the water to prevent recontamination.

- Not introduce substances in concentrations that may be detrimental to health.
- Be reasonably safe for household storage and use.
- Have an adequate shelf life without significant loss of potency.
- Have a cost that is affordable for the household.

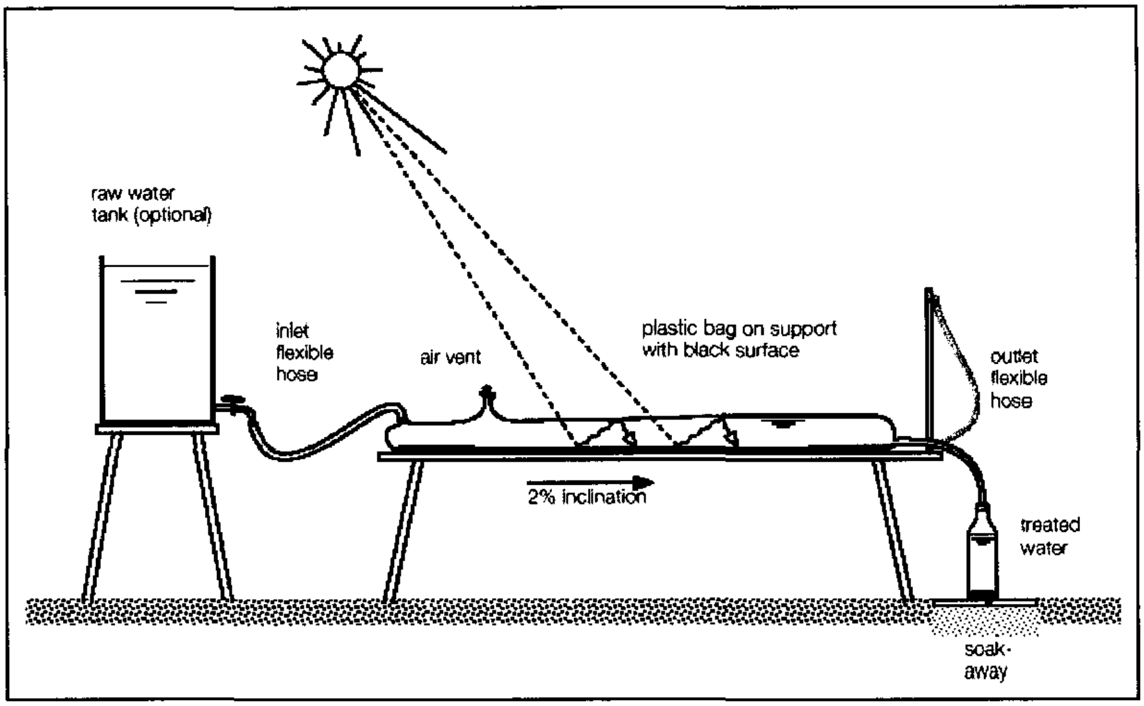


Figure 3-9: Diagram of larger scale SODIS bag installation (SANDEC)

Chlorination

Chlorination is the most widely used method for disinfecting drinking water, both in large-scale urban settings (see paragraph 3.2.4 of this dissertation) and in household scale rural schemes. The source of chlorine can be sodium hypochlorite as found in household bleach, or it can be electrolytically generated from a solution of salt and water. High test hypochlorite, or more correct calcium hypochlorite, as used for domestic swimming pool disinfection (*HTH* is a well known brand name in Southern Africa), and chlorine tablets are also used to some extent.

Disinfection with a 0.5% sodium hypochlorite solution is the basis for the CDC promoted Safe Water System (CDC, 2000), together with narrow mouth water storage containers to prevent re-infection of the water. Where chlorine is not commercially available they also promote the generation of sodium hypochlorite solution on site with solar powered electrolysis of common salt, or NaCl.

This electrolysis process is described as follows by the United States Peace Corpse (USPC, 2002):

- NaCl dissolved in H_2O gives $Na^+ + Cl^- + H_2O$
- Applying 2.3 volts + 1.0 volt over-voltage to the solution causes
  - $2Cl^- - 2e = Cl_2$ at the anode, with water $Cl_2 + H_2O \leftrightarrow HOCl + HCl$
  - $Na^+ + e = Na$ at the cathode, with water $2Na + 2H_2O \leftrightarrow 2NaOH + H_2$

They show that to produce 10 g of chlorine per hour, 7.5 amps at 3.3 volt is needed. This is a 25 W direct current supply, easily delivered by a solar PV panel of medium (0.5 m^2) size.

This 10 g of chlorine is sufficient to make 2 litres of 0.5% concentration sodium hypochlorite solution, which can be used to disinfect up to 1000 litres of water. Higher concentrations of sodium hypochlorite tend to lose their strength too rapidly to provide a useful shelf life. If stored in a closed, non-transparent, polyethylene bottle at below 20°C, a 0.5% concentration of sodium hypochlorite has a useful shelf life of 50 to 60 days (Reiff *et al*, 1996).

Common household bleach is available in Southern Africa under several brand names. Perusal of their labels on a supermarket shelf showed that their concentrations range from 3% to 6% sodium hypochlorite. Recommendations (EPA, 1993) for the dosing are given in Table 3-3, together with the resulting chlorine level in the water assuming 20 drops per millilitre.

It is recommended to double these doses for cloudy (slightly turbid) or coloured water (EPA, 1993). Burch and Thomas (1998) gives the required dose variation as an increase of roughly ten-fold for an increase in turbidity from 1 to 10 NTU, an increase of roughly ten-fold for an increase in pH from 6 to 10, and a decrease of roughly ten-fold for a 20°C increase in water temperature, up to a maximum of 40°C.

Adding and dissolving one heaped teaspoon of granular calcium hypochlorite to 1 litre of water can also make a 0.5% disinfection solution. This is again sufficient to disinfect up to 1000 litres of water. Care must, however, be taken with calcium hypochlorite because it is a powerful oxidising agent and is included in class 5.1 of the International Maritime Dangerous Goods (IMDG) Code (FPA, 1999). The substances of this class yield oxygen when involved in fires and can therefore sustain the combustion process. Experiments has also shown spontaneous combustion of granular calcium hypochlorite in some conditions at temperatures as low as 35°C, substantially lower than the IMDG Code (page 5138 as reported by FPA, 1999) recommended maximum storage temperature of 55°C.

Table 3-3: RECOMMENDED DOSING OF WATER WITH BLEACH (EPA)

Available Chlorine in commercial bleach	Drops per litre of clear water	Resulting Chlorine (mg per litre of water)
1%	10	0.5
5%	2	0.5
10%	1	0.5

Chlorine tablets containing the necessary dosage for drinking water disinfection can be purchased in a commercially prepared form, and is more often used by travellers in need of a convenient means of disinfecting dubious water than by rural inhabitants (EPA, 1993). This is probably due to infrastructure supply problems and the high cost of the tablets available in general commerce.

A well-known brand of chlorine tablets is *Milton* anti-bacterial tablets, which contains 500mg sodium dichloroisocyanurate (NaDCC) per tablet with 32% w/w available chlorine (Milton, 2003). At the WHO recommended level (WHO, 1993[a]) of 5 mg per litre, one tablet is sufficient to disinfect 32 litres of water. Solutions of *Milton* are also generally used in South Africa to disinfect baby bottles.

Iodine

Iodine and iodine compounds can be effective water disinfectants, but the World Health Organization (WHO, 1993[a]; Reiff *et al*, 1996) does not recommend iodine for long-term disinfection of drinking water. Use of iodine or iodine compounds for more than a few weeks at a time may lead to side effects in humans because it can interfere with the working of the human thyroid.

Commercially prepared iodine tablets containing the necessary dosage for drinking water disinfection can be purchased at pharmacies and sporting goods stores. Common household iodine from the medicine chest or first aid kit may be used to disinfect water. The EPA (1993) recommends that five drops of 2 percent tincture of iodine added to a litre of clear water will disinfect it of most bacterial micro-organisms in 30 minutes of exposure. The dose has to be doubled for cloudy water.

Some viruses and most protozoa will, however, survive this treatment, and some sources (WHO, 1993[a]; Reiff *et al*, 1996, Burch & Thomas, 1998) therefore do not recommend the treatment of water obtained from open sources with iodine.

Steripure

Steripure is a new South African product that uses the ability of some metal salts to disinfect water, effluent and sewage without causing harm to the environment. The product is presently in the process of being patented worldwide, and as such very little published data is available.

In an interview with the technical director of the company GES Environmental Services (GES, 2002) some information about the product came to light.

Steripure is a complex acidic solution of metal salts, mainly copper and zinc, in water. It has a faint smell of nitric acid, is translucent green in color, and boil at 100°C. It has an unlimited shelf life, however, decomposition starts at approximately 80 °C. It may lead to slightly irritating gases and vapours being released from the solution. Concentrated solutions should not be heated above this temperature as it loses its disinfectant properties.

The CSIR, the University of Natal, the Umgeni Water Board, the Transvaal Sugar Board and the Mbabane (Swaziland) City Council tested *Steripure* as a disinfectant for drinking water. While independent published data would help to substantiate claims, viewing of some of the test results during the interview showed a full removal of all coliform bacteria, including *Escherichia coli*. No results were available for viruses, and helminths or oocysts of parasites, nor were any claims to this regard made.

Further claims of the product are that it helps to remove turbidity from water by reacting with the materials suspended in the water. This result in a reaction product that rapidly settles out of the water. The sludge is not harmful to the environment, and any unreacted *Steripure* remaining in the water has residual disinfectant qualities.

Steripure will be available in different stable concentrations suitable as a disinfectant from mixing ratios from as low as 1 part per million to 1 part per 10 000. It is classified according to the European directive on the classification of hazardous preparations, 90 / 492/ EEC, and does not need to be labeled as a hazardous substance in any concentration supplied.

Other

Reiff *et al* (1996) describes the use of a mixed oxidant solution instead of hypochlorite in one Bolivian community in which water sources were heavily polluted with organisms difficult to inactivate. The mixed oxidant solution is a disinfectant that is produced by the electrolysis of a salt solution using special catalytic electrodes to yield a number of oxidants including short-lived species of oxygen, ozone, chlorine dioxide, hydrogen peroxide and various chlorine species.

This disinfectant was found to be very efficient in eliminating the pathogens and it was also found to improve taste and odours. Unfortunately it has the disadvantage of a short shelf life, it cost more than hypochlorite, and the generating equipment is difficult to operate and maintain (Reiff *et al*, 1996).

3.2.5 Community involvement

Many lessons have been learned in 'selling' safe water practices to disadvantaged communities through internationally funded assistance programmes.

Through their involvement in developing countries, the US Peace Corps found that simple changes in hygiene and public health reduced morbidity (illness) and mortality (death) more than sophisticated medical treatment, specifically diarrhoea. Safe excreta disposal, improved hygienic behaviour, and use of an adequate quantity of water all typically result in large reductions in diarrhoea (USPC, 2002). Burch and Thomas (1998) confirm this with figures published by Esrey *et al* (1991), included here as Table 3-4.

A pre-requisite for any improvement is the awareness and recognition of a community that contaminated water will lead to poor health. There are several barriers to overcome in this involvement of the community. Burch and Thomas (1998) describes some of these barriers, of which the obvious ones are:

- awareness of disease (the faecal–oral cycle)
- hygiene practices
- sanitation practices
- community structure and culture
- infrastructure issues
- income

Table 3-4: OBSERVED REDUCTIONS IN DIARRHOEAL DISEASE

Improvement	Mean reduction in morbidity (%)
Hygiene	33
Water quantity	27
Sanitation	22
Water quality	17
Water quantity and sanitation	20
Water quality and quantity	16

Proper education in hygiene, and frequent household visits by local health personnel to demonstrate and reinforce correct use, storage, and maintenance of water purification methods are essential (Reiff *et al*, 1996; Rolla, 1998; Riley, 2001). Widespread use of these methods in public settings such as schools, markets and community centres enhance the formation of good hygienic habits. It is usually preferable to have a community-based operation that is supported by national, state, or even municipal agencies and organisations than *vice versa* (Reiff *et al*, 1996).

However, it is feasible for the impoverished people of developing countries to enjoy the benefits of microbiologically safe water through community-based initiatives (CDC, 2000; Reiff *et al*, 1996). It is also essential that the individual households unfailingly carry out the task of water disinfection on a daily basis.

With developed countries controlling the majority of resources for assistance programmes, the input and knowledge of the affected local communities are often ignored.

The Cooperative for Assistance and Relief Everywhere International (CARE), as reported in Riley *et al* (2001), however, promotes a participatory community-based model for the research usually inherent in such programmes. It capitalizes on the strengths and resources inherent in host communities, and each study involves and is influenced by the community partners.

Examples of programmes

In a 2000 CARE initiative in the endemic cholera areas of Madagascar, the Safe Water System were promoted on a commercial scale, as described by Dunston *et al* (2001). The 0.5% sodium hypochlorite solution was marketed in bottles as *Sûr'Eau* (French for 'safe water'), with sales going from 8000 bottles per month in March to 80000 in December 2000, but with peaks during the rainy (cholera) season.

The authors concluded that *Sûr'Eau* was perceived as a cholera prevention product rather than a general water treatment method. This called for a change in consumer perceptions. Another finding was that, even though *Sûr'Eau* was sold at a very low price, many people could still not afford it. Partial subsidies and ongoing donor support would be necessary to continue the project.

Oral rehydration solutions (ORS), has become the cornerstone of modern therapy for cholera and paediatric diarrhoeal disease. In many clinics in the developing world, where access to potable water is limited, ORS is prepared from water that has not been chlorinated or boiled. Even in clinics that use safe water, ORS may also become contaminated when it is stored in open buckets or extracted by patients or staff dipping contaminated cups and hands into large open containers. This leads to re-infection of patients.

Daniels *et al* (1999) conducted trials in a Guinea-Bissau clinic during a cholera epidemic to determine whether disinfecting water with commercial bleach before ORS preparation would improve its microbiologic quality. They also used the Safe Water System of closed, narrow-mouth vessels for ORS preparation and storage. In some cases this led to a five-log (100000 times) reduction in mean coliform bacteria counts and total elimination of *E. coli* from ORS solutions.

Reiff *et al* (1996) describes Safe Water System projects by the Pan American Health Organisation (PAHO) carried out in Bolivia, Columbia, Cuba, The Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Nicaragua, Panama, and Peru. Results showing up to 50% reduction in diarrhoea and cholera are reported.

The University of Texas, in a Safe Water System study on the United States / Mexico border, reports a reduction in the prevalence of household cases of diarrhoea, from around 25% to 7% (Reiff *et al*, 1996).

SANDEC, a department of EAWAG, promotes the SODIS system of water disinfection in projects in Indonesia, Togo, Bolivia, Sri Lanka, Ethiopia, Somalia, Cameroon, Ecuador, South Africa (through the Mvula Trust), Bangladesh, China, Thailand, Burkina Faso, and Colombia (SANDEC, 1999[b]). They report similar results than the previously described studies and projects.

3.2.6 Conclusion

These studies and results achieved in field projects around the world, led to the conclusion that it is not the specific method of water purification that is important, but the fact that a working system is present and available to a community. Any improvement in the water quality has a positive health outcome on disadvantaged communities.

Community 'buy-in' into such a system is of the utmost importance, and this can be best achieved by education and participation in the system by the community itself. However, sustainability of this water purification system is often dependant on continued financial and technical assistance of external organisations.

3.3 *SHB* water disinfection

Where a community has access to pure disinfected water with residual disinfectant from a system of community taps, the users of the *Solar Heat Barrow* have to take no additional measures other than to prevent the re-infection of the stored water. This is already the case in many South African rural communities.

In all other cases, the selected water purification method for implementation with the *SHB* must be robust. It must follow the 'defence in depth' principle, in that complimentary methods should be selected to achieve the highest possibility of delivering disinfected water meeting at least the minimum recommended sanitary requirements. At the same time, the basic function of the *SHB*, i.e. to heat water for domestic use, must not be impeded.

The only prerequisite to these aspirations is that the community should be responsible for the basic protection of their water supply, and that the rudimentary pre-treatment principles of sedimentation and filtration, if required and as explained in paragraph 3.2.1 of this dissertation, is implemented simultaneously.

3.3.1 Solar disinfection for this application

The proposed configuration of the *SHB* does not make the use of solar UV assisted disinfection in the device possible. The black surface of the solar collector will not allow any UV to reach the water. This method could, however, be of some assistance if small settlement ponds are used with the pre-treatment of the water.

An obvious method of water disinfection that can be utilised with the *SHB* is pasteurisation. Measurements on similar ICS solar water heaters have shown that the required temperature for pasteurisation is within the capability of the proposed *SHB*.

This method would be ideal to apply to the *SHB*, as no additional infrastructure requirements are necessary. If *Vibrio cholerae* is the only pathogen of concern, pasteurisation of the water alone could have a significant effect on the users health outcome.

It would, however, be too high a risk to depend on pasteurisation as the only method of water disinfection. Too many common pathogens require higher pasteurisation temperatures (see Figure 3-2) for destruction. On days with reduced sunshine the water temperature would not necessarily reach this temperature, but it could still reach an acceptable temperature for domestic hot water use.

Just ensuring that the water has in fact reached the pasteurisation temperature would require a temperature measurement device similar to the WAPI. The water would then still have to be kept at temperature for a minimum required period before it could be deemed safe for use.

3.3.2 Chemical disinfection for this application

The best method of water disinfection to use with the elevated water temperature of the *SHB* would be a chemical method. Iodine and iodine compounds are disqualified because of the possible long term health effect, while special short lived high potency disinfectants place a high premium on the distribution infrastructure.

The chemical disinfection method of choice would have to be chlorination. Its wide use, proven capability of disinfection, and low cost is attractive. Preference would have to be given to sodium hypochlorite because of its general availability as a household bleach. Chlorine in both granular or tablet form are susceptible to moisture damage if not properly stored, with granular calcium hypochlorite also posing a danger due to its temperature sensitivity.

The drawback of commercially available sodium hypochlorite solutions (3% to 6% concentration) is its tendency to decompose at temperatures from as low as 25°C. Its shelf life is limited to less than a month unless the concentration is reduced to 0.5%, and the solution is stored at temperatures preferably below 20°C (Reiff *et al*, 1996). The bleach may also already be of dubious concentration when bought at the ever present 'spaza' shops of rural Southern Africa. This is due to a low turnaround and the absence of storage temperature control.

If a 5% sodium hypochlorite solution reaches a temperature of 40°C it starts to 'boil' (Mallinckrodt Baker, 2002). This is not boiling in the true sense of the word, but a rapid decomposition of sodium hypochlorite into common salt and oxygen to the minor decomposition path as shown in Equation 3.6. Depending on conditions and the users' storage diligence, they may in the worst case thus end up with a mild salty solution of water that will be of little use in the disinfection of water.

The remaining chemical disinfectant for implementation with the *SHB* is the patent *Steripure* product as presented in paragraph 3.2.4 of this dissertation. Subject to its formal approval as a product for use in potable water disinfection, it meets most of the requirements for a suitable disinfectant for distribution in Southern Africa.

The high concentration that is feasible reduces the volumes of *Steripure* that have to be distributed and stored. The stability of *Steripure* concentrations at temperature makes it suitable for nearly all storage conditions that could be expected. It even makes it possible to integrate within the *SHB* a storage container with sufficient disinfectant for a reasonable period's usage. This route will thus further be followed for implementation with the *SHB*.

3.3.3 Dispenser concept

Not all users of the *SHB* will require a disinfection device. Some may have access to already purified water, in which case additional disinfection is not required. Others may select to use a different disinfection method such as manual dosing with sodium hypochlorite solutions.

A concept for a disinfectant dispenser to be used with the *SHB* was thus developed on the basis of an add-on device that will dispense an adequate volume of *Steripure* into the water container every time it is filled. In concept this can be done with a disinfectant dispenser that takes the place of the standard spout screw lid on the *SHB* water container. The *SHB* is envisaged to only have one 50 mm spout for both filling and pouring. This would mean that the dispenser must dose the water in the *SHB* on filling, but not every time that water is poured from it.

Filling of the *SHB* will require the spout to be fully opened for insertion of a hosepipe, funnel, or whatever means will be used for filling. The dispenser was thus further conceptualised to be removed from the spout during filling, and to dispense an adequate volume of *Steripure* on replacement.

The dispenser must, however, be prevented from dispensing *Steripure* every time that water is poured from the *SHB*. While this would not have detrimental health effects, it would prematurely deplete the stored volume of disinfectant in the dispenser. A second pouring lid or valve must thus be provided on the dispenser. It should be easy to operate to promote its use in preference of removal of the whole dispenser for the pouring of water. It should, however, not be possible to fill the *SHB* water container through this route.

The container for the storage of *Steripure* will be integrated with the dispenser unit. It should store sufficient disinfectant to ensure a reasonable period of operating without replenishment. Temperatures exceeding 80°C is not expected in the *SHB* except during ICS stagnation on the collector surface during ideal conditions. It should thus be possible to store sufficient *Steripure* for up to a month's supply in the dispenser without the product decomposing prematurely.

This concept of the dispenser also allows for it to be used with water containers other than that of the *SHB*. This should be a feasible goal if a standardised thread system is used for the dispenser / container interface.

3.3.4 Dispenser parameters

Steripure concentration

Steripure will be available in different stable concentrations suitable as a disinfectant for mixing ratios from as low as 1 part per million to 1 part per 10 000. If we count in drops, and assume 20 drops per cm^3, 1 drop of the strongest solution will disinfect up to 50 litres of water. Dispensing 1 drop at a time is, however, relatively difficult, and the storage volume in the dispenser would be so small that the smallest leak or evaporation of *Steripure* would go unnoticed.

If the dilution strength were 1 part per 100 000, 5 drops, or 0.25 cm^3, would be required to disinfect a *SHB* container with 25 litres of water. This is then the selected concentration of *Steripure* for this application.

Dispensing volume

If allowance were made for inaccuracies of manufacture, and other uncertainties, it would be prudent to design the dispenser part of the unit for reliably dispensing between 6 and 7 drops (0.3 and 0.35 cm^3) per cycle. The extra *Steripure* dispensed into the water will not harm people, but will ensure that at least the minimum dosing requirement was satisfied. The unit were thus specified to dispense between 0.3 and 0.35 cm^3 per dispensing cycle.

Dispenser storage volume

The *SHB*, with a storage volume of 25 litres of water, could be used to heat two, and on a good day up to three, loads of water. This could result in the unit being used for approximately 60 loads of water per month. If the dispenser can store sufficient disinfectant for these loads of water, the user only has to replenish the unit once a month.

Sixty *SHB* loads of water would require a volume of at least 15 cm^3 of *Steripure* to be stored in the dispenser. This is indeed a small volume of fluid, and the requirement for the dispenser disinfectant storage was set at double this volume, or 30 cm^3, to allow for spillage and evaporation losses, and variations in dispensing doses. The storage volume must also be transparent, or at least translucent, for the user to easily evaluate the level of the aquamarine coloured *Steripure*.

Materials

Steripure is not as sensitive for the materials of construction as chlorine disinfectant compounds. It is, however, an acidic water based solution, and it would thus be prudent to design the dispenser to be manufactured in polymer materials. This would also have the advantage that injection moulding could be used as manufacturing process for the relatively small components envisaged for the dispenser. The use of metals will be limited to the minimum. Where required, only austenitic stainless steel will be used.

Cost target

The cost target for the *Steripure* dispenser should be set independently of that of the *Solar Heat Barrow*. It could be sold as a separate unit, and the actual numbers will heavily influence manufacturing volumes and costs.

For the purpose of this study, however, it is assumed that dispensers will be sold with every *SHB*. A relative value of $^1/_6$ of the *SHB* was decided upon, which leads to a cost target of not more than R 50 per unit.

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CHAPTER 4: PROTOTYPE DEVELOPMENT

4.1 Design and manufacturing of prototype *SHB*

4.1.1 Design

History

The idea that would become the *Solar Heat Barrow* originated from an old 2-litre *Coca Cola*™ bottle in 1994. One such clear transparent bottle with its black base 'accidentally' heated water when left outside, and stimulated the concept of a simple solar water heater.

It was thought that such a *Coke*™ bottle could not cost more than 10c to manufacture (Taylor, 2001). To produce a solar water heater based on a bottle could thus be very inexpensive if the same manufacturing process were used. Preliminary temperature measurements also showed that the concept would work well to heat water.

This concept was surprisingly close to that of the basic SODIS system as discussed in paragraph 3.2.3 of this dissertation, although the emphasis of the two concepts were different. The SODIS system had water disinfection with solar ultraviolet radiation as a goal, and the heat was seen as a secondary effect. The *Coke*™ bottle concept had the heating of water as a goal, with water disinfection not playing a role at the time.

Growth of the idea led to a plastic bowl solar water heater concept (Mathews & Rossouw, 1997). A small plastic bowl was inserted into a bigger bowl, with a layer of crumpled newspaper as insulation between them. A black plastic sheet placed on the bottom part of the inner bowl increased the absorption of solar radiation. A transparent plastic sheet was used as a top cover.

It was found that water placed inside the smaller bowl had its temperature raised by 18°C from the ambient temperature within four hours when the average radiation was about 600 W/m^2 (Mathews & Rossouw, 1997).

In South Africa, the fraction of solar radiation received by a collector is increased if it is inclined and facing north. The idea therefore came about to incline the solar water heater to take advantage of this, and to use a set of wheels to do so (Taylor, 2001). This was thought to solve a further problem of rural communities, namely the transport of water. The first 'heat barrow' was therefore born, and was conceptualised as a flat rectangular unit with two small wheels.

An initial design was done for the manufacturing of a single exploratory demonstration unit. The first improvement made was a change to one large wheel with a spherical shape instead of the two small wheels. This would increase both the manoeuvrability and stability of the device during cartage. It would also reduce the ground pressure, making it easier to push on soft surfaces, and help to prevent soil compaction.

A slightly bow-shaped body and tank unit was introduced for three reasons. The first was to provide limited form-stiffness to the relatively thin window, and the second to lower the center of gravity of the water filled unit for easier handling. The third reason was to help prevent the integral handles from digging into the ground when stationary, but to still present them in a comfortable attitude to a person pushing the device.

The body and tank of this unit was designed as a unitary construction, and manufactured in welded black high-density polyethylene sheet. It had no insulation other than an air gap between the inner storage-collector and the outer housing. The glazing was 1 mm thick transparent polycarbonate sheet.

The initial goal of the project was to supply water at 30°C above tap water temperature at 20h00, regardless of the season. This unit, with a volume of 25 liters, managed to achieve this goal on wind still days.

Prototype concepts

After the construction and testing of the initial exploratory version of the *Solar Heat Barrow*, the design of the prototype units began.

The specification of the *SHB*, as presented in paragraph 2.4 of this dissertation, was formatted in draft form. The first concept considered was a moulded unitary-body unit in rotationally moulded ('roto-moulded' in general terms) polyethylene. It would combine the lower half of the water storage container with the outer housing, as one hollow component. The cavity in this body could then be filled with self-expanding foam for better insulation than just the air gap.

A double curvature formed black polyethylene sheet would be welded in position as the collector surface, closing off the water storage cavity in an integrated storage-collector tank. The glazing would also be formed with a double curvature to give the maximum form stiffness to the fairly expensive, and therefore thin, polycarbonate sheet.

The handles for the unit was conceptualised to be integral with the body moulding. At the time it was also thought to add pouring supports to the front of the body. They would also double as storage supports for the vertical storage of the unit, for example against a wall. The wheel mounts were also envisaged to be integral with the body moulding. This concept is shown in different attitudes in Figure 4-1.

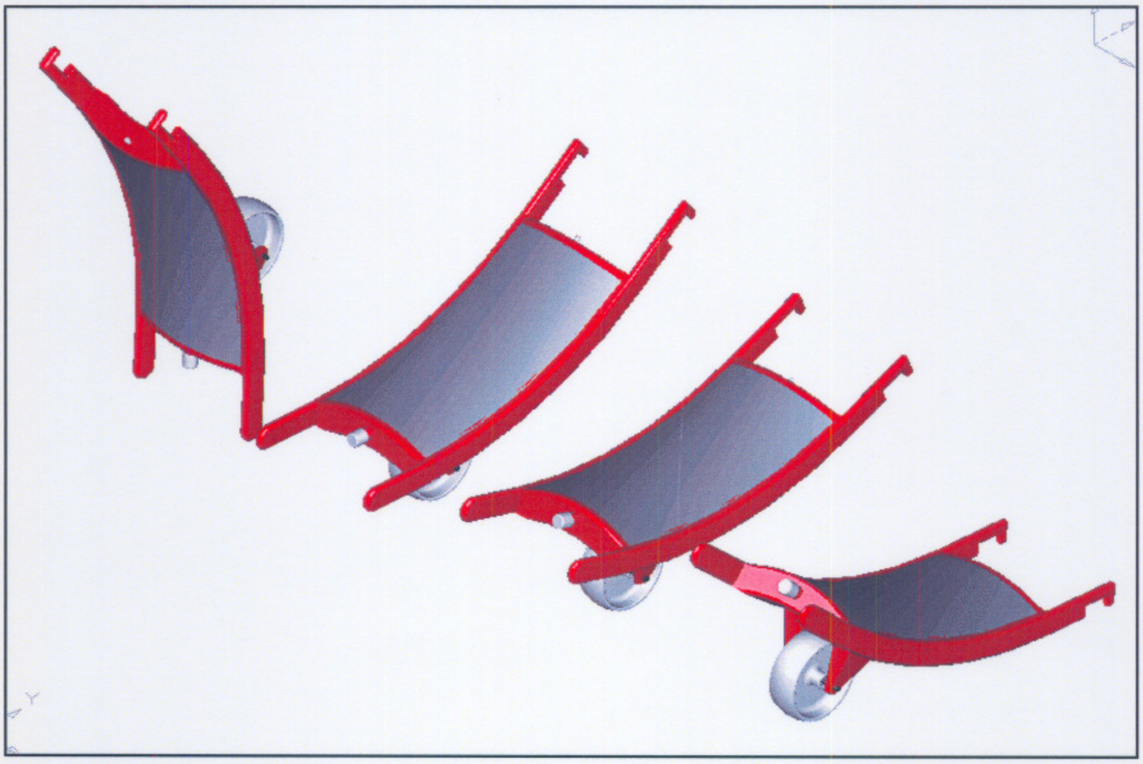

Figure 4-1: Fully moulded frame/tank concept evaluated for SWH device

Discussions with manufacturers brought two serious problems to light. The first problem was the complexity of the mould required for the manufacturing of the body.

The combination of the tank with the handles, and pouring and wheel supports, would require an expensive multipart mould. It would also be difficult to ensure a high quality component with a reasonable constant wall thickness, and a high moulding scrap rate was foreseen.

The second problem foreseen was with the plastic welding of the collector plate. Polyethylene welding is regularly used for the repair of roto-moulded components, and for the manufacturer of many components made from sheets and pipes in specially the chemical industry. In this application the manufacturer was, however, adamant that welding of the two components would again be a high-risk process, and would probably delaminate during long term use at the temperatures that could be reached by dry stagnation of the unit.

This concept was thus discontinued for reasons of cost and risk of manufacture.

The second concept considered was a separate integral collector storage (ICS) solar water heater unit, mounted on a wheeled pipe frame that performed the same functions as the integral moulded components of the preceding concept. This idea could also allow a person to leave the filled tank in the sun during the day, while using the frame, with or without other attachments, for basic cartage purposes.

The frame consists of two longitudinal pipes, of a diameter similar to a wheelbarrow's frame, and bent to follow the contour of the water tank. Suitable bending of these pipes, and a few braces and wheel supports welded in position, would provide a frame that fulfil the set requirements. This frame concept is clearly visible in Figure 4-2.

The solar heater body and storage-collector were also separated for the mentioned manufacturing reasons. The storage-collector tank could now be moulded as a single curvature unit in black roto-moulded polyethylene, while the outer housing could be moulded as a single skinned component in any suitable colour, also in roto-moulded polyethylene.

The inner unit could then be snapped in position into the outer housing, making use of the material and component inherent flexibility. Self-expanding foam could be poured in the cavity between the two components to fulfil two functions. The first would be insulation of the inner tank back and sides against heat loss. The second function was to 'glue' the two components together to increase the stiffness of the unit to an acceptable level without having to resort to unnecessary high wall thicknesses.

Figure 4-2: Original pipe frame concept for SWH device

This concept was entirely workable, except that the welded pipe frame design would be more expensive to manufacture than necessary.

Prototype design

The specification for the *Solar Heat Barrow* was finalised at this stage, and is discussed in paragraph 2.4 of this dissertation. In short, it came down to the following main parameters:

- ICS type solar water heater with a separate pipe frame
- Mobility similar to a wheelbarrow with a single wheel
- Empty unit mass not exceeding 15 kg
- Water storage volume of 25 liters
- Collector surface of about 0.5 m^2
- Width not exceeding 600 mm, preferably 550 mm
- Prototype body and storage-collector tank manufactured in roto-moulded PE.
- Glazing in clear polycarbonate sheet
- Standard wheelbarrow wheel for prototype units
- Insulation in the form of 20 – 25 mm thick expanded poly-isocyanurate foam
- Water that was heated to be stored so that 40°C water is available at 20:00.
- Cost target of about R 200 or less, for a target selling price of around R 300.

A critical evaluation of the last concept for the *SHB* unit, together with the experience gained with the exploratory demonstration model, led to the final prototype design to be manufactured for evaluation purposes.

The first optimisation was to solve the problem of a bulging collector surface when the unit was hot. This was caused by the extreme flexibility of the polyethylene at temperature, and was solved by designing 'tie-tubes' between the front and rear surfaces of the storage-collector unit. It created a multitude of smaller surface cells on the collector, and would limit the bulging of each cell to an acceptable limit.

The second problem to be solved was the difficulty in maintaining an air space of relatively constant thickness between the collector and the glazing. In certain situations the two bodies could be in contact with each other, which would lead to unacceptable convection heat losses. Designing small pointed integral stand-offs on the collector surface solved this problem. The small contact areas between the collector stand-offs and glazing would not lead to an appreciable heat loss.

The design of the storage-collector is shown as a body, semi-transparent from the CAD model, in Figure 4-3. Both the 'tie-tubes' and the stand-offs are visible. The slightly tapered shape of the unit towards the spout is also visible. This is to allow the unit to be fully emptied, without small hidden pockets of water that could remain had the tapered shape not been introduced.

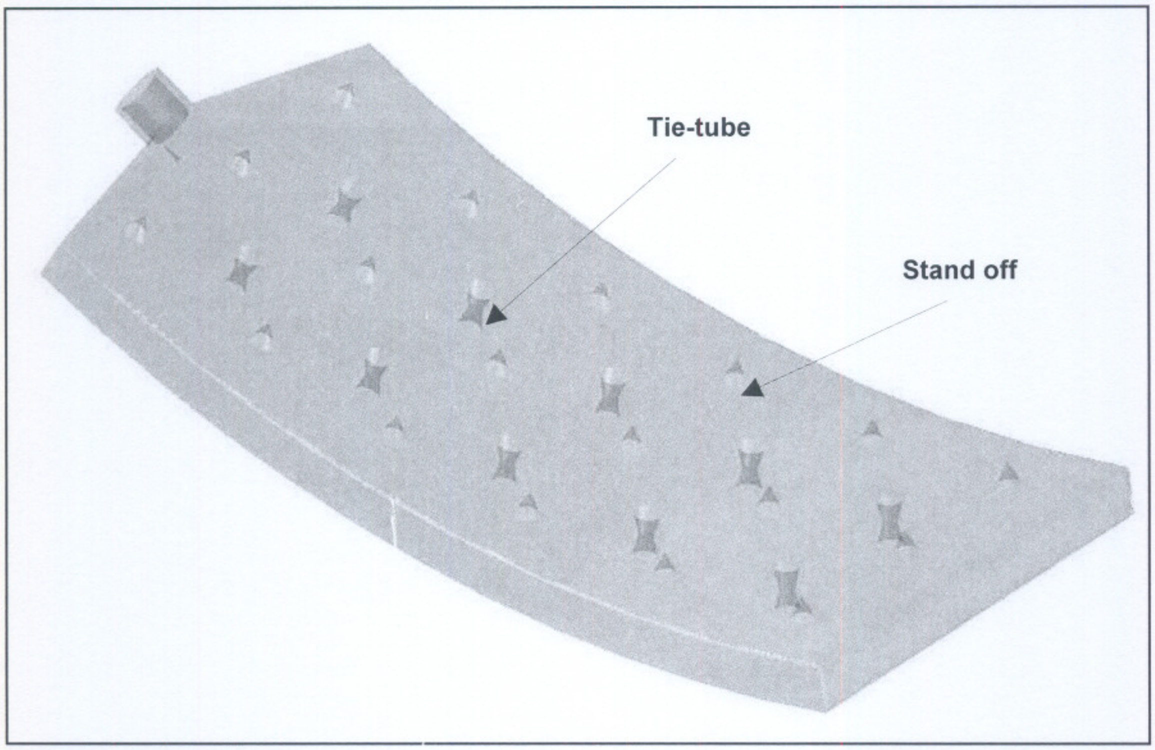

Figure 4-3: Storage-collector tank showing glazing stand-offs and front-back surface tie-tubes

The cost of the welded pipe frame was also excessive. Experience with the exploratory unit showed that the protrusions for support during pouring were not really necessary. By investigating the manufacturing of wheelbarrow frames, and discussions with pipe bending manufacturers, the design of the frame was changed. A one-piece pipe, with an outside diameter of 32 mm and a 1.6 mm wall thickness, bent on a numerically controlled pipe bender could be manufactured cheaper than the original layout, especially in quantity. One flat bar brace, probably unnecessary, was included across the frame for an added perception of stiffness.

Some co-workers involved with the exploratory model were not satisfied with the housing of the unit standing on the ground when stationary for heating water. The pipe frame of the prototype units was thus designed to include two stands, similar to a wheelbarrow but no as high. These two factors led to the configuration of the frame for the prototype units as shown, with the wheel assembled, in Figure 4-4.

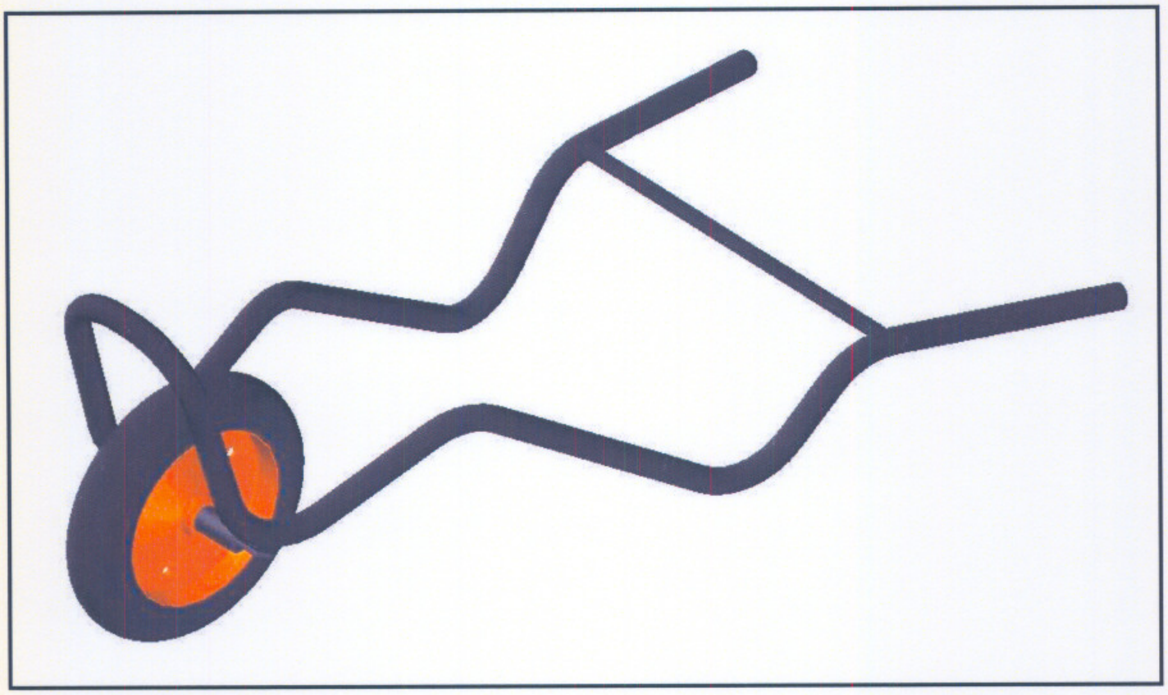

Figure 4-4: Layout of NC bent pipe frame with wheel and brace

The storage-collector tank was again designed as a snap-in-position insert into the body housing, after which it was fixed in position by self-expanding two-component poly-isocyanurate foam. In the case of the prototype units the outer housing was intended to first be riveted to the frame before this action. The heating unit for the prototypes was thus not removable from the frame.

The glazing was designed to be a simple flat sheet of polycarbonate, 1 mm thick. It was cut to suit a moulded relief in the top of the housing, and held down with self-tapering screws. The *Dispenser* did not exist for the original design of the prototype units, and commercial off the shelf (COTS) caps were specified for the spout as showed in Figure 4-5.

The final design of the *Solar Heat Barrow* prototype is shown in Figure 4-6. The body housing unit could be moulded in any one of a variety of base-material colours. Figure 4-7 shows the *SHB* with the heating body sectioned. The expanded foam between the two moulded components is visible, as is the glazing and the glazing stand-offs on the collector.

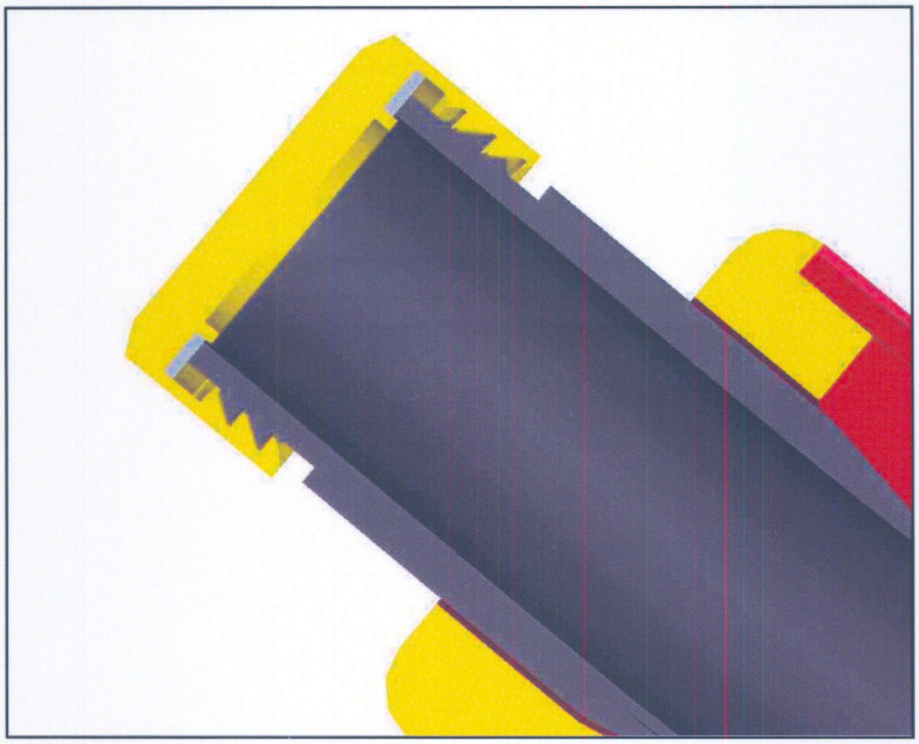

Figure 4-5: Section view showing standard spout screw lid

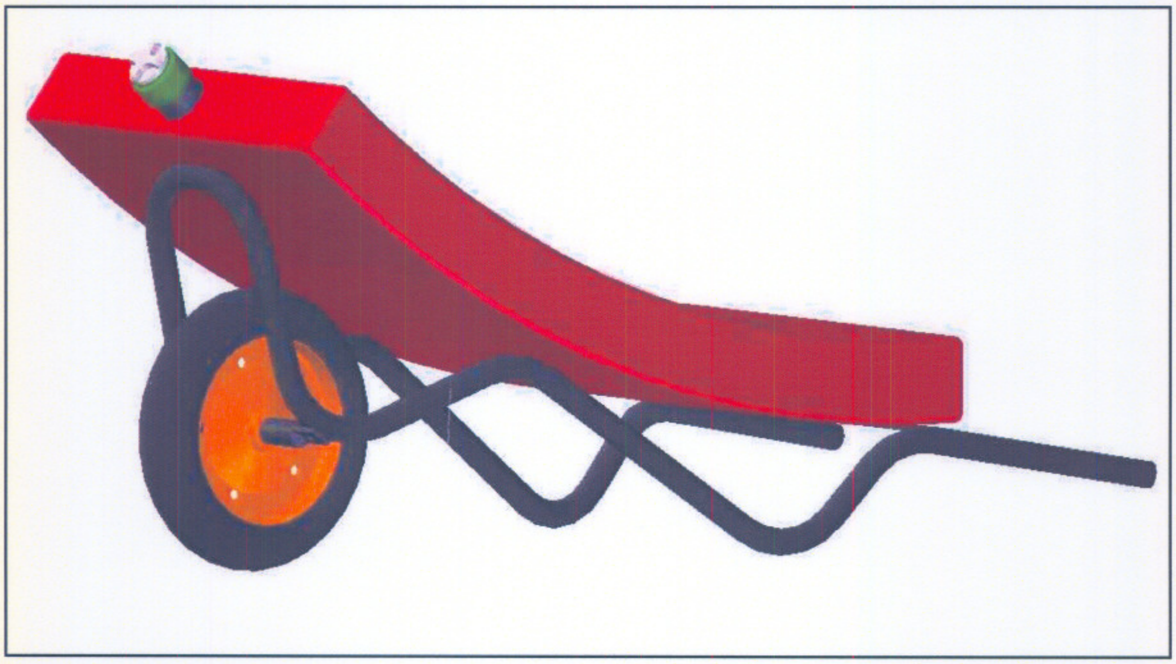

Figure 4-6: Final design layout of *SHB* prototype

The final designed parameters of the *Solar Heat Barrow* was as follows:

- Pipe frame handle maximum width 600 mm.

- Body housing width 550 mm.
- Body housing arc length 1050 mm.
- Body housing depth 110 mm.
- Storage-collector tank width 500 mm.
- Storage-collector tank arc length 1000 mm.
- Storage-collector tank depth 60 mm.
- Material thickness for both body housing and storage-collector tank specified as nominally 3 mm thick.
- Nominal water storage volume 25 liters.
- Empty unit mass 14 kg.
- Collector surface 0.46 m^2.
- Nominal air gap between glazing and collector 25 mm.
- Insulation 25 mm thick expanded foam.
- Collector inclination ranging from 30° (top) to 5° (bottom)

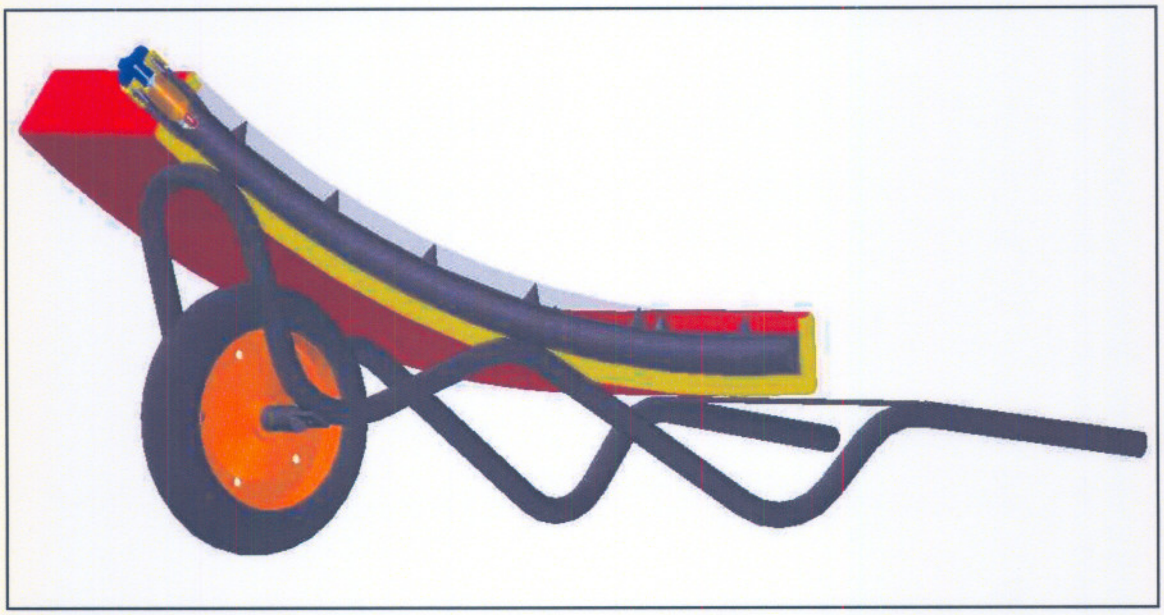

Figure 4-7: Section through *SHB* body showing insulation between outer body and water container, glazing and stand-offs

The variation in inclination was a necessary deviation from the ideal 35° for South Africa. At the time, the distinctive shape of the *SHB* was judged to add to its visual appeal. Its mobility also meant the unit could easily be placed on a small incline, or could even be elevated with any handy support, to increase the inclination to a near ideal value.

To complete the design, a set of manufacturing drawings were drawn up for the manufacturing of components.

4.1.2 <u>Manufacture</u>

Two batches of *Solar Heat Barrows* were manufactured. The first batch of 10 was completed in 2000 as demonstration and test units, amongst others by Taylor (2001). The second batch of 15 units was manufactured in 2002 for the Eskom sponsored field evaluation at the community of Mabedlane in KwaZulu Natal. This evaluation is described in paragraph 5.2 of this dissertation.

The manufacturing of the two batches followed the same procedure, using the same manufacturers. All development was done during the manufacturing of the first batch, and only this process is described further.

Components

Manufacturing of components started with the housing and storage-collector tank moulds. A local firm specialising in roto-moulding, and with an in-house mould manufacturing facility, was contracted to supply the low-cost sheet metal moulds and moulded components. The design change to a single curvature design of the housing and tank made these low-cost moulds possible.

Initial test components in UV stabilised linear low density polyethylene were moulded once these were completed. Assembly and foam insertion tests with these components showed that the two components fitted well into each other, but that the spacing between the two bodies were difficult to maintain during the foaming of the insulation.

It also showed that the outer housing needed to be supported to prevent it from bulging outward by the pressure of the foam during the foaming cycle. The tank should also be slightly pressurised with air to prevent it from being 'squashed' by the same action. Screwing a cap on the tank, and leaving it in the sun for an hour easily solved this. The temperature rise caused a sufficient increase in air pressure.

The mould of the housing was modified to add integrally moulded storage-collector supports to the outer housing. These stand-offs are shown in Figure 4-8. A frame was also manufactured to support the outer housing during the foaming process. More test components showed that these modifications worked well.

The first batch of mouldings for both the black storage-collector tank and the coloured outer housing were then manufactured.

The bent pipe frame was contracted to a firm with numerically controlled pipe bending facilities. The expensive part, approximately 75% of the cost, of the manufacturing of these components were in the time required for setting up to bend only a few frames. The manufacturing of large batches of frames would thus be considerably cheaper.

The glazing was bought as a 1 mm thick clear polycarbonate sheet. These sheets are delivered with white protective plastic film on both sides to protect the polycarbonate from scratches during handling. The individual glazing for the units were cut from this large sheet using standard household scissors, with the protective film still in place.

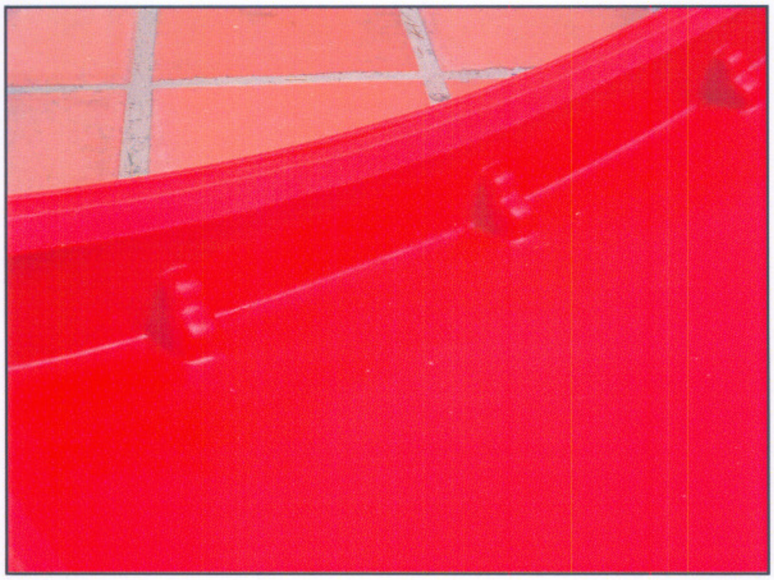

Figure 4-8: Storage-collector support stand-offs in outer housing moulding

The wheelbarrow wheel assemblies, complete with axles and bushings, were bought as COTS bolt-on items from a manufacturer that uses recycled rubber for the tyre part of the wheel. The poly-isocyanurate foam for insulation was bought as two separate fluids. Bolts, nuts, screws, washers and rivets were also bought for the assembling of the units.

Assembly

Assembly of the *Solar Heat Barrows* started with the frame. Suitable holes were drilled and the wheel assemblies were bolted to the frames. The next step was to rivet the outer housings to the frame. All units of a batch were completed to this stage to allow for a single foaming exercise.

The mixing, pouring and cleaning of the poly-isocyanurate foam was the most difficult, and by far the messiest, part of the assembly process. Because this process was not done in a temperature-controlled environment, it had to be done on a day when the temperature was above 25°C to obtain the best results, as recommended by the supplier.

Two litre soft drink bottles, with the top part removed, were used to mix the 1.6 kg total of the two equal fluid parts of the foam for a single *SHB*. This should provide a foam density of 80 kg/m^3 for the *SHB*. At the right moment, it was poured into the outer housing, which was supported level. The storage-collector tank was then snapped into place and the unit was manually gyrated to ensure an even distribution of the foam.

After a few minutes the foaming process was complete and the unit could be left to dry. The process was then repeated for the next unit. Silicon spray was used as a release agent only on the collector surface of the tank to ensure that foam overflow could easily be removed. The need for this is clear in Figure 4-9. The units were left for a day to allow the foam to fully cure. The overflow was then removed by breaking it away and smoothing the exposed edges with a scraper.

The final step in the assembly was to cut the individual glazing parts for the *SHB*'s. This was necessary because of the relatively crude moulding tooling, and the small variations caused by different behaviour of the housings during foaming. After cutting to suit, the inner protective sheet was removed from the glazing, and it was drilled and screwed to the housing using self-tapering screws.

Figure 4-9: Prototype *SHB's* showing foam overflow during assembly

Figure 4-10: Completed prototypes with unassembled components in foreground

Completed *Solar Heat Barrow* units are shown in Figure 4-10. The protective films were removed from the outer face of the glazing specifically for the photo session. These films should, however, be left in place on later units to protect the glazing from scratching and rubbing damage during transport. A set of unassembled components is also shown in the foreground, and it demonstrates the insertion of the tank into the housing unit.

Figure 4-11: Completed prototype *Solar Heat Barrow*

A complete *SHB*, standing in the position at which the sun will heat the water, is shown in Figure 4-11. The indentations in the lower part of the outer housing are the mould-side cavities for the storage-collector tank stand-off supports.

Costs

The approximate cost per unit came to R 2 135 for each of the 25 *Solar Heat Barrow* prototypes. The cost of tooling was amortised evenly over the units, and no time value of money (interest) was included in the costing. The cost breakdown for the *SHB* prototypes is shown in Table 4-1.

Table 4-1: MANUFACTURING COST OF 25 *SOLAR HEAT BARROW* PROTOTYPES

No	Component / Activity	Material	Process	Tooling Cost		Component Cost	
1	Outer Housing	LDPE UV Stabilised	Rotomould	R	6 000.00	R	250.00
2	Absorber Tank	LDPE UV Stabilised	Rotomould	R	9 000.00	R	300.00
3	Standard Cap		Buy-in Component			R	5.00
4	Glazing	PC Clear 1mm	Cut			R	100.00
5	Frame	Tubing Steel 32mm	NC Bend / Weld			R	250.00
6	Wheel Assy		Buy-in Component			R	60.00
7	Isolation Materials	PU Foam	Mix / Pour	R	1 000.00	R	100.00
8	Fasteners	Bolts & Screws				R	20.00
9	Consumables Assy	Si Spray, Rags, Rivets				R	10.00
10	Labour Buying					R	100.00
11	Labour Assy Mechanical					R	200.00
12	Labour Assy Isolation					R	100.00
			Tooling total	R	16 000.00		
			Cost/unit			R	1 495.00
			Tooling/unit			R	640.00
			Total cost/unit			**R**	**2 135.00**

4.2 Design and manufacturing of prototype *Dispenser*

4.2.1 Design

Motivation

One of the important requirements of the *Solar Heat Barrow* is to also disinfect water. Although this was not a requirement in the initial stages, the cholera epidemic of

2000 and 2001 in KwaZulu Natal and Mocambique highlighted this waterborne threat.

Initial scoping for this capability showed the vulnerability of the cholera pathogen, *Vibrio cholerae*, to temperature. The investigation of designing the *SHB* for water disinfection was then started in earnest, and the requirement was formally added.

It was decided not to limit the study on the disinfection of water to only the cholera pathogen. A defence-in-depth approach to the general waterborne pathogens necessitated the concept of a chemical disinfectant dispenser to be added to the *Solar Heat Barrow* where water conditions warranted it. It was concluded that *Steripure* should be selected as the disinfectant, as was shown in paragraph 3.3.2 of this dissertation.

Prototype design

The resultant specification for the *Dispenser* is summarised as follows:

- Unit to be incorporated in *SHB* spout as replacement for COTS cap.
- Design to ensure dosing for every filling.
- Design to prevent dosing for every pouring of water.
- *Steripure* in a dilution strength of 1 part per 100 000 will be used as disinfectant.
- Volume between 0.3 and 0.35 cm^3 to be dosed per dispensing cycle.
- Minimum *Steripure* storage capacity of 30 cm^3.
- Only polymers and austenitic stainless steel to be used as materials of construction.
- Cost target of about R 30 or less, for a target selling price of around R 50.

The layout of the *Dispenser* converged relatively quickly to that shown in quarter section view in Figure 4-12. The complete unit, except for the spout insert, is removed for filling the *SHB* with water. It interfaces with the same thread as the standard COTS screw cap.

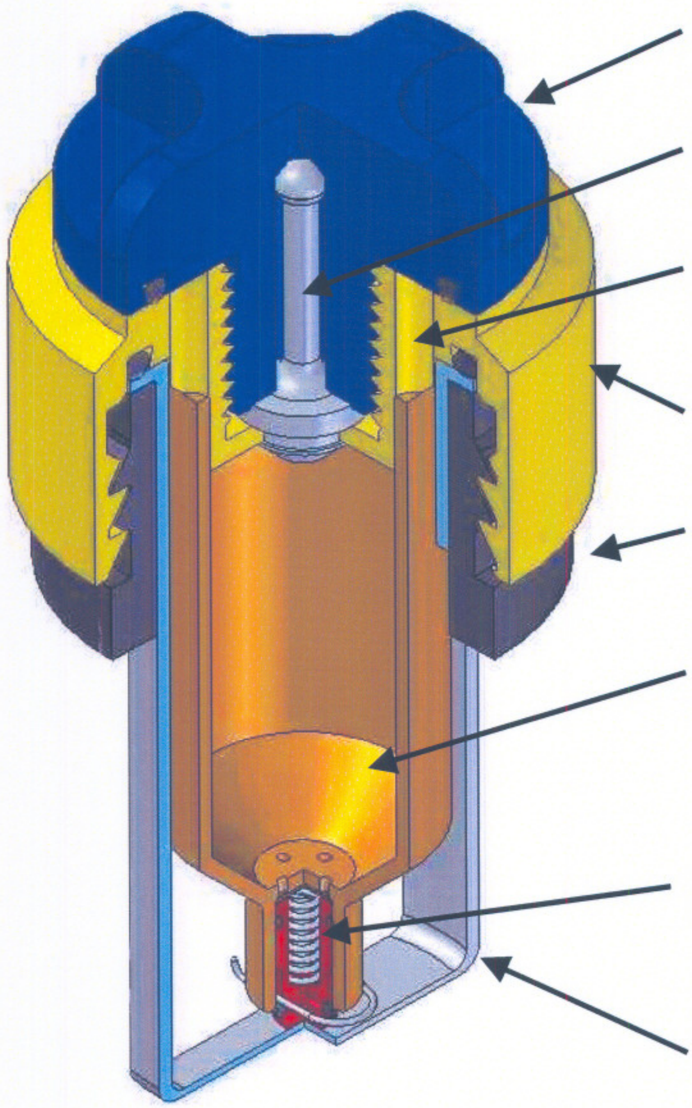

Figure 4-12: Quarter section view through *Dispenser* with insert for water container mouth

Integral with the main screw cap is a disinfectant storage container. It can be filled by removing the secondary screw lid and a rubber plug, for example by using a long spouted storage bottle for the *Steripure*. At the bottom of the disinfectant container is a dosing piston with a double valve arrangement.

When the *Dispenser* is in place on the *SHB* spout, the spout insert pushes the piston up against the rear of its cylinder where a thin elastomer flap valve is situated, which seals the disinfectant container outlet ports. The spout insert is a permanent installation in the *SHB* spout, sealed at the spout lip. Its bottom crossbar is sufficiently flexible to allow both the piston to be properly seated and the screw cap to seal on the upper spout surface of the insert. This arrangement is shown in Figure 4-13.

When the *Dispenser* is unscrewed from the *SHB* spout, the spring inside the piston pushes it out to the retaining stop. The flap valve, kept in place by the spring, allows fluid to flow from the storage volume. The volume behind the piston is then sucked full with disinfectant.

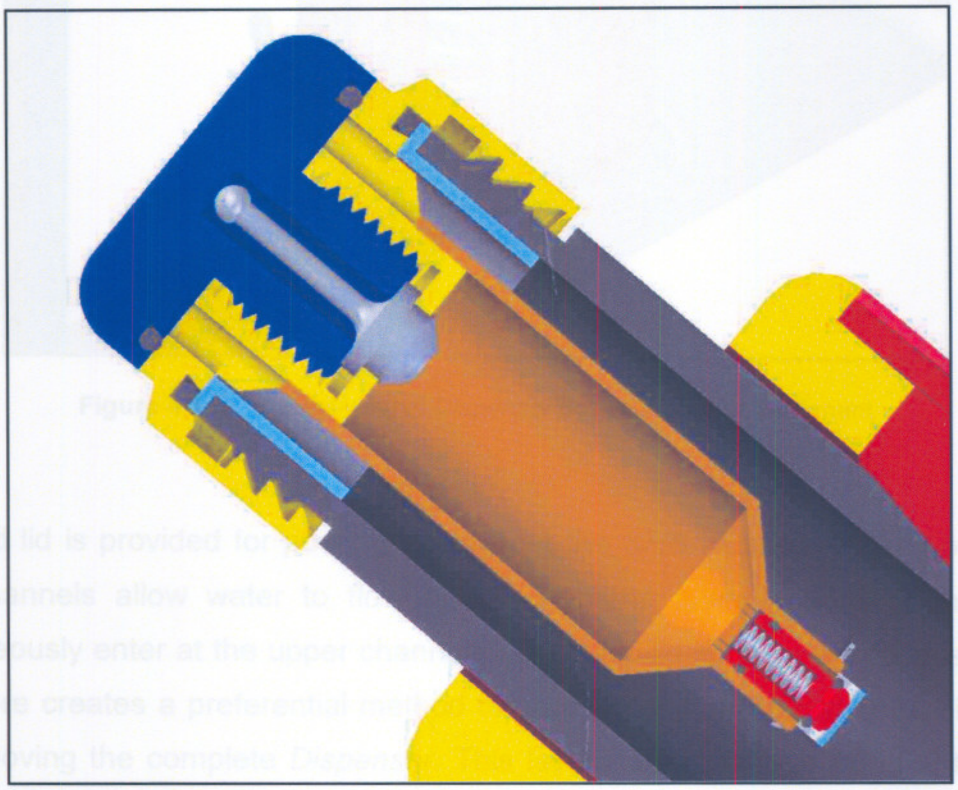

Figure 4-13: Section view showing prototype disinfectant *Dispenser* unit in place of standard screw lid

After filling the *SHB* with water, the *Dispenser* is screwed onto the spout. The flap valve prevents the disinfectant behind the piston to be forced back into the storage container. The pressure build-up then pushes the disinfectant through small holes to an elastomer O-ring on the lower piston circumference. The O-ring stretches and allows the disinfectant to be released in the *SHB* water storage volume. Figure 4-14 shows an enlarged view of the bottom of the storage container with the dosing piston arrangement, its spring, retainer and seals.

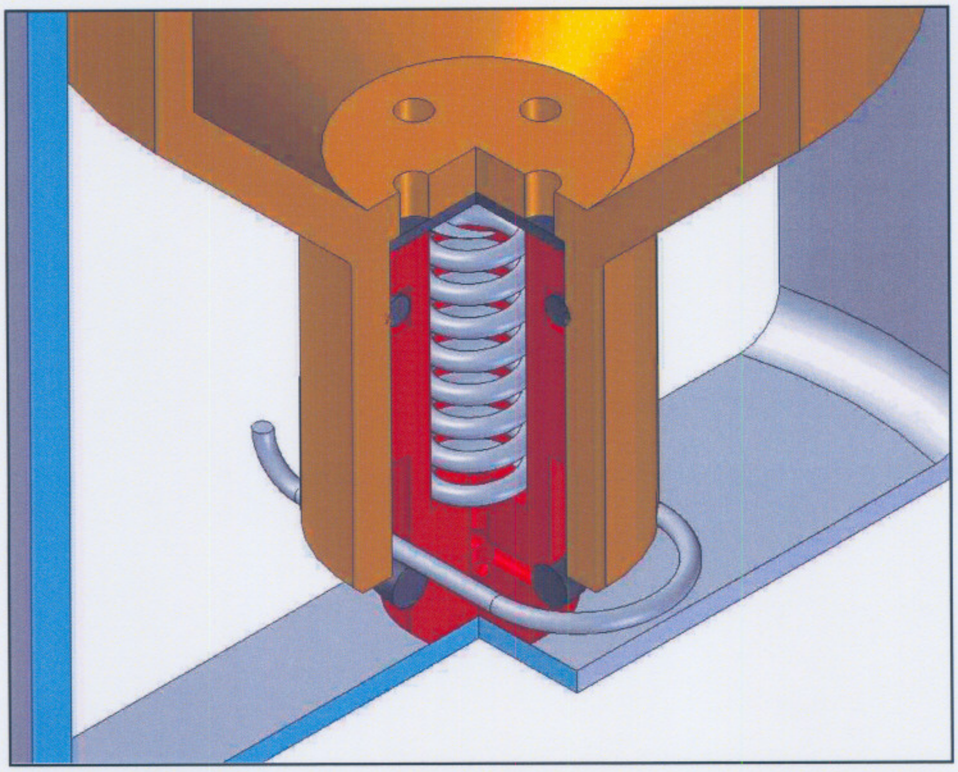

Figure 4-14: Detail view of *Dispenser* dosing piston arrangement

A second lid is provided for pouring water from the *SHB*. A circular array of narrow water channels allow water to flow out through the lower channels, and air to simultaneously enter at the upper channels, when this lid is only partially unscrewed. It therefore creates a preferential method to pour water from the *SHB* that is easier than removing the complete *Dispenser*. This layout also prevents filling of the *SHB* via this route even if the second lid is fully removed.

The design of the *Dispenser* was done for the manufacturing of a single prototype unit only. A standard COTS stainless steel spring and standard *Viton*™ fluoro-elastomer sealing components were selected. The material for the spout insert was specified as 304L stainless steel. All other components were specified to be machined from rigid unplasticised polyvinyl chloride (uPVC) because of its good machinability.

The final functional parameters of the *Dispenser* as designed is as follows:

- Cylinder diameter of 9 mm and piston stroke of 6 mm providing a dispensing dose potential of 0.34 cm^3 at an assumed volumetric efficiency of 90% maximum.
- Cylinder diameter of 9 mm and piston stroke of 6 mm providing a dispensing dose potential of 0.30 cm^3 at an assumed volumetric efficiency of 80% minimum.
- *Steripure* storage capacity of maximum 40 cm^3 is provided for.

A set of manufacturing drawings were prepared for the machining of the individual components of the *Dispenser*.

4.2.2 Manufacture

The intention from the outset was to only manufacture one prototype *Dispenser* as a proof of concept model. Experience with the design and the manufacturing of similar products, proved that this prototype would be relatively expensive. The limited project budget therefore did not allow multiple units to be manufactured.

The *Dispenser* components were machined from the manufacturing drawings in the specified materials. While these materials, especially the uPVC would not be suitable for actual production, it was, however, selected for the prototype specifically for its machinability.

After buying the balance of the COTS components of the *Dispenser*, the unit was assembled and functionally tested to demonstrate its ability to dispense low viscosity fluids with a constant dosing volume. Figure 4-15 shows the prototype unit in main sub-assemblies and Figure 4-16 shows it fully assembled with the pouring lid opened sufficiently for pouring fluid from the *SHB*. One component not made to specification is visible. The role of the piston retaining stop was fulfilled by a humble paperclip, suitably modified of course!

The disinfectant container of the prototype is obviously not transparent. While it could have been machined from clear uPVC, it would have increased the cost of manufacturing even more. Material is bought in minimum lengths, and it would have meant buying another few hundred rands worth of material just for the container. Clear uPVC also tends to crack easier, especially during machining, than the grey uPVC material generally available. This again was a lesson learned from experience and it was therefore deemed unsuitable for the other *Dispenser* components.

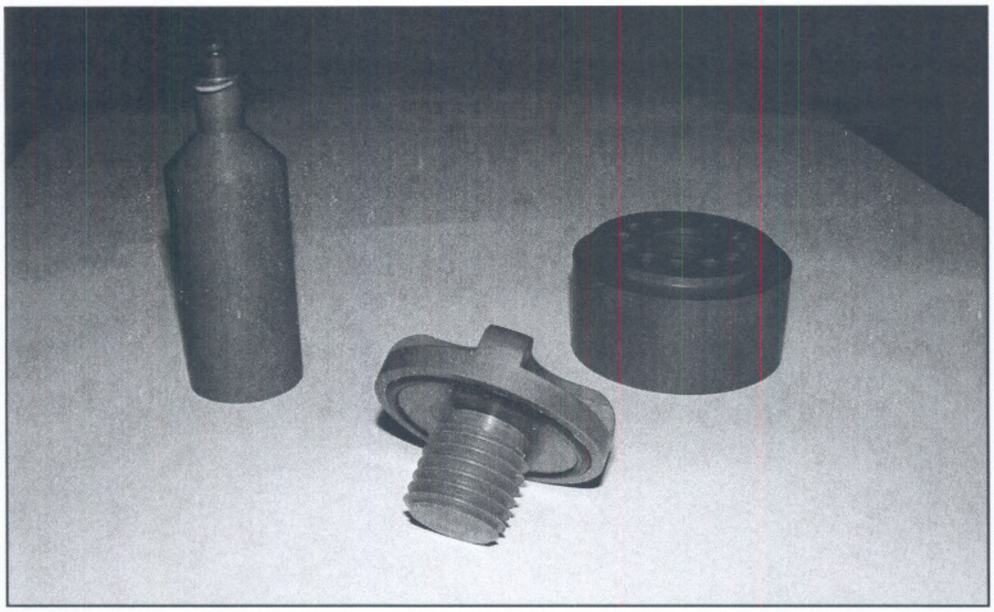

Figure 4-15: Three main sub-assemblies of the *Dispenser*

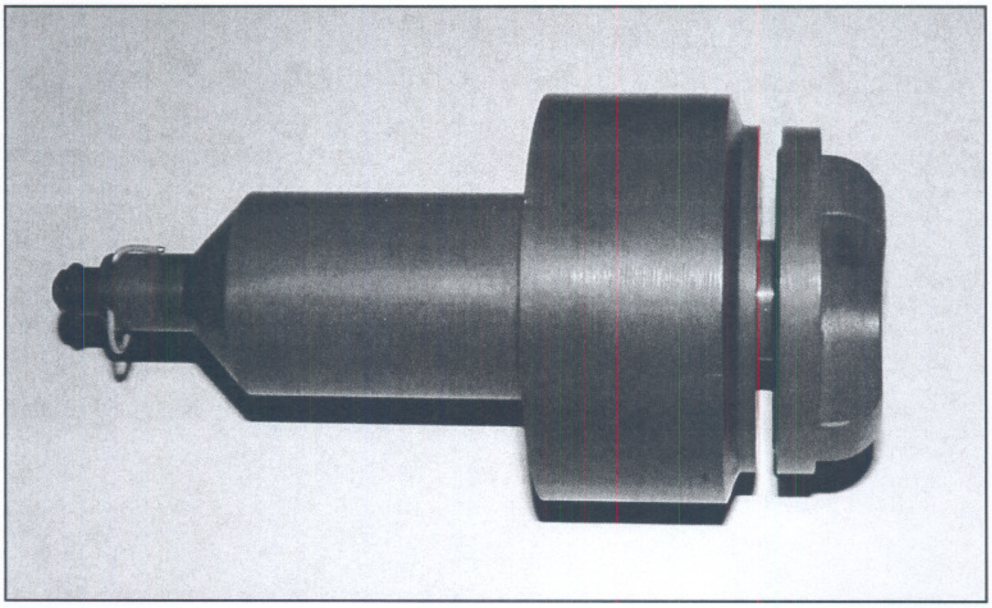

Figure 4-16: Prototype *Dispenser* with pouring lid in open position for pouring

Costs

The approximate cost of the prototype *Dispenser* unit came to R 3 364. The cost breakdown is shown in Table 4-2.

Table 4-2: MANUFACTURING COST OF *DISPENSER* PROTOTYPE

No	Component / Activity	Material	Process	Tooling Cost	Component Cost
1	Screw Body	uPVC	Machining	None	R 935.00
2	Screw Lid	uPVC	Machining	None	R 550.00
3	Container	uPVC	Machining	None	R 275.00
4	Container Stopper	Rubber	Buy out	None	R 2.00
5	Mouth Insert	Stainless Steel	Machining	None	R 525.00
6	Piston	uPVC	Machining	None	R 125.00
7	Spring	Stainless Steel	Buy out	None	R 0.50
8	Piston retainer	Stainless Steel	Buy out	None	R 0.50
9	Screw Body Seal	Viton O-ring	Buy out	None	R 3.00
10	Screw Lid Seal	Viton O-ring	Buy out	None	R 3.00
11	Piston Seal 1	Viton O-ring	Buy out	None	R 2.00
12	Piston Seal 2	Viton O-ring	Buy out	None	R 2.00
13	Piston Seal 3	Viton Rubber Sheet	Punch Cut	None	R 36.00
14	Buying Components		8 hours	None	R 800.00
15	Assy		2 hour	None	R 100.00
16	Consumables	Glue, etc		None	R 5.00
			Tooling total	R -	
			Cost/unit		R 3 364.00
			Tooling/unit		R -
			Total cost/unit		**R 3 364.00**

4.3 Conformance to specification

4.3.1 SHB prototype

Measured thermal performance

Measurements for the thermal performance of the *SHB* were conducted, under the studies of Taylor (2001), from the 30th of July 2000 to the 15th of August 2000. The *Solar Heat Barrow* was placed on the roof of a building in Pretoria. The tests were designed to find out whether the design would meet the old specification of 30°C above tap water at 20h00 in winter.

For all measurements, the *SHB* was placed facing north in a position of rest. This negated the full potential of the unit, because its mobility provided for easy manual tracking, especially in winter when it has less than optimum average inclination.

Nevertheless, four *Tinytag* temperature data loggers were used for measuring the following:

- Air temperature
- Tap water temperature
- Water area at the top of the solar water heater
- Water area in the middle of the solar water heater

The temperature data loggers have an accuracy of approximately 0.6°C. This is an overall accuracy that includes the logger resolution and thermistor accuracy. All the data loggers had certificates of conformity. The data loggers were programmed with increments of 10 minutes by using the program '*Orion Tiny Logger Manager*' to measure the following:

- Water temperature for the solar water heater from 7:00am to 7:00am the next day.
- Tap water temperature from 7:00am to 7:00am the next day. To simulate tap water, a 1-litre cylinder was filled with tap water and placed in the shade.
- Air temperature from 7:00am to 7:00am the next day.

The average results of the measurements taken for water and air temperatures are shown in Figure 4-17. It can be seen that the water temperature inside the *Solar Heat*

Barrow peaks at about 15:00, at which time the water is completely mixed by convection. The average peak temperature achieved was approximately 60°C, with specific peaks of more than 65°C shown on the raw data (not included here).

The 'tap water' temperature was omitted from the graph because the evaluation for this dissertation was done against the 40°C water temperature requirement at 20:00. As can be seen from the graph for water temperature in Figure 4-17, this hot water storage requirement was just met. No collector isolation was used during these tests, and the units stayed outside, radiating to the cold night sky. If the unit was moved indoors before sundown, and the collector surface was covered, for example by a blanket, higher temperatures could have been expected at night.

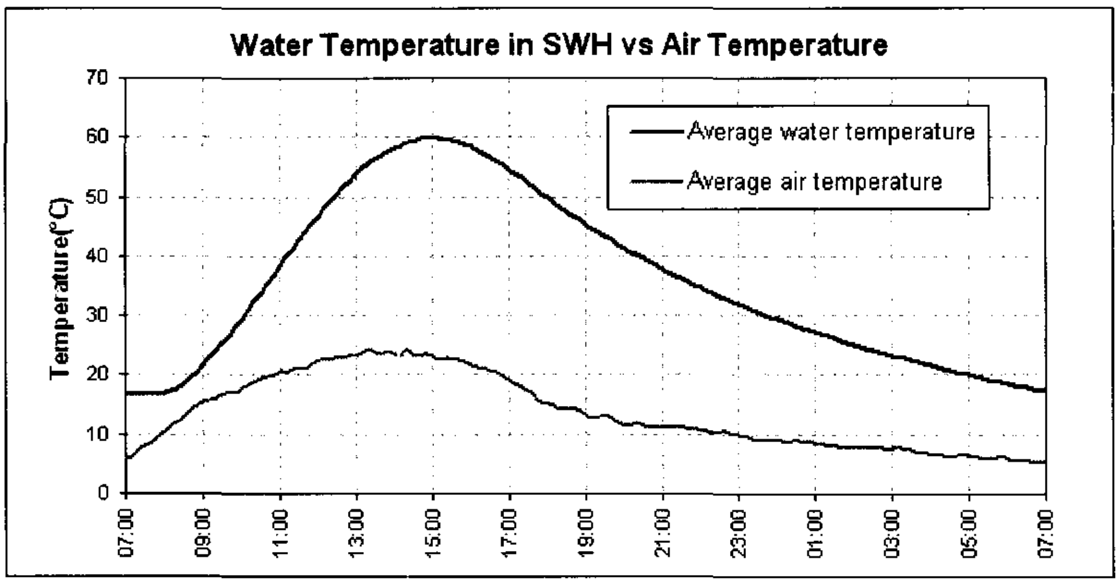

Figure 4-17: Heating performance of the prototype *Solar Heat Barrow*

Physical

The *Solar Heat Barrow* showed a high physical conformance with the specification as generated in paragraph 2.4 of this dissertation.

The mobility of the unit was judged to be excellent, though the tyre of the wheel was harder than expected. This led to a very bouncy ride when the unit was empty. A softer tyre as intended for production units would alleviate this tendency.

The mass of the units as manufactured varied between 16 and 17 kg. This was measured with a fish scale, which was roughly calibrated using known water volumes in a bucket. The unit mass was slightly higher than the specified 15 kg empty mass and the calculated mass of 14 kg. Two factors led to this. The wheel assembly was approximately 1 kg heavier than assumed, and the frame was bent from a 32 mm pipe with a 2 mm wall thickness, instead of the specified 1.6 mm. Production units should thus be within specification.

All the units tested could store a minimum of 25 litres of water. This was measured by filling the units with water from a graduated 5 litre oilcan. Though not an officially calibrated measure, it was judged to be accurate enough for this test.

The physical dimensions of the units conformed to specification. The thickness of the insulation was measured by cutting up one of the original test units, and it was found to vary between 20 and 30 mm thick. This conformed to the specified minimum 20 mm, but exceeded the maximum 25 mm. The only consequence, however, would be slightly higher material consumption during production.

Problems identified

A few problems were identified during the test and evaluation of the prototype *Solar Heat Barrow*. Two of these are relatively serious and need to be addressed for production.

The first was the 'melting' of a collector surface during an exceptionally hot and clear period in the summer of 2002. Not intended as a test, but revealing in its results, a half empty unit was left outside in an ideal heating orientation. The upper half of the collector experienced dry stagnation, and the low density polyethylene reached a temperature where it plastically flowed, resulting in a failed collector. This can be seen in Figure 4-18. The glazing of the unit was removed when the photographs were taken. Figure 4-19 shows a close-up of a failure around a tie-tube, where the support of the tube actually assisted with the failure. It can also clearly be seen that the flow was gravity assisted, and not caused by internal pressure.

While the maximum recommended service temperature of roto-moulded linear low density polyethylene is only 50°C, it has been successfully used in ICS solar water heaters before. Measurements by Mathews & Rossouw (1997) on dry polyethylene sheets optimally exposed to the sun, showed that material temperatures exceeding

80°C can be achieved. Their results are shown graphically in Figure 4-20. The melting point of LLDPE is 125°C, but its Vicat softening point is 91°C (LLDPE, 2001). It can therefore be assumed that the *SHB* collector, due to its glazing, approached or even passed the softening point temperature when it failed.

Figure 4-18: Failure of a water container in a prototype due to overheating of collector surface

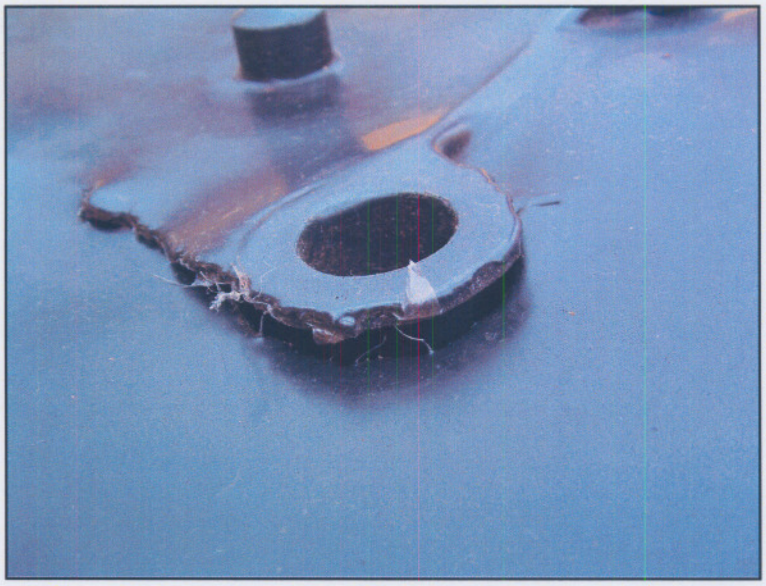

Figure 4-19: Close up view of heat failure showing typical signs of material plastic flow and subsequent complete failure

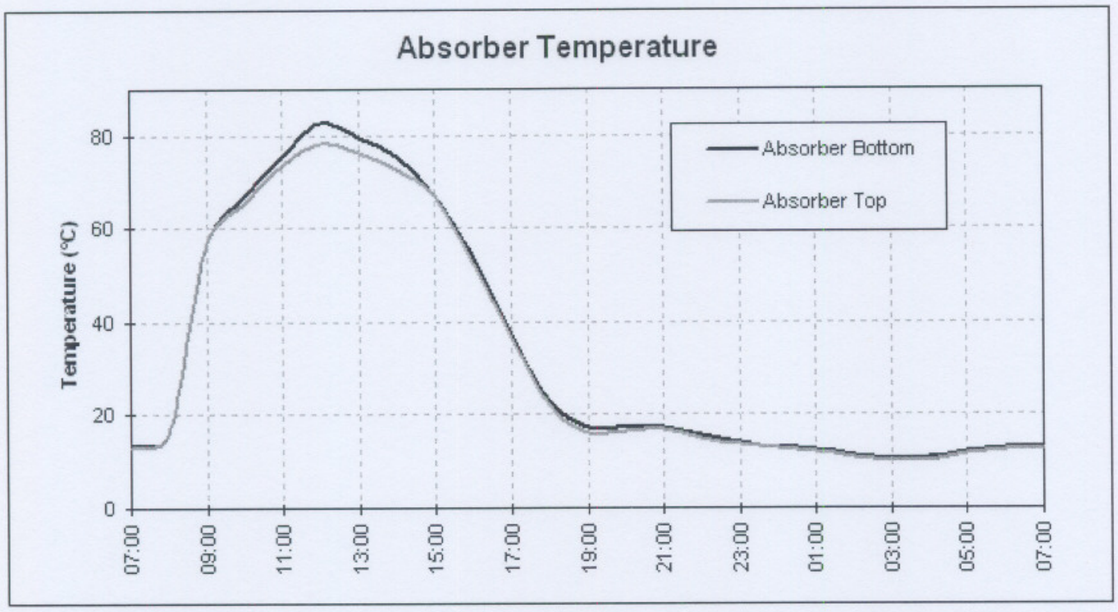

Figure 4-20: SWH absorber temperatures (Mathew & Rossouw)

The lesson to be learned from this failure is two-fold. While the glazing is necessary for ensuring thermal performance, some ventilation must be allowed to ensure that the collector does not accidentally overheat and fail. The second point is that dry stagnation of the *SHB* must be prevented. Empty or partially empty units should at least be turned out of the optimum heating orientation. A change to high density polyethylene for the storage-collector material would also help, as this material has a higher Vicat softening point at 110°C (HDPE, 2001), even though it melts at only 5°C higher than LLDPE.

The second problem experienced with *SHB* test units was the stresses that the glazing fixing screws applied to the housing moulding. This caused the material to fail in several units at some of the screw positions, as is shown in Figure 4-21. Two features of the design can explain this failure.

The first is the flat sheet of polycarbonate used for glazing, which is very stiff in the sheet plane. The second is the differential expansion of the polyethylene body unit and the polycarbonate glazing. The coefficient of expansion for the LDPE is 140 µm/m.°C (LLDPE, 2001), while that of polycarbonate is 75 µm/m.°C (PCUV, 2001).

The glazing also does not reach the temperature of the body unit during exposure to the sun.

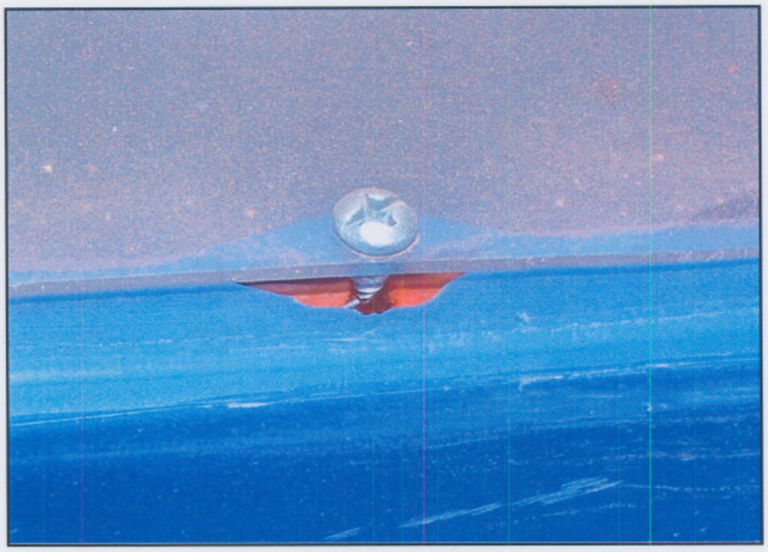

Figure 4-21: Typical failure of outer body at glazing attachment screws due to differential expansion between body and glazing

The lesson learned from this failure is that the glazing needs to be geometrically formed in a way that allows it to flex when temperature influences cause differential movement of the mounting interface between the glazing and the body unit. The design must allow for a low in-plane stiffness of the polycarbonate glazing. This can be achieved by using the relatively low cost vacuum forming method (Sheffield, 2001). Tooling would, however, be required.

4.3.2 *Dispenser* prototype

Measured dispensing

The average dosing discharge volume of the *Dispenser* was tested by determining the number of discharges that could be obtained from a known volume of water in the disinfectant container. This test was repeated 5 times.

The disinfectant container was charged with a volume of 5 or 10 cm^3 using a medicinal syringe. By slowly pushing the dispensing piston onto paper sheets, the number of discharges was counted until empty. The average dose per discharge was found to be 0.35 cm^3. This is at the top end of the specified range of 0.30 to 0.35 cm^3. The results of the five tests are shown in Table 4-3. The physical size of the water puddles on the paper also gave an indication of the consistency of the discharged volume. Figure 4-22 shows the results for test number 4.

Table 4-3: ***DISPENSER*** **DISCHARGE TEST RESULTS**

Test No.	Volume [cm^3]	No. of discharges	No. of discharges per cm^3	Average discharge volume [cm^3]	Consistency
1	5	14	2.80	0.36	Fair
2	5	15	3.00	0.33	Good
3	5	15	3.00	0.33	Good
4	10	28	2.80	0.36	Good
5	10	29	2.90	0.34	Good
Average	-	-	**2.98**	**0.35**	**Good**

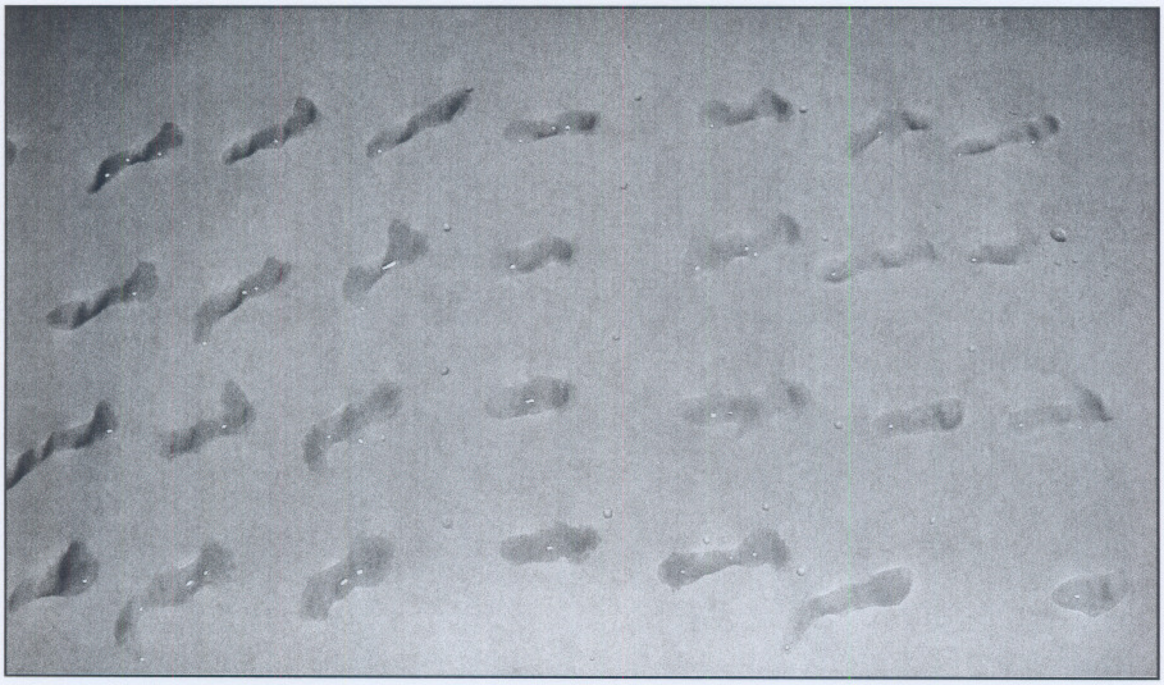

Figure 4-22: Individual dispensing volumes for test no. 4 of prototype *Dispenser*

Pouring

The *Dispenser* was easy to use, and performed well when pouring water from the *Solar Heat Barrow*. The water flow was easy to control during pouring, and amounted to approximately 1 litre every 5 seconds. Pouring is shown in Figure 4-23.

Figure 4-23: Water being poured from *SHB* using *Dispenser* preferential pouring lid

Problems identified

No problems were identified during this basic testing of the *Dispenser* prototype. Long term testing, specially when filled with *Steripure* must, however, be conducted. This should be done in conjunction with the disinfectant manufacturer to verify that the *Steripure* does not degrade due to its long term exposure to the temperature experienced in the *Solar Heat Barrow*.

4.4 Production considerations

4.4.1 Proposed *SHB* design changes

Outer housing

The foaming process was the weak point in the assembly of the *Solar Heat Barrow*. There was no easy way to ensure that the cavity was fully filled, and design improvements together with pressure and foam containment tooling will have to be developed for larger scale manufacturing. The foam is also an expensive part of the unit, and minimum wastage must be strived for.

One of the proposed design changes would be for the outer housing to be changed to a closed container again. This closed container could then be put into a shape conforming confinement tool, and the poly-isocyanurate foam could be pressure transferred into the cavity (Blaga, 2001). This would ensure a consistent density and quality of the insulation. This exact process was used in the manufacturing of high quality, insulating, large-calibre ammunition containers by the South African armaments industry during the 1980's and 1990's.

Another process that is newly available in South Africa is the foamed roto-moulding of polyethylene. The process is described on the website of Kaymac Rotomoulders of Pietermaritzburg in KwaZulu Natal. Structurally strong components can be made in a single process (Kaymac, 2003), and depending on the insulation properties and cost it may be suitable for the manufacture of the complete outer housing unit.

Layout

The curved shape of the *Solar Heat Barrow* should also be changed to a flat rectangular shape. While there was good reason for the original shape, the adoption of a piped frame and its configuration negated all these reasons bar one. The curved shape could marginally lower the center of gravity of the *SHB*, making it easier to be pushed and controlled by women and children.

However, if the exact frame is used, and a flat solar heater is fitted as shown in Figure 4-24, the center of gravity could actually be even lower than for the present *SHB* configuration. The complete surface of the collector would also be at a better inclination for solar heating. The inclination of the configuration shown in Figure 4-24 is 30° when stationary in the heating position.

This change to a flat heater would have several advantages. The first is a lower cost of the tooling, especially for the blow mould that would be required for the storage-collector tank. The second would be marginally better heating performance due to the improved inclination. The third would be the easier assembly of the storage-collector tank into the housing if the first proposed design change is implemented.

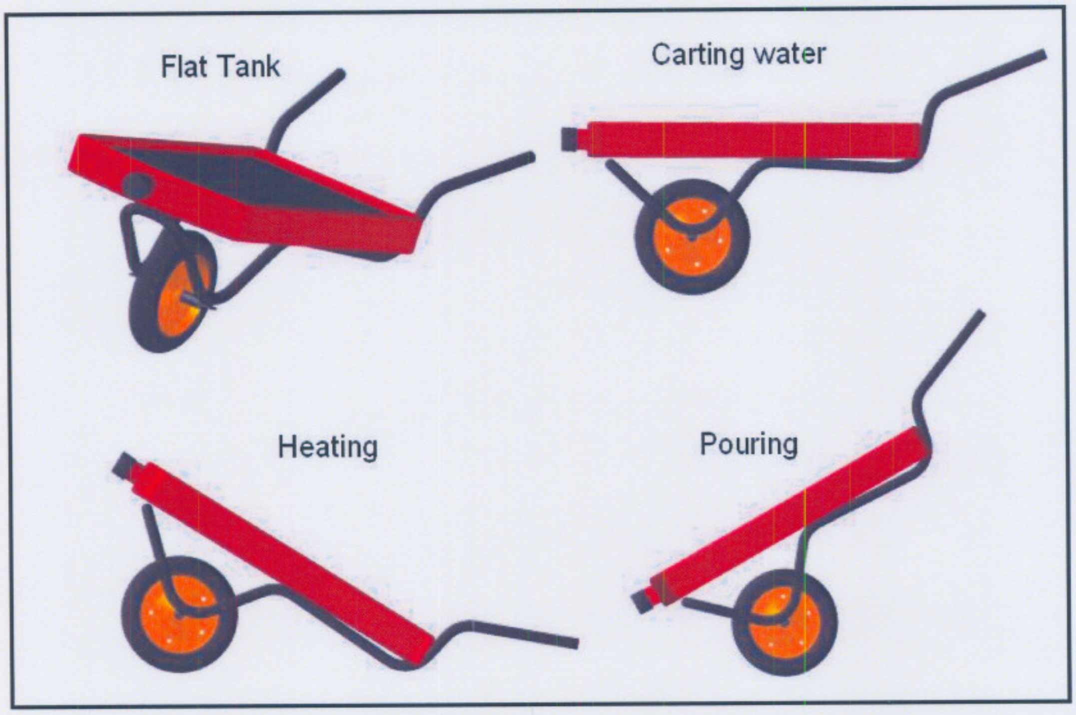

Figure 4-24: Views of proposed *SHB* modification to Flat Tank layout

The complete heating unit should of course also be easily removable from the frame. This will assist with the *SHB* distribution by increasing the packing density during transport of the units. Once in use, it will make the use of the *SHB* frame as a general-purpose cartage tool possible.

Storage-collector

The storage-collector tank could be designed and manufactured to be shape conforming to fit in a hollow relief in the outer housing. This component should also be manufactured in UV stabilised high density polyethylene by the blow moulding process. The properties of HDPE are better suited to this application (HDPE, 2002[a]), and blow moulding will ensure thin walled components with a very consistent quality.

The worldwide experience with the SODIS system and other systems using natural UV to assist with water disinfection was described in paragraph 3.2.3 of this dissertation. It may thus be advantageous to investigate the possibility of making the storage-collector in a transparent polyethylene terephthalate, or PET. It appears to have the correct properties for this use (PET, 2003), and is widely used for soft drink bottles, also in Southern Africa. Local processing knowledge is therefore available.

An American study aroused the suspicion that PET releases carcinogenic chemicals when exposed to sunlight. It was reported widely, and the story can still be followed on the Internet (Mikkelson & Mikkelson, 2003). The SODIS team, supported by several scientists and manufacturers of PET, had, however, already published an informative paper that showed this fear to be unfounded (Wegelin *et al*, 2001). Blow moulded PET can therefore safely be considered as the material of choice for a transparent storage-collector with black rear and side faces. An arrangement for such a unit, incorporating features of the *SHB* prototyping experience, is shown in Figure 4-25.

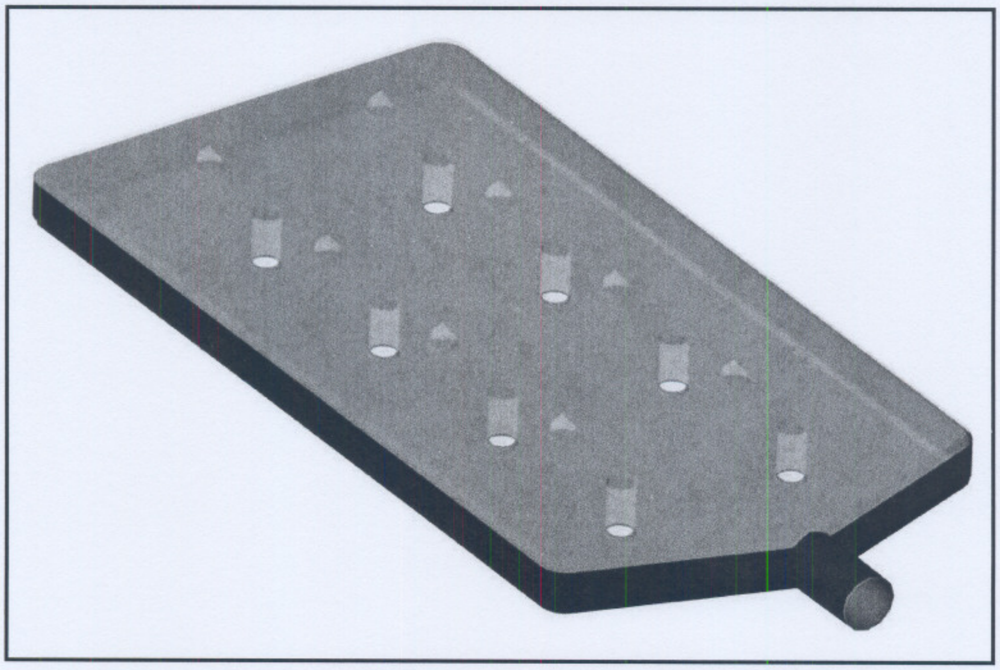

Figure 4-25: Proposed transparent PET storage-collector with black rear and side surfaces

4.4.2 Proposed *Dispenser* design changes

While the prototype *Dispenser* proved to be functionally acceptable, the unit has to be re-designed in total to allow for large scale manufacturing. Injection moulding of most of the polymer components would drastically reduce component costs, but with a relatively high tooling cost.

The screw cap body and the screw lid can be manufactured in HDPE (HDPE, 2002[b]), while the disinfectant container can be injection moulded in polypropylene for its higher temperature resistance (PP, 2002).

The piston may be manufactured in one of several materials, with polypropylene probably being the most suitable. The spout insert may be machined from stainless steel, bent and spot welded from stainless steel sheet, or injection moulded from a glass fibre reinforced polyamide (Nylon) material.

Detail investigations will be required to select the best materials and processes to ensure low cost components that still meet the functional requirements.

4.4.3 *SHB* cost at factory

A cost study was done to estimate the manufacturing cost of a *SHB* unit for two different production strategies. The first option was to examine the cost of a single batch of 1000 *SHB*'s. This was assumed to be the order of batch size one could expect to manufacture if a commercial company would want to sponsor a community for advertisement purposes.

For a batch of this size it would, however, not be justified to start up a production facility. Most of the manufacturing methods would be as for the prototype unit. Improved tooling for roto-moulding would be required, as well as new tooling for the foaming cycle and the vacuum forming of the glazing. The tooling cost should also be amortised in the cost of this single batch. The result of this study is shown in Table 4-4. No time value of money was used, and the cost of the *Solar Heat Barrows* would be approximately R800 per unit.

The cost of the production option was also estimated. This assumed a production rate of 1 000 *SHB* units per month for at least a year. The basis of this number is explained in paragraph 5.4 of this dissertation. A small production facility with a few full time employees would be required. The overhead estimate is shown in Table 4-5, and assumes only a facility added to an already established manufacturer.

Table 4-4: MANUFACTURING ESTIMATE FOR *SHB* BATCH OF 1 000 UNITS

No	Component / Activity	Material	Process	Tooling Cost	Component Cost
1	Outer Housing	LLDPE UV Stabilised	Rotomould	R 15 000.00	R 150.00
2	Absorber Tank	HDPE UV Stabilised	Rotomould	R 15 000.00	R 150.00
3	Standard Lid		Buy-in Component		R 2.50
4	Glazing	PC Clear 1mm	Vacuum Form	R 20 000.00	R 75.00
5	Frame	Tubing Steel 32mm	NC Bend / Weld		R 100.00
6	Wheel Assy		Buy-in Component		R 40.00
7	Isolation Materials	PU Foam	Mix / Pressure Pour	R 20 000.00	R 50.00
8	Fasteners	Bolts & Screws			R 10.00
9	Consumables Assy	Rags, Rivets			R 5.00
10	Labour Assy Mechanical				R 100.00
11	Labour Assy Isolation				R 50.00
			Tooling total	R 70 000.00	
			Cost/unit		R 732.50
			Tooling/unit		R 70.00
			Total cost/unit		**R 802.50**

The production cost of units were costed as shown in Table 4-6, and include the cost of tooling amortised over the first year of production, without a time value of money. The estimated production cost of a *Solar Heat Barrow* unit was found to be approximately R380.

Table 4-5: OVERHEAD COSTS FOR *SHB* PRODUCTION

Personnel/Overhead	Cost/month		Cost/unit	
1 x Technician	R	25 000.00	R	25.00
1 x Administrative	R	16 000.00	R	16.00
1 x Artisan	R	16 000.00	R	16.00
3 x Labourer	R	15 000.00	R	15.00
Factory space 375 sq.m	R	5 000.00	R	5.00
	Total/unit		**R**	**77.00**

Table 4-6: MANUFACTURING ESTIMATE FOR PRODUCTION OF *SHB* (12 000 / YEAR)

No	Component / Activity	Material	Process	Tooling Cost		Component Cost	
1	Outer Housing	LLDPE UV Stabilised	Rotomould	R	45 000.00	R	100.00
2	Absorber Tank	HDPE UV Stabilised	Blowmould	R	200 000.00	R	50.00
3	Standard Lid		Buy-in Component			R	1.00
4	Glazing	PET Clear 1mm	Vacuum Form	R	40 000.00	R	20.00
5	Frame	Tubing Steel 32mm	NC Bend / Weld			R	50.00
6	Wheel Assy		Buy-in Component			R	20.00
7	Isolation Materials	PU Foam	Mix / Pressure transfer	R	40 000.00	R	25.00
8	Fasteners	Bolts & Screws				R	5.00
9	Consumables Assy	Si Spray, Rags, Rivets				R	2.00
			Tooling total	R	325 000.00		
			Cost/unit			R	273.00
			Tooling/unit			R	27.08
			Overhead/unit			R	77.00
			Total cost/unit			**R**	**377.08**

4.4.4 *Dispenser* cost at factory

A similar costing exercise was also performed for the *Dispenser.*

The polymer components for a single 1 000 unit batch would in all probability have to be NC machined, and would thus be of similar materials than the prototype units. The disinfectant container would have to be machined from a more heat resistant material than uPVC, and polypropylene is proposed. The elastomer materials could be obtained in NBR and silicone rubber to reduce cost, but the chemical resistance to *Steripure* will have to be verified. This costing is shown in Table 4-8. The unit price for a *Dispenser* would be approximately R600.

The cost estimate for production of *Dispensers* at a rate of 1 000 per month for at least a year is somewhat more encouraging. Injection moulding can be used extensively, and component costs could be drastically reduced. A production rate of 1 000 *Dispenser* units per month for at least a year is again assumed. A small production facility with a few shared employees would be required. This overhead estimate is shown in Table 4-7, and also assumes only a facility added to an already established manufacturer.

The production cost of units were costed as shown in Table 4-9, and include the cost of tooling amortised over the first year of production, again without a time value of money. The estimated production cost of a *Dispenser* unit was found to be approximately R80.

Table 4-7: OVERHEAD COSTS FOR *DISPENSER* PRODUCTION

Personnel/Overhead	Cost/month		Cost/unit	
1/2 x Tech/Admin	R	8 000.00	R	8.00
1 x Labourer	R	5 000.00	R	5.00
Factory space 100 sq.m	R	1 500.00	R	1.50
	Total/unit		**R**	**14.50**

Table 4-8: MANUFACTURING ESTIMATE OF *DISPENSER* BATCH OF 1 000 UNITS

No	Component / Activity	Material	Process	Tooling Cost		Component Cost	
1	Screw Body	uPVC	NC Machining	R	2 000.00	R	250.00
2	Screw Lid	uPVC	NC Machining	R	2 000.00	R	125.00
3	Container	PP	NC Machining	R	2 000.00	R	50.00
4	Container Stopper	Si Rubber	Mold	R	1 500.00	R	0.50
5	Mouth Insert	Stainless Steel	NC Machining	R	1 500.00	R	125.00
6	Piston	PP	NC Machining	R	500.00	R	15.00
7	Spring	Stainless Steel	Buy out			R	0.50
8	Piston retainer	Stainless Steel	Buy out			R	0.50
9	Screw Body Seal	NBR O-ring	Buy out			R	3.00
10	Screw Lid Seal	NBR O-ring	Buy out			R	3.00
11	Piston Seal 1	NBR O-ring	Buy out			R	2.00
12	Piston Seal 2	NBR O-ring	Buy out			R	2.00
13	Piston Seal 3	Silicone Rubber Sheet	Punch Cut			R	0.35
14	Buying Components		16 hours	R	1 600.00		
15	Assy Labour		0.1 hour by Hand			R	10.00
16	Consumables	Glue, etc				R	0.05
			Tooling total	R	11 100.00		
			Cost/unit			R	586.90
			Tooling/unit			R	11.10
			Total cost/unit			**R**	**598.00**

Table 4-9: MANUFACTURING ESTIMATE FOR PRODUCTION OF *DISPENSER* (12 000 / YEAR)

No	Component / Activity	Material	Process	Tooling Cost		Component Cost	
1	Screw Body intgl Seal	HDPE	Injection Mould	R	18 000.00	R	18.00
2	Screw Lid intgl Seal	HDPE	Injection Mould	R	15 000.00	R	15.00
3	Container	PP	Injection Mould	R	10 000.00	R	10.00
4	Container Stopper	NBR	Injection Mould	R	2 500.00	R	0.25
5	Mouth Insert	Nylon 66	Injection Mould	R	10 000.00	R	10.00
6	Piston intgl Seal	Nylon 66	Injection Mould	R	3 000.00	R	3.00
7	Spring	Stainless Steel	Buy out			R	0.25
8	Piston retainer	Stainless Steel	Buy out			R	0.25
9	Piston Seal 2	NBR O-ring	Buy out			R	0.25
10	Piston Seal 3	Silicone Rubber Sheet	Punch Cut			R	0.25
11	Consumables	Glue, etc				R	0.05
			Tooling total	R	58 500.00		
			Cost/unit			R	57.30
			Tooling/unit			R	4.88
			Overhead/unit			R	14.50
			Total cost/unit			**R**	**76.68**

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CHAPTER 5: EVALUATION AND COMMERCIAL VIABILITY

5.1 Policy background for implementation of *SHB*

The policy background is discussed from the South African perspective. Where information is available, the policies of other countries in Southern Africa are included.

5.1.1 General scenarios

Since 1994, social and economic policies in South Africa have largely been influenced by the *White Paper on Reconstruction and Development* (RDP, 1994), and its programme "for integrated and coherent socio-economic progress".

The five programmes of the Reconstruction and Development Programme (RDP) is:

- meeting basic needs
- developing human resources
- building the economy
- democratising the state and society
- and implementing the RDP

It is against the first of these, meeting basic needs, that this study must be seen. The main water supply emphasis in the *White Paper on Reconstruction and Development* was the access to basic water and sanitation services for all South Africans by the year 2000. The main energy emphasis was the electrification of 2.5 million households by 2000.

South Africa's *Constitution* (Act 108, 1996) tasks the State to deliver on these expectations. To do so, the *Constitution* provides the legal basis for allocating powers to different spheres of Government. It also contains a number of rights specifically relevant to the national water, sanitation, health, housing and energy policies.

In the larger African context, the United Nations Economic Commission for Africa (ECA) describes the continent's pressing problems (ECA, 2002), and those applicable to this study is:

- Inadequate water resources where Northern and Southern Africa in particular are at risk of severe water stress due to the low natural rainfall and lack of other natural fresh water resources.
- The growth in urban and peri-urban populations leading to deterioration in human settlements and increased discharge of unprocessed waste into the environment, which results in severe health problems.
- A failing physical infrastructure leading to a shrinking share of urban populations that has access to good health services, regular garbage disposal, and clean, piped water.
- Deforestation growing at 0.8% per year due to a high demand for wood fuels, causing water run-off problems, water storage sedimentation, and pollution.

The ECA (2002) thus calls for an approach that uses new and emerging technologies in catalysing Africa's transition to sustainable development.

5.1.2 Water and Sanitation

The Department of Water Affairs and Forestry (DWAF), in support of the RDP, generated the first white paper on *Water Supply and Sanitation* in 1994 (DWAF, 1994). While very broad in its outlook, it defined a basic water service as:

- Minimum 25 liters per person per day for direct consumption, for the preparation of food and for personal hygiene.
- Maximum cartage distance of 200 m that a person should have to cart water to their dwelling.
- Quality of water should be in accordance with accepted minimum standards with respect to health related chemical and microbial contaminants.
- Water should be available on a regular, daily basis with the minimum service interruptions.

In its guidelines it also warned against the closure of "sub-standard" water supplies, which forces communities to revert to sources of even lower quality.

A basic sanitation service is defined as the provision of appropriate health and hygiene education, and a sound toilet acceptable to the users, at least within 200 m of all dwellings.

In 1997, the department generated another white paper on a *National Water Policy for South Africa* (DWAF, 1997). This document focused on the additional subjects of the protection of water resources, and especially on the plight of women and children in rural areas, particularly those living in female headed households. Women are seen as the traditional custodians of natural resources and of family health in the rural areas. They are also the people who suffer most from degradation of water and other natural resources. The policy of Government thus became to empower women, through education and communication, in the management of rural water sources and distribution. In short, they support the feminisation of water management.

The *National Water Act* (Act 36, 1998) gave the legal teeth for the implementation of the water policy with the disadvantaged in mind. This is stated implicitly in the purpose of the act, as quoted below:

> *"2. The purpose of this Act is to ensure that the nation's water resources are protected, used, developed, conserved, managed and controlled in ways which take into account amongst other factors -*
>
> a. *meeting the basic human needs of present and future generations;*
> b. *promoting equitable access to water;*
> c. *redressing the results of past racial and gender discrimination;*
> d. *promoting the efficient, sustainable and beneficial use of water in the public interest;*
> e. *facilitating social and economic development;..................."*

In two more draft white papers, one on *Water Services* (DWAF, 2002[a]) and the other on the development of a *Sanitation Policy and Practice* (DWAF, 2002[b]), the definition of basic water services and sanitation as stated in 1994 (DWAF, 1994) is confirmed. It further targets an additional 7 million people to be served with at least a basic water supply service by 2008, an additional 18 million people (3 million households) to be served with at least a basic sanitation service by 2010, and all schools and clinics to have basic water and sanitation services by 2005.

These policy documents also tasks other Government departments. The Department of Education must ensure that hygiene education and the wise use of water are taught in all schools by 2005. The Department of Health is tasked with providing hygiene education to the 3 million households targeted to be served with a basic sanitation service by 2010.

The policies reiterate the role of women, and encourage technology innovation undertaken in the spirit of promoting the achievement of the goals set out. It also explicitly calls for the consultation with local communities in planning for mixed levels of service, allowing consumers to elect a level of service which suits their needs and which is affordable to them.

In addition good hygiene practices, i.e. hand washing, safe water storage, and food hygiene and good waste management should be promoted through implementation of appropriate awareness campaigns.

5.1.3 Renewable energy

In the white paper on *The Promotion Of Renewable Energy and Clean Energy Development* (DME, 2002[a]), the South African Government is developing a framework within which the renewable energy industry can operate, grow, and contribute positively to the South African economy and to the global environment.

Renewable energy is defined as the "*naturally occurring non-depletable sources of energy, such as solar, wind, biomass, hydro, tidal, wave, ocean current and geothermal, to produce electricity, gaseous and liquid fuels, heat or a combination of these energy types*".

The white paper states that domestic solar water heating systems have the potential to save up to 70% on water heating electricity costs and up to 40% on total household electricity costs. It defines a considerable scope to increase the application of solar water heating, which would contribute favourably to electricity demand-side management and deferral of new generation capacity. In a paper to the World Renewable Energy Conference (WREC) of 1996, Schaller (1996) summarised that this deferral could amount up to 7500 MW in winter peak demand.

The Renewable Energy policy goal is to promote the implementation of sustainable renewable energy through the establishment of appropriate financial instruments, technology development, and the development of mechanisms to raise public awareness of the benefits and opportunities of renewable energy. The role of women in decision-making and planning is also emphasised, and their empowerment in renewable energy programmes promoted.

Some of the financial instruments may also be tailored to take advantage of the opportunities offered for the so-called Clean Development Mechanism (CDM) under the Kyoto Protocol as described by Wohlgemuth and Missfeldt (2000).

Botswana has similar policies with regard to the implementation of renewable energy equipment, as described by Olayiwola-Fagbenle (2001). They specifically promote the installation of solar energy equipment in the form of solar photovoltaic installations and solar water heaters.

The domestic sector accounts for the majority of the 10 000 SWH units currently installed in Botswana, with the Botswana Housing Corporation leading the way in many of its housing projects throughout the country. They, however, experienced some barriers to the widespread uptake of solar thermal energy, with the most important factors identified as:

- Product quality and standard of installation workmanship
- Non-availability of financing schemes
- Equipment and system guarantee/warrantee
- Lack of trained manpower for repair and maintenance of solar thermal systems

Jain *et al* (2002) describes this last factor in more detail. They propose a system of national education programmes to train manpower for repair and maintenance of the solar energy equipment in Botswana. Without proper support of the equipment, they foresee a dwindling of consumer faith in solar technologies.

This experience is in line with the warning of Tsur and Zemel (2000) against the introduction of solar technology, without the necessary infrastructure, just to replace the use of fossil fuels. They thus promote substantial early engagement in solar R&D and training programmes that should precede, rather than follow, the application of the technology.

5.1.4 Health

The Department of Health, in collaboration with other relevant sectors, is responsible for the improvement of South Africa's environmental health status (DH, 1997). It therefore endeavours to limit the health risks that arise from the physical and social environment. Environmental health services should contribute towards sustainable physical and socio-economic development, and must be implemented with the active participation of the communities.

Environmental health practitioners (EHP's)[1] focus on primary environmental health protection. They identify, monitor and evaluate risks, and plan interventions that relate to a range of microbiological, chemical or physical environmental hazards (HST, 2002). In rural and informal settlement areas, their main priority is to monitor water, waste and sanitation services.

A growing component of the work of EHP's is pro-active and educational, so that potential hazards can be understood, identified and addressed by local residents before they become a problem. EHP's thus have the potential to play an important role in supporting and promoting integrated development planning.

In the South African Health Review of 2002 (HST, 2002), the lessons learned by the Mvula Trust in rural projects are summarised. One of the main conclusions made is again that consultation with the community in water, sanitation and environmental health programmes is crucial, and that sufficient time and resources must be allocated to this facilitation process.

The aim of the Governments of Southern Africa is to approach health issues from a common platform. In the *Protocol on Health in The Southern African Development Community* (DH, 2000), signatories agree that they shall act in pursuit of the objectives of a common health goal. One of the objectives is to collaborate, co-operate and assist each other in addressing regional environmental health issues and concerns. It can thus be expected that similar health policies to that of South Africa, exists in the rest of Southern Africa.

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[1] Previously called "Health Inspectors".

5.1.5 Housing

In the white paper on *A New Housing Policy and Strategy for South Africa* (DOH, 1994), the South African Department of Housing summarised the expected structure of households in 1995 in South Africa as follows:

- The total number of households was estimated at 8.3 million, with an average of just below 5 persons per household.
- A relatively small portion of the population (less than 3 million households) lived in formal housing.
- Approximately 1.5 million urban informal housing units existed in South Africa. These units were defined as informal houses on serviced sites where only basic services were provided.
- Approximately 1.1 million households lived in squatter settlements nationwide. Most settlements were around cities and towns. It was estimated that around 150 000 new squatter households per year were added, with no basic services available.
- Of the 3 million households in the rural areas, more than two thirds live under the poverty datum line. There was a mix of both formal and informal housing, but they generally had inadequate access to potable water and sanitation.

As far as basic services are concerned the following situation existed:

- More than 2 million of all urban and peri-urban households in South Africa did not have access to a piped potable water supply.
- An estimated 4 million households did not have access to flush toilets or ventilated improved pit latrines.
- More than a million households had no access to any type of sanitation system.
- It is also estimated that nearly 4 million households were not linked to the electricity supply network in South Africa.

The Department of Housing realises that minimum standards for basic services are required for new housing projects. It is, however, a proven principle that there are always cost implications for the setting of standards. As a general rule, the higher or more restrictive the standard, the higher the cost to the community as a whole. There may be instances where alternative standards that do not meet the accepted norms may have to be considered.

5.1.6 Conclusion

Within the national and international policies outlined in this section, there exists a strong possibility to implement the *Solar Heat Barrow* with the approval of all the departments tasked with the provision of basic services. The addition of a water disinfectant dispenser may just give the product a profile for it to be formally included in the options offered to especially the poor communities.

A pre-requisite to this would, however, be the proven ability of the *SHB* to deliver on its promises, both for water heating and for water disinfection. Acceptance by actual users will be of great value in this quest.

5.2 Evaluation of prototype units

Laboratory tests have been performed to determine the heating performance of the *Solar Heat Barrow*. A second prototype batch of 15 *SHB* units was manufactured to be implemented in a rural community for a test period of 2 months. Together with the implementation of the units the socio-economic response of the users were monitored to determine the need for this product in rural communities. Due to budget limitations, the units were evaluated without the disinfectant dispensers.

The results of this evaluation were published by Le Roux (2003) in an Eskom research report. As the sponsoring agency for this evaluation, they had full entitlement to this data.

5.2.1 Objectives and approach

Certain questions needed to be answered by the use of the *SHB* in a typical rural community. These questions were as follows:

- The daily use of hot water.
- The response of the users of the *SHB* regarding its operation, durability, utility and satisfaction of needs.
- To what extent the target community would purchase the *SHB*.

- If a business case could be developed for the *SHB* as a product to this typical community.

To obtain these answers, a suitable study area was selected (see paragraph 5.2.2 of this dissertation) and 15 households used the *SHB* units for a period of 2 months at the end of 2002. Before, during and after the test period the users and other members of the community were interviewed to establish their socio-economic status with respect to biographical data, conventional forms of heating and transporting of water, opinion and perception of the *SHB*, and the quality, durability and the need for the *SHB*.

Three types of questionnaires were given to the people of the pilot site. The first questionnaire went into the community before the two month test period started. It focused on biographical information which included conventional ways of heating and transporting water for domestic use. The perception of the people about a product that can transport and heat water for domestic use was also tested.

The second questionnaire was given to the 15 households who used the *SHB* one month after the test period started. The aim of this questionnaire was to obtain feedback from the users about the suitability of the *SHB*.

The third questionnaire was also given to the 15 user households after the two month test period had been completed. The aim of this questionnaire was to obtain the opinion of the users about the product as well as to gather information about the quality and durability of the *SHB*.

5.2.2 Study area characteristics

The rural community of Mabedlane in the Valley of a Thousand Hills in KwaZulu Natal was selected as the demonstration site for the field evaluation. It is a remote rural area 20 km's north of Botha's Hill and is situated along the Umngeni River. The community is to a large extent dependent on the river for domestic water. Women head most families. The area has low levels of infrastructure, poor roads, a high unemployment rate, and poor health facilities.

The first survey, which was conducted before the test period started, showed a very positive response from potential users. Out of 112 responses by households of

Mabedlane, all indicated that they were interested in a product that can transport and heat water for domestic use.

Figure 5-1 shows that 69% of the households collect their water for domestic use from the Umngeni River, and that 46% of the respondents indicated that they have a water tap in the house. It is interesting to note that 15% of the households depends on both the piped water and the river for water for domestic use. This may mean that the piped water supply may not be functioning all the time.

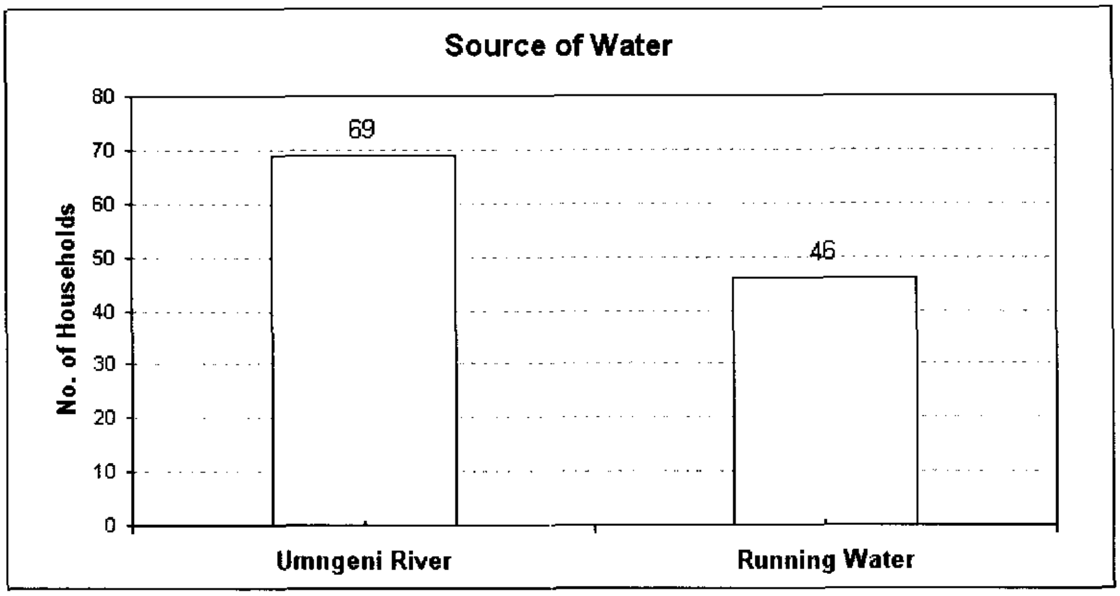

Figure 5-1: Sources of water in Mabedlane

The survey also showed that 81% of the people of Mabedlane collect water twice and more per day (Figure 5-2). The average distance covered to collect water for domestic use is more than 2 km, far more than the goals of the Government. This harsh condition puts a burden on rural women and children who have to carry plastic containers filled with fresh water over these long distances

The survey indicated that 64% of the people collecting water were teenagers between the age of 11 and 19 years of age, 37% of the people were between the age of 20 and 29 years. Only 12% of the people were younger than 10 years and older then 60 years of age. This is shown in Figure 5-3.

It was further established that 39% of the households use between 10 and 25 litres of hot water per day, while 34% indicated that they use between 25 and 50 litres of hot water per day. This usage volume correlates fairly well with the 25 litres design volume of the *SHB*.

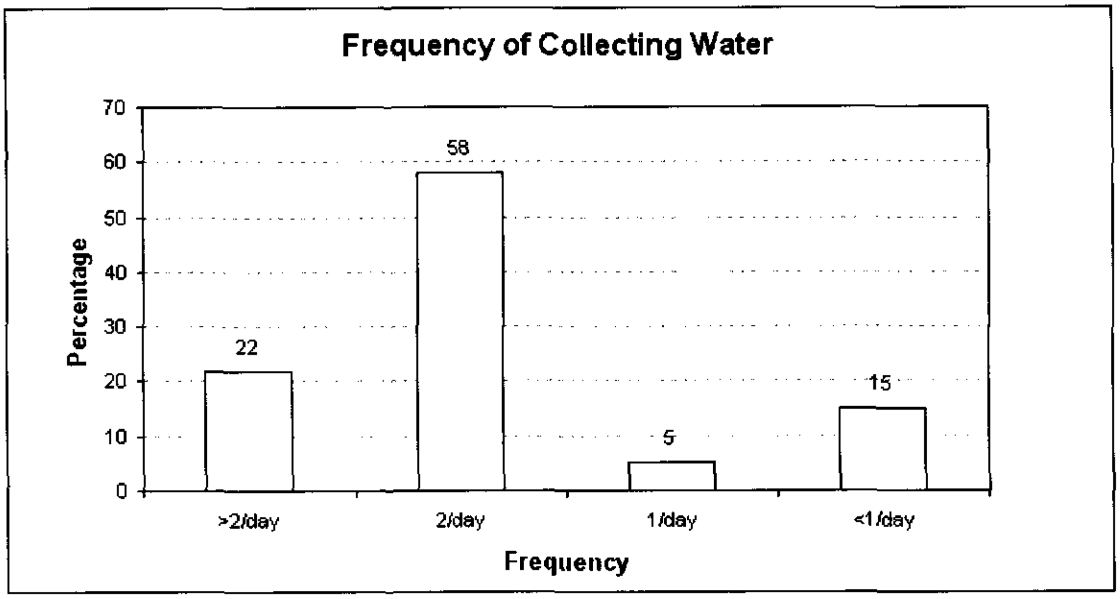

Figure 5-2: Daily frequency of fetching water

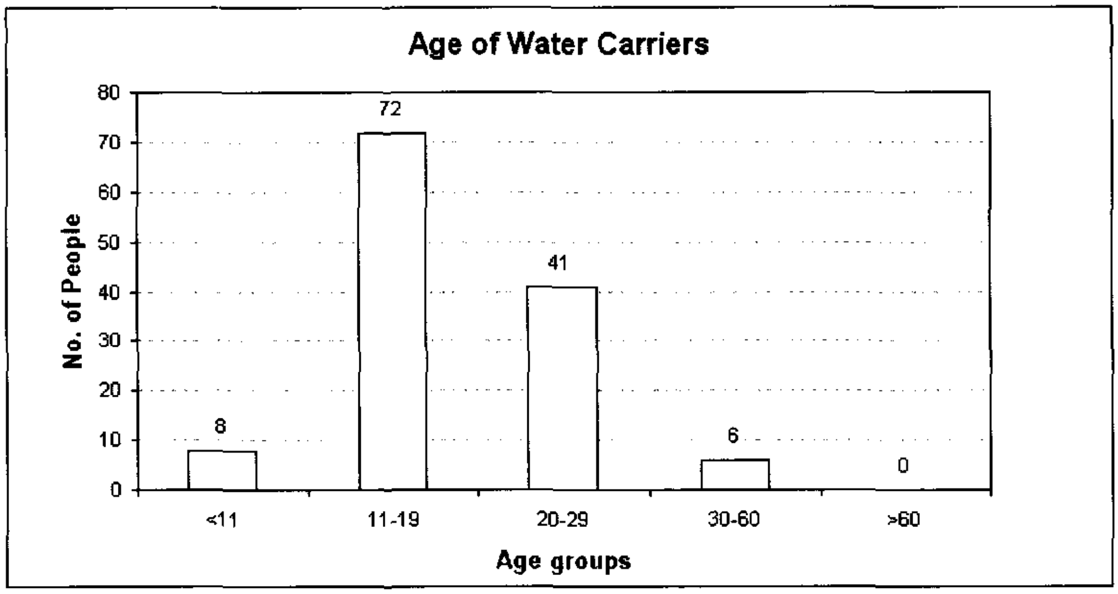

Figure 5-3: Age of people who are responsible for fetching water

The survey showed that more than 75% of the people are still using wood or coal to heat water for domestic use. Only 11% of the households have access to electricity. The remaining houses use paraffin and LP gas in about equal proportions.

The time that people use hot water is important to ensure that the original design specification (hot water at 40°C at 20:00) is realistic. From the 112 households, 90% indicated that they required hot water in the mornings, 34% in the afternoon and 57% in the evening. These responses provide a total in excess of 100% as multiple responses were allowed.

People were asked to indicate the uses of hot water. Figure 5-4 provides this information for the morning, afternoon and evening uses. Bathing has the highest priority in both the morning and evening.

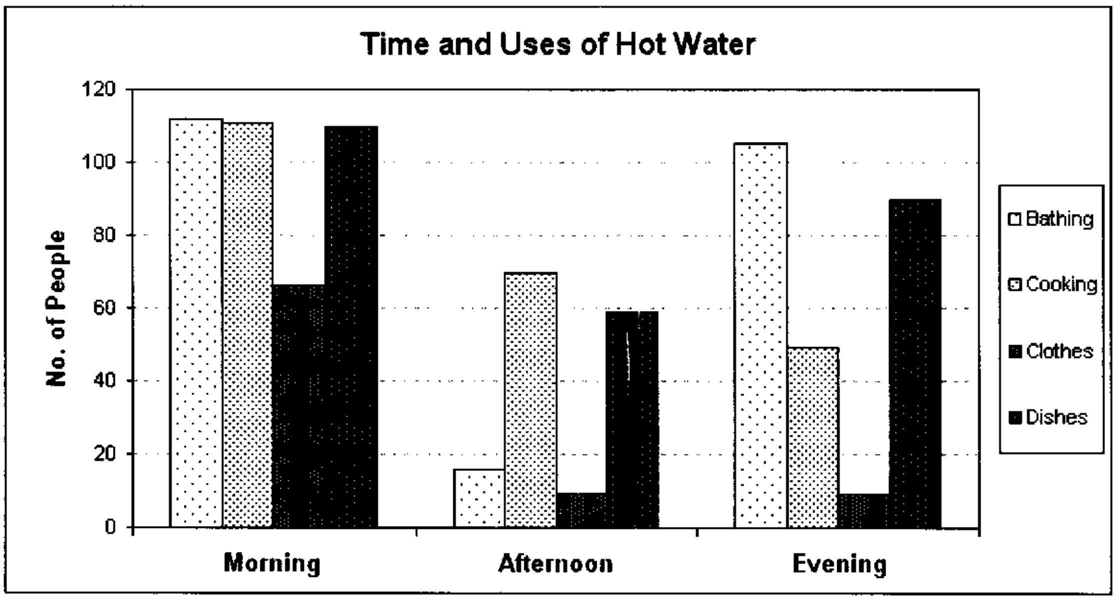

Figure 5-4: The uses of hot water and the time of day when it is used

The socio-economic study showed that the 85% of the people who participated in the survey indicated that they could only pay less than R100 for the product. The other 15% indicated that they would be able to pay between R100 and R200. There is definitely a need in this rural area for a water carrier that can heat the water for domestic use, but the unit price needs to be as low as possible, and must probably be subsidised to make it affordable for the users.

It is important to correlate this result with the annual income of the potential users. The survey showed that 42% of the households have a monthly income of less than R200. 24% of the households have a monthly income of between R200 and R500 and 23% between R500 and R1 000. Only 11% have an income of more than R1 000 per month. Figure 5-5 shows this result graphically.

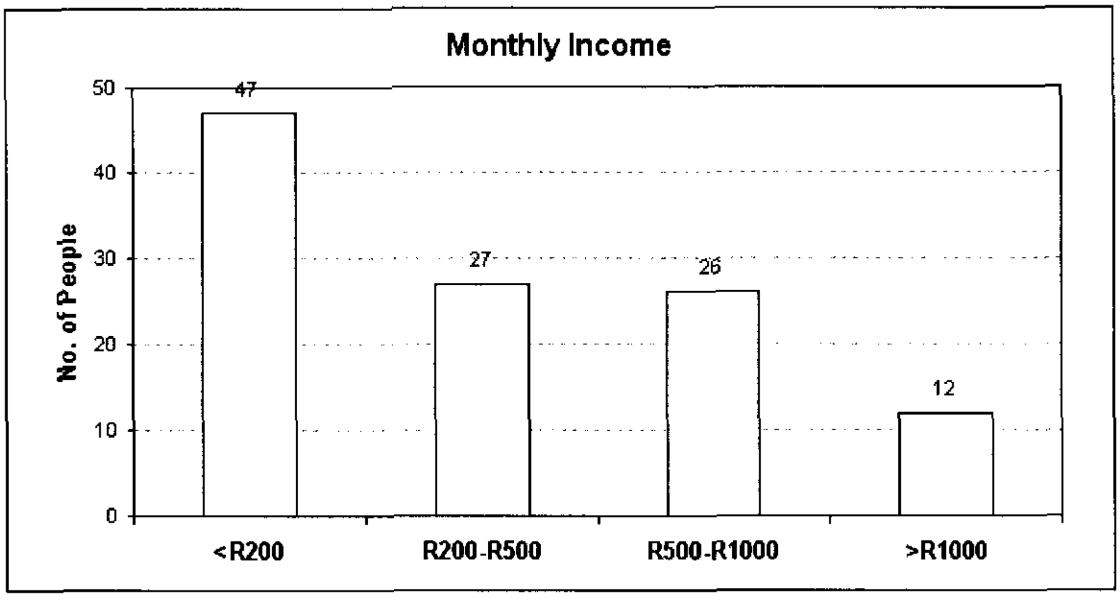

Figure 5-5: Monthly income of households interviewed in Mabedlane

5.2.3 <u>User impressions</u>

Response to the second and third questionnaires indicated that the users were exceptionally happy with the heating and transporting perfomance of the *SHB*. All the households indicated that the *SHB* heat the water warm enough, in fact the people were amazed to see how warm the water from the unit was at peak times during the day. All the participants indicated that they were using less wood and coal for the heating of water.

The only problems experienced by users were slow water leaks from the spout caps of 8 units during the transport of water. A better type of seal arrangement will have to be provided for units in the future.

All 15 households indicated that they were interested in purchacing *SHB* units. All of the households also indicated that their neighbours and friends who have seen how a

SHB unit works were likewise interested in buying the product. However, when the people were asked what they were willing to pay for a unit, the answer was very much the same as the answer obtained from the first questionnaire.

Two households indicated that they were only able to pay less than R50 per unit. The rest of the households indicated that they were able to pay between R50 and R100 per unit. From these results it is apparent that the people who need a *SHB* most, will not be able to pay the full retail price.

Figure 5-6: User with *SHB* in Mabedlane (Natal) with typical domestic bowls into which water is poured

5.2.4 Comparative results

In the survey conducted by Taylor (2001) around Pretoria, most of the respondents, if they had work, were employed in and around the city. By contrast, the people in Mabedlane had high unemployment and a more agricultural way of living. The difference in responses in the two surveys should be taken into account for the marketability of the *SHB*.

If we compare the energy sources used for heating water, the urbanised population had more access to electricity and fluid fuels such as paraffin than the people of Mabedlane. Here more than 75% of the population still depended on wood and coal as the primary fuel. Only 11% of the households have access to electricity to heat water versus 43% of the peri-urbanites. The comparison in the fuel usage is shown in Figure 5-7.

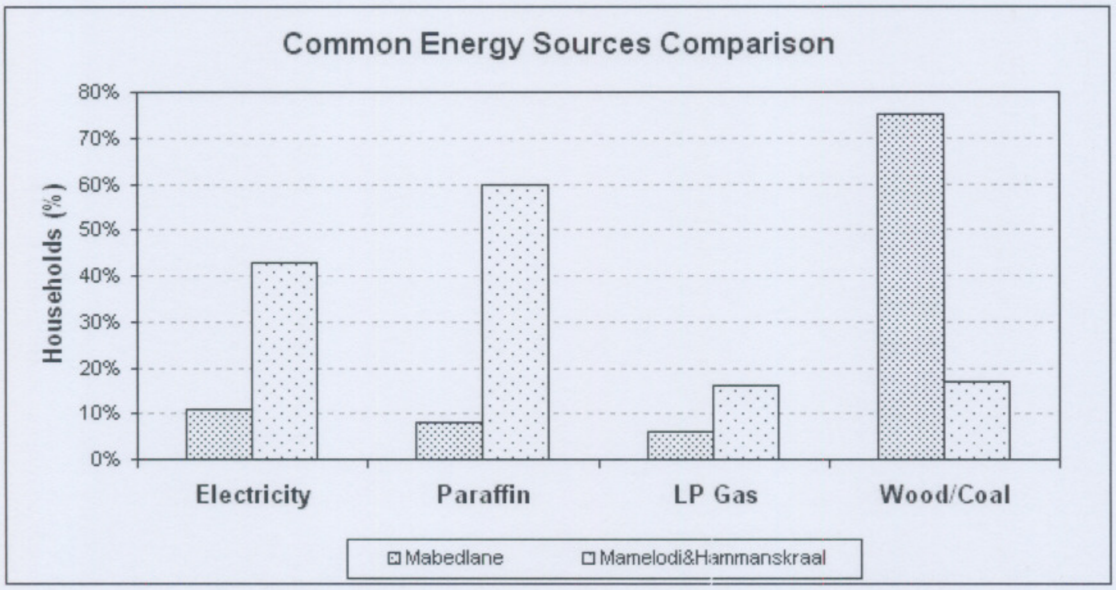

Figure 5-7: Comparison between Mabedlane and Pretoria informal settlements with respect to water heating energy sources

Piped water to the two areas was, however, found to be on a similar level, 49% for the Pretoria area and 46% for Mabedlane. The big difference was, however, found to be in the distance people had to cart water if they did not have access to piped water in the household. Whereas Mamelodi and Hammanskraal residents had access to communal taps less than 200 m away on average, the Mabedlane residents had to cart water from the Umngeni River over 2 km away.

The biggest discrepancy between the two surveys is the price people are able or willing to pay for a *SHB* unit. The majority of the Mabedlane residents were only able to pay up to R 100 for a *SHB*, with only 15 % indication a willingness to pay more than R 100. In contrast, 21% of the Pretoria area residents were willing to pay up to R 300, while 10% were willing to pay more than R 300.

It thus seems that people in rural communities, living further away from the city, will not be able to pay the same price as people living and working closer to cities. This will in all probability also be true for residents of other countries in Southern Africa. It could be expected that the further people live away from South Africa, the less they will be able to pay for a *SHB*. The tragedy is that these people probably need this or similar products the most.

The field evaluation of *Solar Heat Barrows* in Mabedlane can also be compared to a comparative study by Biermann *et al* (1999) on the acceptance of 7 different solar cookers by 66 South African rural households in 3 study areas.

They have found that solar cookers reduced wood consumption by approximately 38% in their study groups. By placing a value on the time saved in collecting wood, they argued that the payback period of the cookers could be as low as 8 months. The downside of this argument is, however, that the person buying the unit would have to convert that saving in time into money. This is no easy matter in areas already bearing the brunt of high unemployment and low economic activity.

The study does present valid conclusions though. An important realisation was that, since most user-related evaluations have been carried out by the manufacturers or designers themselves, rather than by independent observers, there has been differences in opinion on the user acceptance of solar cookers, and on the type of solar cooker that is best accepted.

A conclusion that can be made from the positive outcome of their study with regards to solar cooker acceptance, is that, once people are familiar with a simple solar technology device, they will use it because it makes their life easier. Like for the *SHB*, the greatest barrier for the large-scale use of these devices is the price. People who need it most cannot afford to buy it.

5.2.5 Conclusion

In general, people in the Mabedlane community showed great interest in the *Solar Heat Barrow*. It was established that most people would like to use the *SHB* both to collect water and also as a heating device. This implies that the initial concept was successful in meeting the specified objectives.

From the responses to the second and third questionnaires it was clear that the users were satisfied with the water heating performance of the *SHB*, and were very interested in purchasing a *SHB*.

The only area where implementation of the *SHB* may be impaired is in the pricing. People living closer to a city generally have a higher income and more exposure to urban development. They have less time available because of their fixed working schedule and time required for commuting. They will therefore be more willing to try new appliances that aid them in saving money, time or effort. As a result, the price that they will be prepared to pay will also be higher.

However, the poorer people will probably benefit the most from using the *SHB*. From the results off the three questionnaires distributed in Mabedlane it is apparent that people who will benefit most from a *SHB* are the people who will not be able to pay the full retail price.

5.3 Potential marketing options for *SHB*

5.3.1 Acceptance of solar technology

The acceptance of a new technology by a community of possible users depends on several factors. If solar water heating was used by the general affluent society, it would have been something that people would have become used to, and even could aspire to.

At present there is very little incentive for the affluent society to use solar water heating in Southern Africa. Electricity and electric domestic water heaters ('geysers') are both relatively cheap (Kok, 1994). There is also no tax rebates or other advantageous financial schemes, and the decision to invest in solar domestic water heating is often made on emotional issues or a genuine environmental concern.

Innovative incentives will have to be offered to rural communities to inspire them to use low cost SDWH. Peter *et al* (2002) investigated this subject for the general acceptance of solar technology by rural communities in developing countries. The purpose of the study was to identify the factors that influence the adoption of solar-based technologies.

They proposed a conceptual framework for the adoption of new technologies as shown in Figure 5-8, and concluded that the adoption decision was heavily influenced by interest and familiarity. For this to happen, a broader framework of social, technological and economic factors first had to be installed: The most important of these were found to be:

- financial incentives
- government led initiatives
- reduction of investment costs
- increase in product reliability
- dissemination of information, and
- environmental awareness

All of these factors are represented in the conceptual framework.

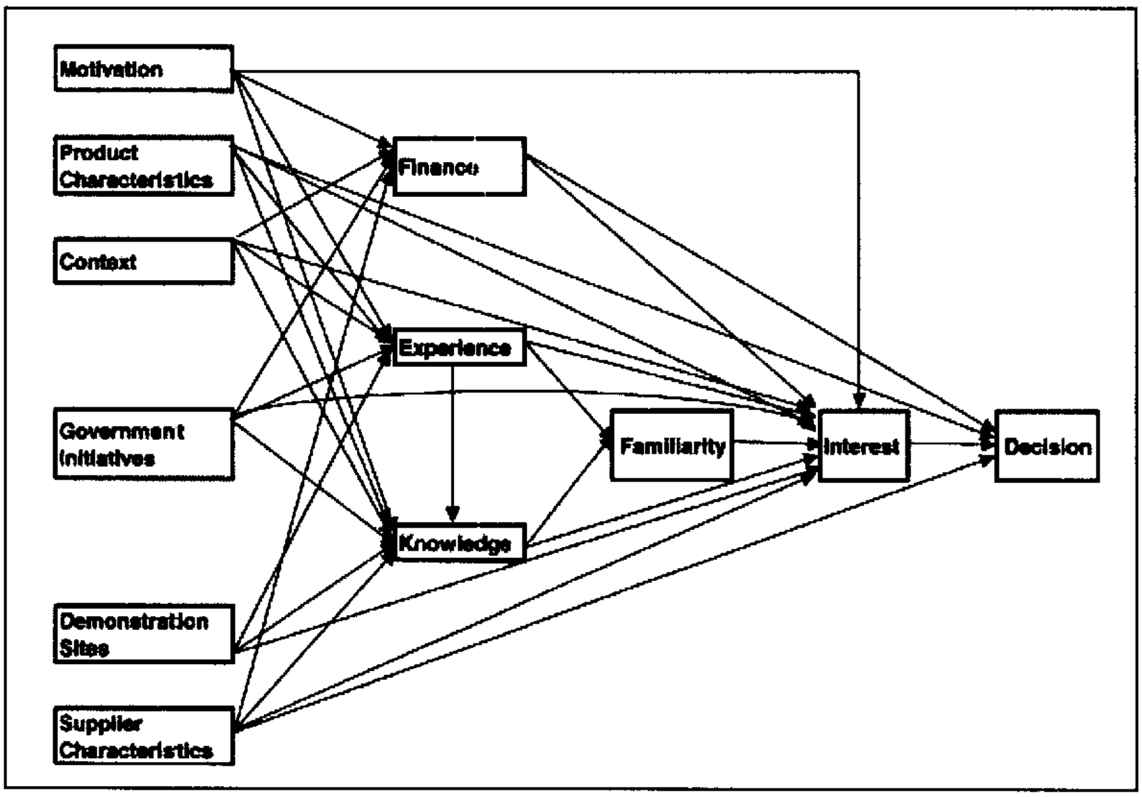

Figure 5-8: Conceptual framework for the adoption of solar based technology (Peter *et al*)

Role of government

The government can play a leading role in the adoption of solar technologies by formulating favourable policies (as described in paragraph 5.1 of this dissertation). Government can also show a practical commitment through pilot projects, and by enhancing public awareness of the potential of solar technologies in all walks of life. Often, the majority of the people constituting the potential market are unaware of the existence of systems and their capabilities.

Knowledge

Three types of knowledge are relevant to a potential adopter of a new technology: *awareness*, *how-to*, and *principles* (Peter *et al*, 2002). Awareness precedes the others. When a potential adopter perceives that an innovation can solve a problem, he or she begins to seek information about its operation, its features and its application to the situation. The information obtained is classified as "how-to" knowledge. Principles knowledge refers to information about the principles that make the innovation work. An example is the basic theory of solar energy conversion into heat.

Finance

Financial schemes and financial support are essential for the dissemination of new technologies into a community. The capital needs, in relative terms, are equally high for the investor or manufacturer on the one hand, and for the user on the other. Financial institutions are not always interested in giving or opening lines of credit for private investors in for example solar water heating technologies.

In India, the government recognized the limitations of conventional banks and set up the Indian Renewable Energy Development Agency (IREDA) in 1987 to finance new renewable energy technologies (Peter *et al*, 2002). The budding domestic solar energy capacity in India is due to the considerable guaranteed funds from this government agency.

Multinational and national donors can also supply funds for financial assistance. Examples such as the Global Environmental Fund, The World Bank, and USAID have sponsored programmes that have led to the formation of promising renewable energy markets in developing countries. In South Africa some funds could be obtained from local instances such as Eskom, the Government itself through rural development funds, and from countries supporting development in developing countries, such as the USA, Canada, Japan, Australia, the European Union, the United Kingdom, Germany, Denmark, Holland, Norway, and others.

The most consistent financial incentive, however, remains the price of a device. If the potential users can afford a device or appliance, and the manufacturer can still make an acceptable profit, no other financial incentives are required. This is then the driver for a supplier to reduce his or her costs as much as possible, amongst others by using applicable technologies for the manufacturing of his or her products.

Nahar (2002) showed how this could be done by redesigning a standard flat plate solar domestic water heater for manufacturing from materials with a low cost and high availability in India. The resulting unit, with a similar performance, was more than 20% cheaper than the original unit.

5.3.2 Direct sales

The first obvious marketing option for the sale of *Solar Heat Barrows* and disinfectant *Dispensers* is a direct sales approach. This may mean direct sales to users, sales to dealers who then sell to users, or sales through a network of agents working on a commission basis.

The first problem expected with a direct sales approach is in the way of informing people of the existence of the product. An expensive conventional advertising campaign may not be successful, because the target market for these devices has limited access to the general media. Formal dealers are also relatively scarce in the rural areas of Southern Africa, and may only buy a few units due to the risk and cost involved in keeping stock.

Using a network of formal and informal agents could, however, stimulate a product awareness through the distribution of relatively cheap printed leaflets and, more importantly, through the demonstration of actual units to the prospective buyers. The formal agents could be the same dealers mentioned previously, but they will not have to carry stock, thus reducing their risk.

Informal agents could be organised in a similar model to the well-known '*Tupperware*™' agents operating in South Africa. Orders could be placed, deposits paid, and units delivered in batches to the agents for delivery to users on full payment. These agents could also act as training officers to the users, and should be able to perform the few small maintenance tasks that may arise from time to time.

This method is thought to be a relatively slow way of breaking into a market. It will require a detail viability study, and the establishment of an initial network of agents will have to be targeted where the highest sales could be expected. It may also be possible to obtain some form of assistance from Government via the small, medium and micro enterprises (SMME) development funds (DTI, 1995), especially in the establishment of the distribution network of agents.

An aspect that has to be considered is the transport of especially the *Solar Heat Barrows*. While *Dispensers* are small and will be easy to transport, the *SHB* is a relatively bulky unit. If it is transported in a 'knocked-down' fashion as envisaged in paragraph 4.4.1 of this dissertation, the agents will also have to be trained to perform the final assembly of the units on site. This would, however, not be an intricate procedure, and would require a very small investment in one or two standard hand tools. These same tools (a medium wrench and a screwdriver comes to mind) would probably also be required for maintenance.

In the case of the *Dispenser*, the distribution of the disinfectant (*Steripure* is envisaged in this case as described in paragraph 3.3.2 of this dissertation) could also be managed by either of the two types of agents.

5.3.3 Commercial enterprise sponsoring

A second marketing option for the sale of *Solar Heat Barrows* and disinfectant *Dispensers* is the sponsoring, in full or in part, by commercial enterprises. Companies in the soft drink, fuel, washing powder, automotive, or any other consumer related market sector may see an advertisement opportunity in having branded *Solar Heat Barrows* and/or *Dispensers* manufactured and distributed in target areas. Even tobacco and liquor companies might see the opportunity in this strategy, although the associated health warnings on the devices may seem quite out of place!

Batches of devices manufactured under these sponsoring schemes would in all probability be in special unique colour schemes, easy to relate to the product or brand being promoted. In an interesting study by Tripanagnostopoulos *et al* (2000), the researchers showed that coloured solar absorbers might be utilised with surprising little negative impact on the overall efficiency of a solar water heater. The efficiency of these collectors can be close to that of collectors with black absorbers if colours of dark tone with an absorptivity of 0.8 are used. Several dark blue, green and brown hues are suggested as suitable. Although more experimentation will have to be conducted, it could offer a further branding option to interested sponsoring enterprises.

Pricing of these special batches of devices would have to be adjusted according to the size of the batch as well as to the complexity of the additional features to be added to the devices. The opportunistic marketing and resulting public awareness of the *SHB* and *Dispenser* as products could also benefit by careful canvassing and selection of potential sponsoring companies. This may also be an ideal opportunity for establishing demonstration sites early in the product life cycle.

One negative aspect of this strategy could be due to the fact that commercial enterprises usually conduct advertising campaigns over limited periods. This may lead to a situation where users of the devices end up without any support infrastructure for maintenance or the re-supply of disinfectant. This in turn may have a negative effect on the market perception of the products.

Any such limited period commercial enterprise sponsoring would thus have to be followed up with a sustained support of the devices in use. This may have to be reflected in the original price of the devices to the sponsoring enterprise.

5.3.4 Institutional sponsoring

Direct or indirect institutional sponsoring may be the best marketing option for the *Solar Heat Barrow* and the *Dispenser.* Institutions may be state departments, aid organisations, donor countries and development organisations as identified in paragraph 5.3.1 of this dissertation.

An interesting opportunity may be on the cards in South Africa in the form of the possible Integrated Energy Centers promoted in the 2002 *Budget Vote Speech* of the Department of Minerals and Energy (DME, 2002[b]). Integrated Energy Centers are designed to provide a one-stop service regarding access to affordable and reliable energy carriers for rural and peri-urban communities. The centres are also intended to provide an economic push for community development, linking energy sector provision into local economic development. With the help of corporate sponsors the government planned to open seven such centres in 2003. Total, Sasol, and PASASA (Paraffin Safety Association of Southern Africa) are contributing to these centres. If the *SHB* and *Dispenser* can be sold and supported through these energy centres, many of the distribution and infrastructure problems will be solved.

Other institutions that should be targeted are those active in poverty relief, health programmes, refugee housing and disaster management in other parts of Southern Africa. The United Nations organisations especially may be the most likely sponsors. Institutions may even stockpile devices for rapid deployment to the often-occurring epidemic outbreaks of, for example, cholera in Southern Africa.

One of the main advantages of institutional sponsoring would be the longer time span of the projects and interventions under their control. This could lead to a proper support and infrastructure base for the devices on offer, and user confidence should be maintained.

5.4 Commercial viability

5.4.1 Potential market size

At a first glance the market for rural solar domestic water heating seem to be huge. Southern Africa has and estimated population of more than 120 million people. If we use an average of 6 people per household (slightly higher than the South African average of just below 5) this population translates to about 20 million households. If only 10% of these households would buy these appliances, the market size for rural solar water heaters would be 2 million units. The *Solar Heat Barrow* with *Dispenser* would thus compete for a share of this market.

A more conservative estimate would be to use the market size estimate for rural solar domestic water heating of Mathews and Rossouw (1997). They followed the argument that the size of the market can be based on a system that targets the women in rural households, because they, together with their children, perform the household tasks such as gathering wood and water. Out of an estimated 3 million rural women collecting wood daily in South Africa alone, they estimated that 1 in 5 could be reached with solar water heating. This would thus create a potential market of about 600 000 rural solar domestic water heaters for rural South Africa alone.

These 600 000 women form 1.5% of the estimated South Africa population of 40 million people.

In the white paper on *A New Housing Policy and Strategy for South Africa* (DOH, 1994) the income distribution of households in South Africa are estimated as shown in Table 5-1. If half of the households in the two lowest income groups are assumed to be the rural and peri-urban poor without basic services, we again reach nearly 3 million households. This correlates well with the number of households that could use solar water heating as estimated in the previous paragraph.

Table 5-1: ESTIMATED 1995 HOUSEHOLD INCOME DISTRIBUTION IN RSA (DOH)

No.	Income Category	Percentage	No. of Households
1	R 0 – R 800	39.7%	3.30 million
2	R 800 – R 1 500	29.0%	2.41 million
3	R 1 500 – R 2 500	11.8%	0.98 million
4	R 2 500 – R 3 500	5.6%	0.46 million
5	> R 3 500	13.9%	1.15 million
TOTAL		**100%**	**8.3 million**

Scrutiny of the household structure by the Department of Housing (DOH, 1994) as presented in paragraph 5.1.5 of this dissertation, and again assuming half of the rural poor, squatter and informal households could use solar water heating, reveals the same number of approximately 3 million households.

This figure of 3 million can thus be used as a reasonably robust estimate of the number of rural South African households that could, as an upper limit, be open to solar domestic water heating. A penetration of 1 in 5 of these households with solar water heating would probably be possible with the right incentives, as was proven in Cyprus (Mathews & Rossouw, 1997).

If it is assumed that the market potential for the rest of Southern Africa is the same at 1.5% of the total population, it brings the total potential Southern African market for rural solar domestic water heating to approximately 1.8 million units. This value correlates well with the earlier quick estimate of 2 million units. It does, however, supply a better basis for the distribution of the market potential that one could assume in each Southern African country. This distribution is shown in Table 5-2.

5.4.2 *SHB* Market penetration

As shown previously, the total potential market for solar domestic water heaters in rural Southern Africa is an estimated 1.8 million units. It would be pleasing if the *Solar Heat Barrow*, with a *Dispenser* for every *SHB*, could capture this whole market. But that would be wishful thinking.

Table 5-2: ESTIMATED MARKET POTENTIAL FOR *SHB* IN SOUTHERN AFRICA

Country	Population	Potential Market	Market Penetration	No of Units
	(Million)	(1.5% of Pop.)	(%)	(Total)
RSA	40	600000	10	60000
Lesotho	2	30000	5	1500
Swaziland	1	15000	5	750
Namibia	1.6	24000	5	1200
Botswana	1.5	22500	5	1125
Zimbabwe	11.5	172500	2.5	4313
Mocambique	18	270000	2.5	6750
Angola	12	180000	1	1800
Zambia	9	135000	1	1350
Malawi	10	150000	1	1500
Madagascar	15	225000	1	2250
TOTAL	121.6	1824000	4.53	82538

An assumed market penetration for the *SHB* is shown in Table 5-2. In South Africa, with the best-developed infrastructure and as the base of manufacturing and distribution, the *SHB* should be able to capture at least 10% of the potential market.

The relatively rich and closely situated markets of Lesotho, Swaziland, Namibia and Botswana should yield at least a 5% penetration of potential. Zimbabwe with its current economic problems should yield 2.5% of its potential, and Mocambique could be penetrated with this same value.

The other Southern African countries (Angola, Zambia, Malawi and Madagascar) are assumed to only yield 1% of its potential to the *SHB*. Serving these countries would be complicated due to distance and poor infrastructure.

This distribution of penetration of the potential market is shown graphically in Figure 5-9. South Africa, with an estimate market of 60 000 *Solar Heat Barrows*, accounts for nearly 73% of the total assumed market of 82 538 units.

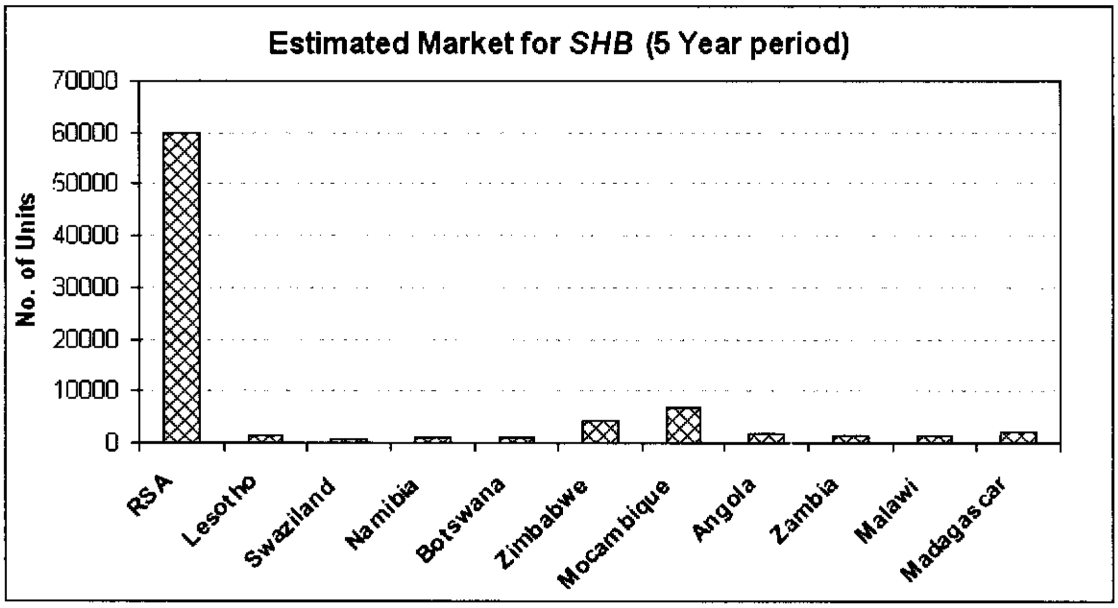

Figure 5-9: Estimated *SHB* market in Southern Africa over a 5 year period

It is further assumed that a five year window exists for this penetration to be achieved, and that total sales will follow a simple S-curve distribution over this period. This provides a basis for planning for the production of *Solar Heat Barrows*, and is shown in Figure 5-10. The S-curve is assumed to follow a 10% – 20% –40% –20% – 10% distribution over the five years.

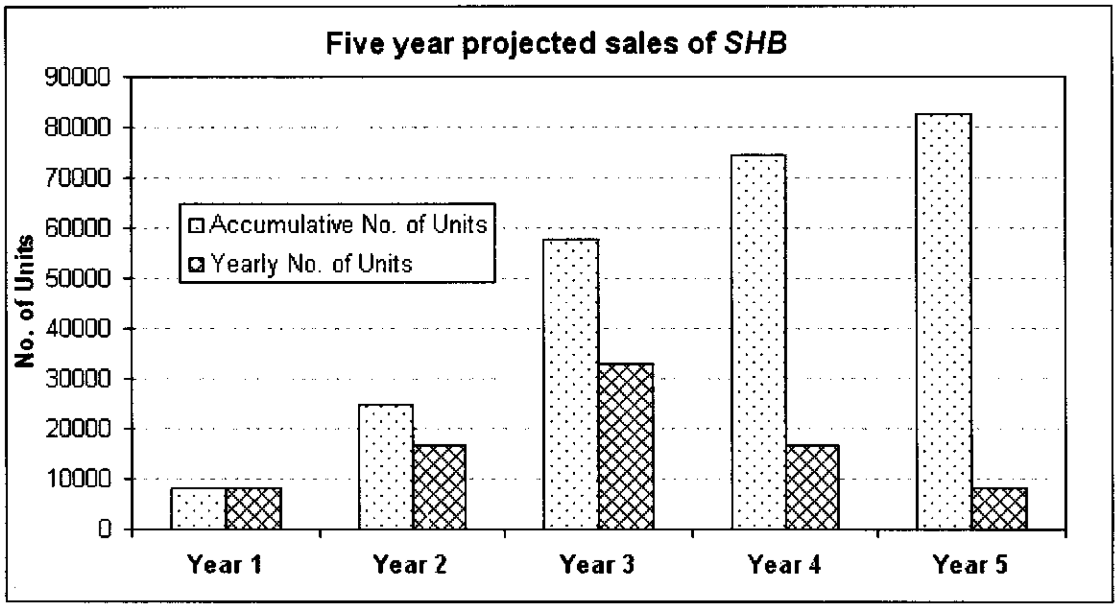

Figure 5-10: *SHB* Projected sales over 5 years to S-curve distribution

For the purpose of this study, it is assumed that a *Dispenser* will be manufactured and sold for every *SHB*. While it will not be necessary to fit a *Dispenser* to every *SHB*, the balance of the units should be relatively easy to sell to related markets.

5.4.3 <u>Market price of devices</u>

The socio-economic surveys around Pretoria (Taylor, 2001) and in the Mabedlane community in 2002 suggest that the general expectation of the price of the *Solar Heat Barrow* is very low.

In paragraph 4.4.3 the basic cost price of initial units produced at a rate of 1 000 units per month was determined to be about R380 per unit. Added costs for development, distribution, financing and commission, and a reduction in basic costs in later production (see paragraph 5.4.3 of this dissertation), suggests that a minimum selling price for a *SHB* would have to be in the vicinity of R600 per unit to have any chance of commercial success.

Although this price is double the early target price estimates it still compares favourably with the price of nearly R1 000 advertised for units similar in size and performance offered in a pilot project in KwaZulu Natal (see paragraph 2.1.1 of this dissertation).

The basic cost price of disinfectant *Dispensers* was investigated in paragraph 4.4.4 of this dissertation. If also produced at a rate of 1 000 units per month, this cost would be nearly R80 per unit initially. Added costs, and a reduced basic cost in later production, would suggest a minimum initial selling price of around R100 for a unit. This is a high price for a seemingly simple device; however, the production techniques suggested would be quite sensitive to economies of scale. A tenfold increase in the number of units produced could lead to a basic cost of less than R25 per unit. If a ready market for these extra units could, however, be found to justify the production of the *Dispenser* in these numbers, the selling price could be reduced to below R50 per unit.

The prices of the units used for analysis in this study would thus be as follows:

- *Solar Heat Barrow*: Sold at R600 throughout the product life.
- *Dispenser*: Sold at R100 throughout the product life, assuming the costs for low production volumes equivalent to the *SHB*.

The challenge in obtaining a viable income from the devices at these suggested prices would be to obtain the maximum benefits from sponsoring and financial incentives. This income should be used to attempt to subsidise the selling price of a *SHB* preferably to below R300 per unit, and a *Dispenser* to below R50.

5.4.4 Profitability of *SHB*

Based on the manufacturing cost and the price of the units, and assuming the market penetration as shown in Figure 5-10 over a 5-year period, a very simple financial schedule for the *Solar Heat Barrow* was drawn up. This is shown in Table 5-3.

The additional costs, over an above basic manufacturing cost, are shown as percentages of relevant accumulated costs. The turnover, or total sales, is the simple product of price and the sales budget. The gross profit or loss is simply defined as the difference between the turnover and the total cost. Initial development costs are not included here, but tooling for manufacturing is allowed for in the unit manufacturing cost. In paragraph 4.4.3 the tooling was fully amortised in the cost of manufacturing for the first year.

Marketing

Marketing is shown as a percentage of the manufacturing cost. In the first year 25% is budgeted to introduce the *SHB* to the market. The second year's budget is 15% and the last three years allow 10% of manufacturing cost to marketing.

Operations

The distribution and administration of the product is allowed for under operations costs. Again the first year's budget is higher at 20% of manufacturing cost, with 15% of manufacturing cost allowed for the balance of the 5-year period.

Research and Development

After initial development, the budget for R&D of the *SHB* is set at 15% of manufacturing cost for the first year, 7.5% for the second year, and 5% for the third and fourth years.

Table 5-3: SIMPLE COST TABLE FOR *SHB* PROFITABILITY ESTIMATION

	Year 1	Year 2	Year 3	Year 4	Year 5
Quantity	8254	16508	33015	16508	8254
Cost/Unit	R 400.00	R 375.00	R 350.00	R 300.00	R 300.00
Sell/Unit	R 600.00	R 600.00	R 600.00	R 600.00	R 600.00
Manuf. Cost	R 3 301 500.00	R 6 190 312.50	R 11 555 250.00	R 4 952 250.00	R 2 476 125.00
Marketing	25% R 825 375.00	15% R 928 546.88	10% R 1 155 525.00	10% R 495 225.00	10% R 247 612.50
Operations	20% R 660 300.00	15% R 928 546.88	15% R 1 733 287.50	15% R 742 837.50	15% R 371 418.75
R&D	15% R 495 225.00	7.5% R 464 273.44	5% R 577 762.50	5% R 247 612.50	0% R -
Base Cost	R 5 282 400.00	R 8 511 679.69	R 15 021 825.00	R 6 437 925.00	R 3 095 156.25
Finance	10% R 528 240.00	10% R 851 167.97	10% R 1 502 182.50	10% R 643 792.50	10% R 309 515.63
Turnover	R 4 952 250.00	R 9 904 500.00	R 19 809 000.00	R 9 904 500.00	R 4 952 250.00
Commission	10% R 495 225.00	10% R 990 450.00	10% R 1 980 900.00	10% R 990 450.00	10% R 495 225.00
Total Cost	R 6 305 865.00	R 10 353 297.66	R 18 504 907.50	R 8 072 167.50	R 3 899 896.88
Profit/Loss	-R 1 353 615.00	-R 448 797.66	R 1 304 092.50	R 1 832 332.50	R 1 052 353.13
% on Turnover	-27.3%	-4.5%	6.6%	18.5%	21.3%
Acc. Turnover	R 4 952 250.00	R 14 856 750.00	R 34 665 750.00	R 44 570 250.00	R 49 522 500.00
Acc. Profit/Loss	-R 1 353 615.00	-R 1 802 412.66	-R 498 320.16	R 1 334 012.34	R 2 386 365.47
Acc. % on T/over	-27.3%	-12.1%	-1.4%	3.0%	4.8%

Finance

This total of manufacturing, marketing, operations and R&D provide a base cost total on which financing is allowed at 10% per annum for the full period.

Commission

Assuming that the marketing model of a network of agents is followed, commission to the agents is budgeted at 10% of turnover for the full 5-year period.

Profit/Loss % on Turnover

This percentage value provides a 'seat of the pants' evaluation of just how deep in trouble, or perhaps not, the manufacturer is for each production year! It is equivalent to the profit margin on sales as defined by Brigham and Gapenski (1991) in Chapter 22 of their book on financial management..

Accumulated totals

The accumulated totals, for turnover, profit or loss, and profit or loss percentage of turnover, again give a first glance evaluation of state of the business. These last two accumulated totals are shown graphically in Figure 5-11 and Figure 5-12.

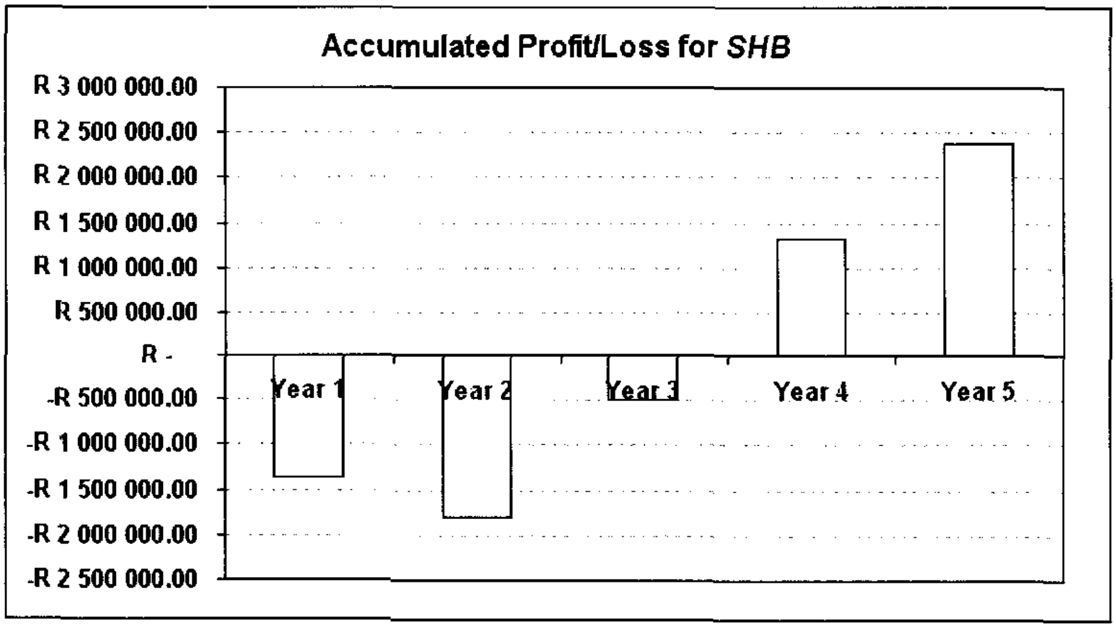

Figure 5-11: Accumulated profitability of *SHB* for a 5 year period

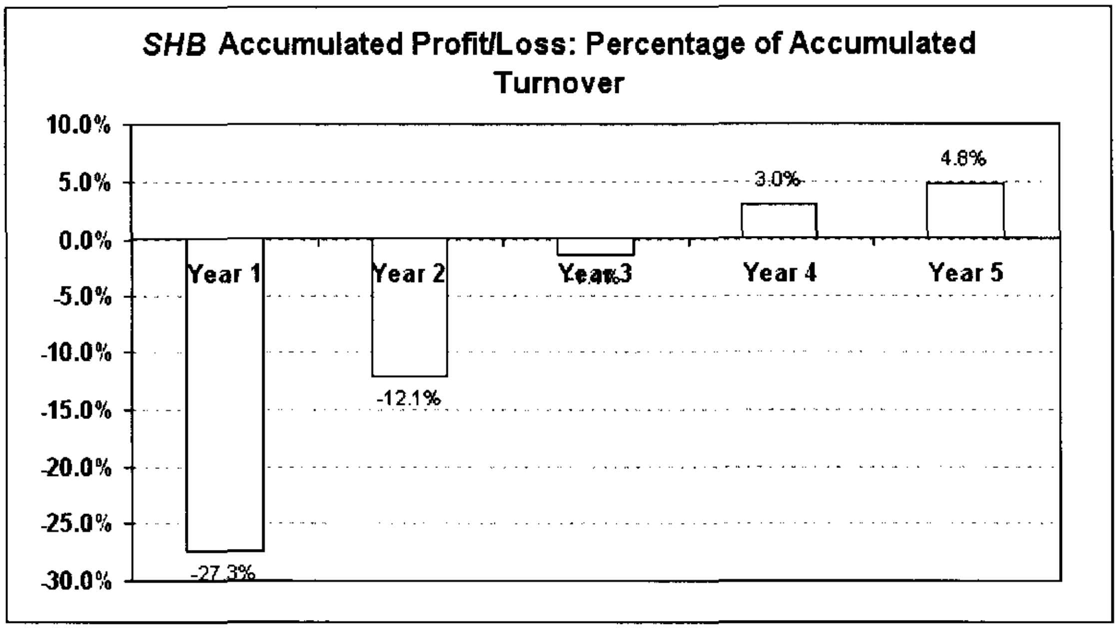

Figure 5-12: *SHB* profitability as percentage of accumulated turnover

Table 5-4: SIMPLE COST TABLE FOR *DISPENSER* PROFITABILITY ESTIMATION

	Year 1			Year 2			Year 3			Year 4			Year 5		
Quantity			8254			16508			33015			16508			8254
Cost/Unit		R	80.00		R	65.00		R	50.00		R	50.00		R	50.00
Sell/Unit		R	100.00		R	100.00		R	100.00		R	100.00		R	100.00
Manuf. Cost		R	660 300.00		R	1 072 987.50		R	1 650 750.00		R	825 375.00		R	412 687.50
Marketing	25%	R	165 075.00	15%	R	160 948.13	10%	R	165 075.00	10%	R	82 537.50	10%	R	41 268.75
Operations	20%	R	132 060.00	15%	R	160 948.13	15%	R	247 612.50	15%	R	123 806.25	15%	R	61 903.13
R&D	15%	R	99 045.00	7.5%	R	80 474.06	5%	R	82 537.50	5%	R	41 268.75	0%	R	-
Total Cost		R	1 056 480.00		R	1 475 357.81		R	2 145 975.00		R	1 072 987.50		R	515 859.38
Finance	10%	R	105 648.00	10%	R	147 535.78	10%	R	214 597.50	10%	R	107 298.75	10%	R	51 585.94
Turnover		R	825 375.00		R	1 650 750.00		R	3 301 500.00		R	1 650 750.00		R	825 375.00
Commission	10%	R	82 537.50	10%	R	165 075.00	10%	R	330 150.00	10%	R	165 075.00	10%	R	82 537.50
Total Cost		R	1 244 665.50		R	1 787 968.59		R	2 690 722.50		R	1 345 361.25		R	649 982.81
Profit/Loss		-R	419 290.50		-R	137 218.59		R	610 777.50		R	305 388.75		R	175 392.19
% on Turnover			-50.8%			-8.3%			18.5%			18.5%			21.3%
Acc. Turnover		R	825 375.00		R	2 476 125.00		R	5 777 625.00		R	7 428 375.00		R	8 253 750.00
Acc. Profit/Loss		-R	419 290.50		-R	556 509.09		R	54 268.41		R	359 657.16		R	535 049.34
Acc. % on T/over			-50.8%			-22.5%			0.9%			4.8%			6.5%

5.4.5 Profitability of *Dispenser*

This section follows the same arguments and assumptions as for the *Solar Heat Barrow*. One *Dispenser* is assumed to be manufactured and sold for each *SHB* manufactured and sold. The simple financial schedule for the *Dispenser* is shown in Table 5-4.

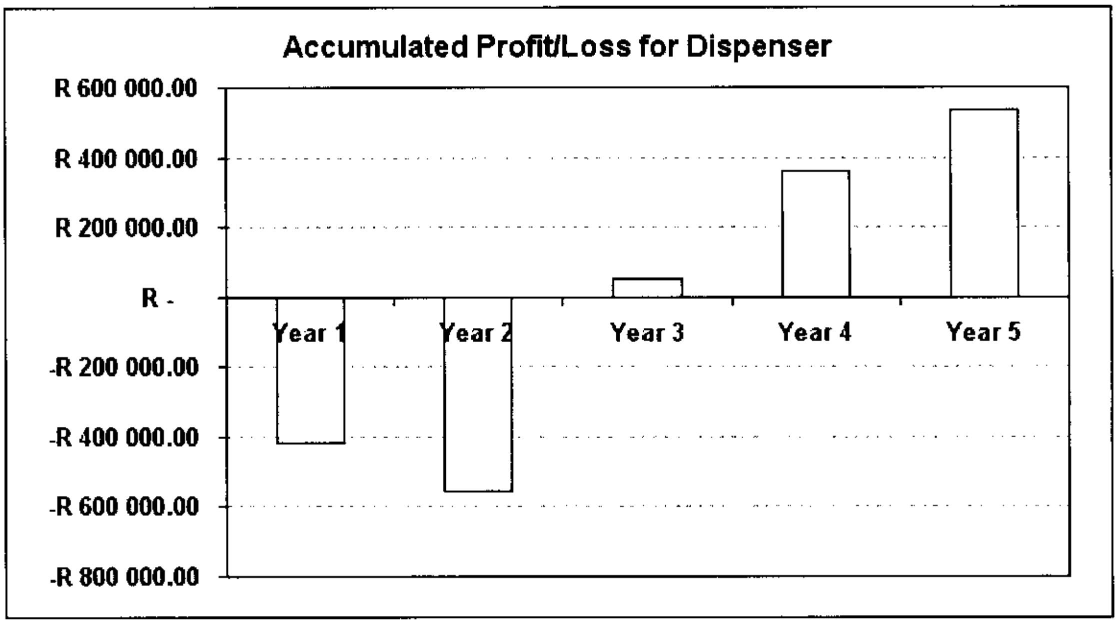

Figure 5-13: Accumulated profitability of the *Dispenser* for a 5 year period

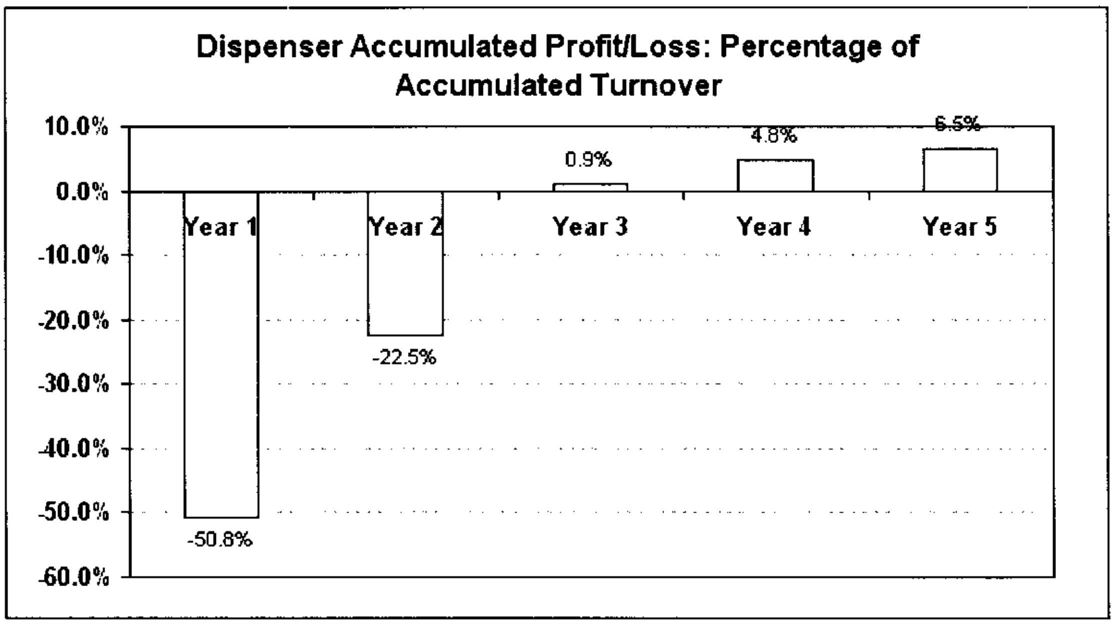

Figure 5-14: *Dispenser* profitability as a percentage of accumulated turnover

Tooling for manufacturing was again allowed for in the unit manufacturing cost, and was also fully amortised in the cost of manufacturing for the first year. Budget costs for marketing, operations, R&D, finance and commissions were calculated on the same basis and percentages as for the *SHB*.

The accumulated totals for the *Dispenser* profit or loss, and profit or loss percentage of turnover, are shown in Figure 5-13 and Figure 5-14.

5.4.6 Product Viability

Several methods are available to financial analysts to determine if a business or a product will be viable or not. All depends on calculating some factors using the following basic steps (Brigham and Gapenski, 1991, Ch. 9):

- Determine the initial cost to get a product off the ground
- Estimate the expected cash flows of the product life cycle, both incoming and outgoing, and its associated risks.
- Determine the cost of capital taking the riskiness of the product in account.
- Put the expected net cash flows on a present value basis.
- Compare the initial cost to get the product off the ground with the present value of the expected cash flows.

The general methods used are payback period analysis, net present value (NPV) analysis, internal rate of return (IRR) analysis, and profitability index (PI) analysis. The NPV method was selected for analysis of this project because the interpretation of the answers show actual value added for the shareholders, instead of just rates or ratios. If the NPV is bigger than zero the project is viable, and the bigger the NPV the more so. If the NPV is negative, the project will make a loss and is not recommended from a commercial point of view (Brigham and Gapenski, 1991, Ch. 9).

The net present value of a project can be expressed as a simple formula:

$$NPV = \sum_{p=0}^{n} [NCF_p / (1 + k)^p] \qquad (5.1)$$

where

NPV is the net present value of the product.

NCF is the net cash flow for a specific time period

k is the cost of capital, as a fraction of 1

p is the time period

n is the life of a product in total number of time periods

SHB NPV

Assuming an initial investment cost of R500 000, a cost of capital of 15%, and using the information from Table 5-3, the net present value of the *Solar Heat Barrow* is calculated with Equation 5.1 to be R412 000 in the positive.

Dispenser NPV

Assuming an initial investment cost of R100 000, a cost of capital of 15%, and using the information from Table 5-4, the net present value of the *Dispenser* is calculated with Equation 5.1 to be R95 000 in the positive.

Epilogue

Though the NPV for both these products are positive, the values are relatively small if the total turnover of nearly R58 million for the two products is considered. Any potential investor would have to enter this market with serious consideration of the risk involved. It would almost be natural to see these products, or devices, as an extension to an existing business, active in the field of general plastics product manufacturing and marketing, rather than as a new enterprise.

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CHAPTER 6: CONCLUSIONS

6.1 Need for *Solar Heat Barrow*

The need for clean domestic hot water has been confirmed. This water is used for bathing, washing dishes, food preparation, cooking, and sometimes for washing clothes. Access to hot water leads to improved hygienic practices, which in turn lead to a higher quality of life and improved health.

A large portion of the Southern African population does not have access to running water in their dwellings. Water has to be carted from communal water sources. Sometimes potable water is available from communal taps. In other cases natural sources of water, not meeting the requirements for human consumption, is the only source available to a community. People are thus exposed to the ailments caused by a large variety of waterborne pathogens, especially in the case of sewerage contamination of the water source.

These people without access to water in their homes normally do not have access to electricity. They use a variety of solid and liquid fuels to, amongst other, heat water. This is expensive in relative terms.

The idea thus originated that an affordable multipurpose device could be of use to people living under these conditions. This device should assist them with the carting of water, its disinfection where necessary, and the heating. With the abundant solar energy available in Southern Africa, a solar water heater was the natural choice for the latter function. This, however, added a functional requirement to the device that hot water should be stored until the middle of the evening at any time of the year.

A device, the *Solar Heat Barrow*, was conceptualised to fulfil this need. To ensure a high level of disinfection, where required, a second add-on device was conceptualised to add a sufficient dose of disinfectant to the water every time it is filled. This device is named the *Dispenser*.

It must, however, be stressed that the success of the final water disinfection will depend to a large extend on the participation of the community to protect their water sources, and to apply simple additional filtering techniques before filling the *SHB*.

6.2 Development of *Solar Heat Barrow*

The development of the *Solar Heat Barrow* started several years ago with experiments on the feasibility of the idea. The development led to the conclusion that an integrated collector storage solar water heater, with insulation and a glazed collector, would be the superior concept. If the unit could further be endowed with the mobility of a wheelbarrow, it should fulfil the original need.

The requirements for disinfection of the water only really came to the fore during the 2000 and 2001 cholera epidemics in Southern Africa. Initial studies showed that the *Solar Heat Barrow* could be of value during these epidemics. The cholera bacteria are so sensitive to heat that even a temperature as low as 45°C destroy them in only an hour.

It was also realised that, for day-to-day use, additional measures over and above the inherent solar water pasteurisation capability of the *Solar Heat Barrow* would be required. This was provided by the second device developed, the *Dispenser*.

Prototypes of both these devices were manufactured. Multiple *Solar Heat Barrows* were tested, evaluated and demonstrated to interested parties. The result of all of this was that it could be said with a high degree of certainty that the device would meet all the requirements that were set for it. Water could be heated to 60°C in winter, and stored for a comfortable bathing temperature of 40°C+ in the evening. Only one prototype *Dispenser* was manufactured, and also proved its functional capabilities.

Some problems experienced, notably with the high dry stagnation temperature on the collector face and the fixing of the glazing, are not deemed serious enough to disqualify the *Solar Heat Barrow* from use. Product development, together with simple usage procedures, can prevent this from happening.

What was clear, however, was that the high standards required for solar water heaters in national and international standards, will be difficult to meet in all respects.

Others active in low-cost solar water heating share this viewpoint. The regulatory environment for the marketing of the *Solar Heat Barrow* will have to be evaluated and understood. The same argument applies to the *Dispenser*, where regulatory requirements and best practice will have to be taken into account.

6.3 Evaluation and affordability of the *Solar Heat Barrow*

Initial evaluations, demonstrations and surveys performed in the peri-urban informal settlements around Pretoria showed that there is an interest in the concept of the *Solar Heat Barrow*. Those interviewed who did not have access to water or electricity in their households perceived the *Solar Heat Barrow* as something that could improve their quality of life. The surveys revealed that there could be an approximate 15% market penetration in these areas if the *Solar Heat Barrow* was to be sold at approximately R300.

Surveys preceding the field trial of the *Solar Heat Barrow* in Mabedlane, KwaZulu Natal, showed that people in this deep rural area had even less access to basic services than those in the peri-urban informal settlements. Unemployment was very high though, and many families had to live on incomes of less than R200 per month. Nearly all interviewees indicated that they could not afford to pay more than R100 for the *Solar Heat Barrow*.

All of the fifteen actual users of *Solar Heat Barrows* in the Mabedlane field evaluation were pleased with the performance of the units. Their enthusiasm stimulated interest from their families, neighbours and friends. All, however, indicated at the end of the evaluation period that, although positive about the device, they could still not afford to buy it for more than R100.

This shortage of money in rural areas can only lead to the conclusion that to market and sell the *Solar Heat Barrow*, with or without the *Dispenser* where necessary, at a realistic price will be extremely difficult.

6.4 Commercial viability of *Solar Heat Barrow*

The total potential market size for low cost solar water heaters in Southern Africa was estimated at about 1.8 million units. Two different arguments and estimations led to this approximate value.

It was assumed that the *Solar Heat Barrow* could penetrate the South African market at 10% of the potential, or 60 000 units, over a period of five years. The rest of Southern Africa was assumed to yield lower percentages of penetration, and a total market penetration of 4.5% of the potential was envisaged for this same period. This increased the number of units only to 82 500.

The production costs of both the *Solar Heat Barrow* and the *Dispenser* were determined based on estimates in conjunction with manufacturers in the respective fields. This led to the conclusion that the initial direct production cost for the *Solar Heat Barrow* would be nearly R380 per unit, while the *Dispenser* cost would be just below R80 per unit for the same strategy.

These costs, together with the operational, marketing, finance and commission to agents, would require the *Solar Heat Barrow* to sell for a minimum price of R600 for the full five year period. The *Dispenser* will have to sell for at least R100 for the full period also to be marginally viable. These viabilities were verified using the net present value, or NPV, method for product and project evaluation.

The amount of money to be made from the *Solar Heat Barrow* and the *Dispenser* cannot be attractive to an entrepreneur wanting to start a new enterprise. At best, a present manufacturer and distributor of products with related manufacturing technologies, and developed markets, may want to invest in these products for reasons other than just turning a quick profit.

The policy background against which these products would be marketed was also investigated. There is considerable scope, especially in South Africa, to use government incentives in the areas of general rural advancement, water and sanitation, renewable energy, health and housing to subsidise the devices.

International donor agencies would in all probability also be interested in assisting with the costs of a well-developed product in this arena. Even local commercial enterprises may help to subsidise the price to the intended users for their own marketing purposes. These opportunities will, however, have to be developed to their fullest potential for the *Solar Heat Barrow*, with the *Dispenser*, to bridge the gap between the required price and what the intended users can afford to pay.

6.5 Recommendations for further work

Both the *Solar Heat Barrow* and the *Dispenser* will require development for production before they could be viewed as market ready products.

In paragraph 4.4.1 of this dissertation, several design changes were proposed for the *Solar Heat Barrow*. The most important one is the return to a flat solar water heating unit instead of the present curved shape. The possibility of manufacturing the storage-collector unit in a transparent material should also be considered seriously.

These changes would further improve its performance in both the solar heating and water disinfection areas. At the same time, it could potentially reduce the production costs of the units by a small margin. Changing the design of the unit for easy removal of the solar water heating unit from the frame should also be done for the earlier envisaged use of the frame as a general cartage tool.

One disadvantage of the *Solar Heat Barrow* is the limitation in the volume of water that it can carry. Increasing the volume will, however, make it more difficult for children and women to push and control, and is therefore not recommended.

It is thus recommended that the use of the *Solar Heat Barrow* as a solar heating unit for an additional stationary water container be investigated. This could increase the appeal of the unit for a relative small additional cost. When disconnected from this arrangement, the *Solar Heat Barrow* would remain as the primary water carrier for the household.

The only development envisaged for the *Dispenser* would be for its production. Most of the initial effort here should, however, be spent on proving the capabilities of *Steripure* as a disinfectant.

All of this work will come to nothing if the footwork for the marketing of the *Solar Heat Barrow* to institutions, donors and commercial enterprises are not treated as a priority. Without the necessary funding, both the *Solar Water Heater* and the *Dispenser* will be stillborn as commercially viable products.