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Solar-Powered Desalination

A case study from Botswana

by

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Abstract

In Africa, chronic drought conditions are reducing access to and the quality of drinking water. In Botswana, recurring droughts have left 80% of the population reliant on water from boreholes. Drilling such boreholes is an expensive proposition and the water is often scarce or saline. One possible solution to this dilemma is solar desalination. The Solar Energy Section of the Rural Industries Innovation Centre (RIIC) in Kanye, Botswana, has been studying solar distillation methods since 1977. This book summarizes the results of an intensive 3-year field study carried out by RIIC, with the support of IDRC (International Development Research Centre), on the technical performance and suitability of various small-scale desalinators. Their findings indicate that small-scale desalinators can provide a clear, palatable distillate; that certain models can provide a constant and adequate supply of potable water when the distillate is added to salty water from traditional sources; and that the technology is readily acceptable to remote area dwellers (RADs). The study also highlights the importance of including intended beneficiaries in the management of a new technology, in this case, the siting, construction, operation, and maintenance of the desalinators.

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Foreword

Chronic drought conditions in Africa are reducing access to, and quality of, drinking water, particularly for those living in arid regions. Surface water sources and shallow wells are not being replenished naturally. Drilling boreholes to access deep, subterranean water tables is expensive and requires sophisticated drilling and pumping equipment. Transporting water supplies to remote communities is difficult and expensive. Consequently, per capita water consumption is severely restricted. Also, water from shallow, hand-dug wells, abandoned boreholes, and surface water sources is often brackish and salty. The lack of sufficient and potable water can only adversely affect the health of and region dwellers.

Since 1977, the Solar Energy Section of the Rural Industries Innovation Centre (RIIC), a nongovernmental organization (NGO) located in Kanye, Botswana, has been carrying out research on solar distillation methods. The objective of their program is to improve the quality and increase the quantity of drinking water for people living in remote areas, particularly for the remote area dwellers (RADs) in the Kalahari Desert. The findings of RIIC's initial studies indicated that desalinators provide a clear and palatable distillate.

In 1983, RIIC approached IDRC (International Development Research Centre) for financial support to carry out an intensive, 3-year field study on the technical performance of small-scale desalinators and their suitability to the RADs. The results of the project confirmed that

- if properly constructed and maintained, certain desalinator models provide a constant and adequate supply of potable water when the distillate is added to salty water from traditional sources, and
- the technology is readily acceptable to the RADs.

The project also highlighted the need to account for managerial aspects related to the promotion and maintenance of the technology, particularly the active participation of the intended beneficiaries in siting, constructing, operating, and maintaining the desalinator units. If the intended beneficiaries are not involved, the technology will not be used correctly, or perhaps not used at all; community members will continue to perceive the technology as a gift from, and therefore a responsibility of, the government.

IDRC believes that the findings of this project provide useful insight into the use of small-scale desalination methods, particularly for government agencies and NGOs involved in planning and promoting the use of such devices. The publication of this report is intended to increase knowledge in these areas, so as to improve the planning and execution of similar projects designed to increase accessibility to drinking water for communities located in and regions of the developing world.

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1 Introduction

Obtaining water is one of the major occupations of rural peoples in Africa. In the desert areas, especially during the last 6 years of drought, it has become, for many, a preoccupation. In Botswana, for example, water is scarce and costly at the best of times. Annual rainfall averages from 250 mm. in the southwest to 650 mm. in the extreme north, the national average, under normal circumstances, being 450 mm. The recurring droughts have left an estimated 80% of the population reliant on water from boreholes, many of which yield poorly or are saline (Botswana 1985).

In areas where saline sources have been tapped by boreholes and the water is too salty for humans to consume without serious consequences, the introduction of desalination promises to enhance the quality of life and to improve health standards, including infant survival. The technology, therefore, seems particularly suitable for the Kalahari Desert.

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This thinking prompted the Rural Industries Innovation Centre (RIIC) in Kanye, Botswana, to investigate small-scale desalinators, with the objective of increasing the available drinking water for people living in remote areas of the Kalahari. RIIC adapted designs of solar stills and tested their use in three communities: Khawa, Lokgware, and Zutshwa.

Installations at two of the settlements have proved successful; the local people participated in making the system work and continue to operate, maintain, and benefit from the stills. The stills are popular in these areas, and they have contributed to the community spirit. In Khawa, for example, there is now less social chaos related to water use than before, and a social conscience as well as cautious use of potable water has emerged.

Although it is still too early to evaluate the overall impact of desalination, the future of settlements with only saline water is no longer bleak, and such areas are now seen as habitable. According to official figures, 80% of Botswana is covered by the Kalahari sands. This whole area is said to be drained by a system of dry rivers that rarely carry any water even during years with good rainfall. In certain areas, shallow depressions (pans) retain rainwater for brief spells after heavy thundershowers. The only reliable source is groundwater accessible through boreholes or hand-dug wells. Such water is being tapped despite the thickness of the sand layers.

According to the National Development Plan 1985-91 (Botswana 1985, p. 200):

Ground water can be found beneath the Kalahari sandbeds, but generally only at large depths (100 metres is not unusual) and with low yields that can support only a few people and livestock. The water is sometimes saline due to lack of recharge from rainfall. Water is found nearer the surface in areas of calcrete, silcrete and ferricrete formations.

Both the public and the private sectors develop water supplies by drilling of deep boreholes, many of which turn out to be blanks or saline. The result has been a call for new techniques such as desalination to render the salty water drinkable.

The Department of Water Affairs (within the Ministry of Mineral Resources and Water Affairs, which oversees development of the national water resources) drills and equips boreholes and hands the systems over to district councils (which fall under the Ministry of Local Government and Lands) to operate and maintain. The desalination units introduced by RIIC now come under the auspices of the Kgalagadi District Council. The district councils decide which villages are priorities for the water program.

In the private sector, the two major industries - cattle and mining have funded the search for water. The government has granted drilling rights to cattle producers in the sandveld, as cattle are second only to diamonds as a source of foreign exchange. At the same time, mining companies have drilled their share of boreholes and have had an impact not only on the availability of water but also on employment and mobility patterns in the desert. Many San, and others who have traditionally been hunter gatherers, have settled. In Lokgware, for example, settlers have taken over a site with a borehole abandoned by a prospecting company.

As the Kalahari's traditional water sources such as sip-wells, melons, and wild tubers have dried up and disappeared, the people have converged around boreholes, some of which are privately owned and are delivering salty water. The cattle farmers who financed the drilling monopolize the potable sources. Few are willing to share their water; they see the provision of water as a responsibility of the government. At Khawa, for example, several boreholes in the surrounding 10-20 km deliver potable water, but the council was forced to truck water from Middlepits into Khawa - about 90 km.

Since 1979, water consumption per person in the 17 biggest villages has remained steady for standpipe users (15 L/day) but has doubled for people with private connections, going from 40 to 80 L/day (Botswana 1985, p. 200). The water is used for drinking, washing, cooking and in some cases gardening. In contrast, in remote settlements, the target is about 2 L/day per person, and water is supposed to be used strictly for drinking and cooking. Although the target for supply of water is small, the schemes for remote communities tend to be expensive to set up and operate.

New technologies such as desalination offer a means to use more of the available water for human consumption. According to the sixth National Development Plan (Botswana 1985, p. 205), "salinity of water is increasingly becoming a problem and has sometimes necessitated drilling of several boreholes in a village [or settlement]......" The lack of rainfall during the past few years has practically halted groundwater recharge, and many boreholes that once delivered water suitable for human consumption have been abandoned because the salt in the water has increased. The lack of reliable water sources hinders development immensely and has the worst effect on people who live in remote areas.

The Kalahari remote area dwellers

Only 20% of Botswana's population can be realistically seen as permanent residents of the desert. Of this group, a minority are in remote areas. Those living outside organized villages such as Tsabong and Hukuntsi are termed remote area dwellers, living in permanent and semipermanent settlements. In Kgalagadi District, about 15% of the population is living in remote areas and a majority of this group (3 633) live in recognized settlements.

The nomadic bands of traditional hunter gatherers are no longer found in Botswana. They either are in the process of settling or have already settled. Since 1977, when the Remote Area Development Programme (RADP) was instituted, government has promoted permanent settlements. The justification has been the relative ease in providing services such as food, education, water, and health care to permanently settled communities. Up to 14 remote settlements in Kgalagadi district alone have come under the program, and, elsewhere, the government is introducing "feeding points" in the hope that they will become settlements. Most settlers have historical links with the areas in which they settle and view the land as their home.

An ethnic perspective

The government has defined remote area dwellers as all the people outside organized villages; this definition encompasses members of several ethnic groups. Until 1977, the only program that served remote area dwellers was the Bushmen Development Programme. The government that emerged after independence realized that groups other than the San (Basarwa) were living in remote comers of the country and were equally underprivileged.

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The transition from the Bushmen Development Programme to the current RADP was not easy. One reason was anthropological interest in the San as a distinct society. David Stephen (1982) wrote in his report *The San of the Kalahari*,

Many people, with very different perspectives, campaign for the San from outside Botswana: some wish to maintain the image of the San as "noble savages" - to maintain a form of human zoo in Botswana; others are interested, as writers or film-makers, in perpetuating a romantic image of primitive people.

Pressure came from academically oriented individuals to resist developmental policies that would change the lifestyle of the San.

The policies introduced in the late 1970s were a negation of the colonial notions embodied in the Bushmen Development Programme. As Egner (n.d.) in his evaluation of RADP put it, "to counter allegations of 'Separate development' and ethnic bias by those who deprecate any form of special assistance for narrowly defined groups of the poor, the ... Basarwa Development Programme was changed to Remote Area Development Programme in 1978 and its target group [to]... all people living outside organised village settlements."

Surveys carried out in four settlements in the Kgalagadi District in 1984-85 indicated people residing in areas designated as remote settlements were from mixed ethnic backgrounds. In Khawa, where no Basarwa had settled, the population comprised Bakgalagadi (4%), Bakgothu (8%) (Hotentots), Batlharo (56%), mixed races (20%), and others (12%); Ncaang was made up of 12.5% Basarwa and 87.5% Bakgalagadi, whereas both Lokgware and Zutshwa were solely Basarwa.

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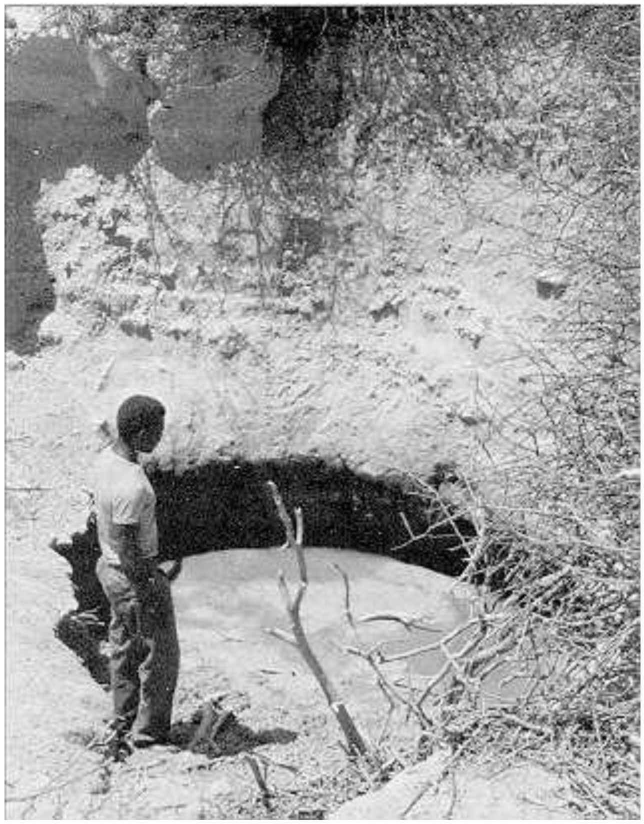

Existing water supplies in settlements are often hand-dug wells that become badly polluted by animals despite being protected by thorn fences.

Non-Basarwa remote area dwellers have always been a part of the country, but have only been covered by the government development program since 1978. Conversely, the pockets of Basarwa living in and around big villages no longer are covered by the program and have no access to its benefits. Many are marginalized sectors of the rural population and live under abject poverty.

Fundamentals of RADP

For the past decade, the Botswana government has devoted much effort to restructuring and strengthening RADP. This program falls under the hegemony of the Ministry of Local Government and Lands, with most of the responsibilities for administration and implementation falling under district councils. Since its institution in 1977-78, RADP has worked toward social, economic, and political objectives for remote dwellers:

- the extension of basic social services such as education, health care, water supply, feeding programs for vulnerable groups;
- the opening of access to land, water rights, and income-earning opportunities; and
- the fostering of self-reliance, social integration, and awareness of rights.

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Although RADP is only a decade old, it has had considerable success in Kgalagadi, especially in implementing the first objective relating to the provision of social services. It has set up transportation for children to go to primary schools in bigger villages (Werda, Hukuntsi, Tshane, Lehututu, and Kang) where they are housed and fed. In the meantime, private schools up to fourth year in primary school are being started in the settlements and will be staffed by council- or government-paid teachers.

All the settlements are served by a mobile health clinic from the nearest village while health posts are being built locally. The posts that have been erected are currently staffed by family welfare educators; however, as soon as it is feasible, the posts will be better equipped and some qualified nurses will be provided. The clinics are responsible for feeding programs for preschoolers, pregnant women, and destitute individuals. Other feeding programs that RADP underwrites are emergency aid for whole communities (drought-relief rations) and meal programs at local schools.

Although some settlements in this district have potable water, others receive drinking water brought into the communities by trucks or obtained through small-scale desalination. Desalination has tended to promote self-reliance, which is not a feature of government schemes to deliver potable water by trucks. The future of such settlements is uncertain and is totally dependent on securing a reliable water supply.

2 Choosing a technology

Governments in developing countries have a variety of possibilities to provide water for remote settlements in the desert: drilling, reticulation, trucking, resettlement, and desalination, among others. Drilling is the most satisfactory in the long term, but in the desert it involves high investment. In Botswana, for example, drilling costs 70 BWP/m, and boreholes are often drilled more than 250 m before they are abandoned as dry (in May 1990, 1.87 Botswana pula [BWP] = 1 United States dollar [USD]). Casing adds another 50 BWP/m to the cost, and screens a further 1 200 BWP.

Salt water is found more often than fresh water. Even with sophisticated prospecting techniques, it is difficult to tell whether underground water will be sweet and whether it will have a significant yield.

At least 55% of boreholes drilled in Kgalagadi District are salty or dry. Once a borehole has been drilled, cased, and equipped, there is no guarantee that it will remain sweet or that its yield will stay the same. In many areas, it is unlikely that any sweet water will ever be found.

Another major constraint to drilling is the lack of rigs and experienced drillers to do the work in developing countries. Even after plans have been made, several years may go by before drilling is completed. Settlements that are fortunate enough to tap ample quantities of sweet water tend to attract new settlers and their livestock. The settlements are often in areas of good grazing, used by livestock only in the rainy season and attracting wild game throughout the year. Few of the people from the settlements have livestock and they often depend on the wild game for their survival. When new settlers bring in cattle, the balance is upset, wild game is driven away, and the local people end up working for the cattle owners for little pay.

The extent to which people migrate to sweet boreholes is illustrated by experience in Kedia, Botswana. Fewer than 50 people lived there in 1984 when rumours of drilling began. In a few months the population had risen to 800. No water was discovered during drilling, so the government began to reticulate water there instead of forcing people to move yet again.

Reticulation

Reticulation is the process by which water is brought from a borehole to the end user by pipeline. this is very satisfactory if a suitable borehole is not too far away. The costs are not excessive and construction of a pipeline is very labour intensive. The total cost of laying a 63-mm pipe is about 2 700 BWP/km. However, the technology is suitable for distances of only about 5 km. For longer distances, 90-mm pipe must be used at a cost of 4 435 BWP/km. The system is simple to maintain and reliable, although leaks may go undetected for some time. The main obstacle to reticulation is that most remote settlements do not have access to sweet boreholes within 40 km and, where the boreholes exist, their output is usually in use.

Trucking

Trucking water is the simplest, most expensive, and least reliable solution to the problem. To administer a water-trucking program is relatively undemanding. A driver is simply told to take a truck and deliver water to a particular settlement. But the operation depends on the availability of transport, and to have trucks permanently being used to deliver water detracts from other developments.

The roads to remote settlements are poor, and the trucks often travel at less than 15 km/h for distances up to 200 km. Because of the sandy roads, loads of water must be kept relatively small, the trucks often having to return several times to fill storage tanks in the settlements. The traffic makes bad roads worse. Breakdowns and other unforeseen circumstances prevent reliable deliveries, so settlements may wait 2-3 weeks after one tank of water is finished before the next is delivered.

In many instances, the tanks lead, so people tend to grab as much water as they can before it is lost. People with containers for water storage at their homes are better off, and the poorest people suffer. Once water reaches a household it is seldom given away.

Commonly, a truck, with driver and two assistants, leaves its base at lunchtime and arrives at a settlement about 6 h later. In the morning, 20 or so 200-L drums are loaded onto the truck, although several leak from damage during off-loading and transit. having loaded the drums, the crew drive for about 3 h to a council borehole and fill the drums at the only available standpipe. Yield is usually low, and filling takes several hours. Late that evening the truck arrives back in the settlement and the water is pumped into holding tanks. The process is repeated the next day, and by the time the truck returns most of the water delivered the night before has been used. The process is repeated for 4 or 5 days before the truck leaves the drums and goes back to base. Within a week, all the water will be finished.

Control over the system is difficult, and the drivers at times persuade their supervisors that particular settlements need water if they have personal reasons for going there. Yet, trucking is the only supply of potable water to about 70 settlements around Botswana.

Desalination

Desalination of water can be done in many ways; the main requirement is a reliable supply of salt water. If the water sources is a hand-dug well, then it must be public property or the owner may claim preferential use.

Shallow-basin solar stills have proved to be simple to construct, reliable and cost effective, but they are also labour-intensive to operate and low yielding, particularly in the winter. Other types of solar distillation can produce more water per square metre than shallow-basin stills, but they are much more complicated.

For example, a small multi-effect solar still, which uses the heat of condensation of the water, can produce three times the output of a shallow-basin still (Heschl and Sizmann 1987). However, this type needs much more water to be pumped, the recovery rate is low, and the system susceptible to breakdowns. It is also unsuitable for very salty water. Multistage flash desalination is efficient but is suitable only for large-scale plants; to power the process by solar energy would require massive investment.

Reverse osmosis, however, can be carried out on a small scale. Salty water is forced at high pressure against a membrane that allows water through but not salt molecules. Large reverse-osmosis plants can produce hundreds of cubic metres of water a day; yet small units, about 30 L/day, are available. The only power needed is to pump and pressurize the water, and this can be supplied by hand or pedal for very small units. The drawback is that the process is sensitive to the quality of raw water, and the membranes easily become clogged or damaged. To clear them requires special procedures that would be unmanageable in remote settlements. Replacement membranes are expensive and not easily available in Botswana. Therefore, in the event of a membrane failure, a settlement could be out of water for months. As the only indication of failure is a reduction in output, people tend to use the system until it totally fails.

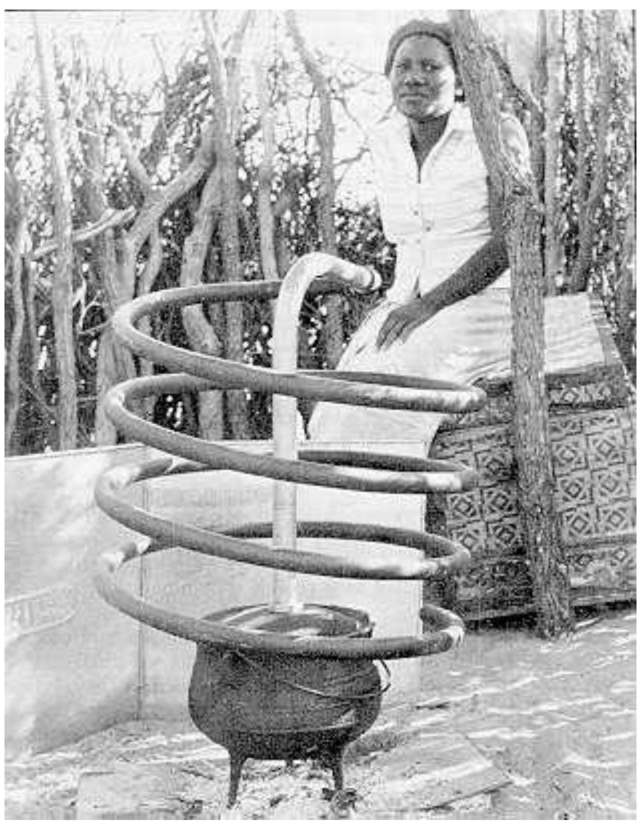
Also, the power requirements of reverse osmosis rise with salinity of feed, and the proportion of sweet water recovered is often low. Reliable pretreatment of the water is another requirement, including filtration, coagulation, balancing of pH, removing free chloride ions and any traces of oil. If pretreatment is not properly managed, with regular sampling, the membranes will fail at some stage. Given the scarcity of skilled labourers in remote settlements, these techniques are impossible to organize.

A network for supply of filters and chemicals would have to be put in place, as well as trained people to support the operators. Such a sophisticated technology would be feasible only in larger and more widespread applications. As a consultant funded by the Swedish International

Development Authority concluded in a report on desalination for the Department of Water Affairs (Dahlberg 1981), "the installment of solar stills rather than reverse osmosis is ... recommended."

Using wood as a fuel for desalination over the long term was never seriously considered in Botswana; however, it was seen as a suitable measure to deal with emergencies, for example when water trucks failed to arrive. Firewood is plentiful in many areas of northern Kgalagadi, so wood supply is not a critical problem. Fires are lit at night in every household in the area, so an attempt was made to introduce stills that consisted of modified lids for the traditional three-legged pots. A hole was drilled in the lid, and a blackened copper pipe connected to it to act as a condenser. Cooling was to be provided by radiation and air convection. Early models used a coiled pipe (called the "kudu horn" by users), but this was difficult to transport and tended to be heated directly by the fire. Later models used a straight pipe, 3 in long, coming away from the fire. These stills were difficult to use, produced little water (0.7 L/h) and could not be left unattended in case they were knocked over by children. Although they were politely accepted (once they were given away together with a pot), they were seldom used.

A larger model was designed to use water as the coolant instead of air. Called the Ghanzi still, this model had a copper coil immersed in a cool drum of salty water. Water was boiled in a separate 100-L drum and the steam piped to the coil to be condensed. The yield was 17 L/h.



A prototype wood-fueled still, called the "kudu horn," was rejected because of low yield.

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When introduced into a village, the Ghanzi still proved unsuitable for several reasons. The salt residue in the boiling drums was not flushed out as-recommended so the drums quickly became scaled and corroded. Also, the firewood in the immediate vicinity became depleted when the still was regularly used. And it was virtually impossible to distribute the water fairly. Those with donkeys were able to bring wood, but they had exclusive rights to the water produced. Thus, those without donkeys had to beg for water.

Nevertheless, two Ghanzi stills on one fire could, in 3 h, with less than a donkey-cart of wood, provide 100 L of distilled water, enough for the daily drinking requirements of 50 people. Therefore, the stills were used.

Solar stills

The principle behind solar stills is simple: salty water is left in the sun in a glass-covered basin that is airtight and has a black base to absorb radiation; the water evaporates, the air inside the unit soon becomes saturated with water vapour, and condensation occurs on the coolest available surface - the glass. If the glass is set at an angle so the condensing water flows down, rather than forming drops and falling back into the basin, then the water can be collected in gutters at the lower edge of the glass and can be directed into storage tanks. If the still is insulated, the water will get hot quickly on a sunny day. The salt molecules remain in the basin and can be collected.

Solar desalination is an obvious choice for the remote areas of Botswana as it is reliable and easily maintained. The challenge is to design a still that is simple (even at the expense of some efficiency), uses local materials and gives long service with minimal care.

In the remote areas, local materials for construction are hard come by. Even the sand is poor for building, as the particles are small and uniform. Few local people have skills in construction, so any project to introduce desalination must include a training component not only for operation but also for erection and installation. One must assume that the stills will at some time be left to dry out, so materials used in construction of the stills must be robust and resistant to corrosion by salt and degradation by heat and ultraviolet radiation.

Botswana has its own construction industry and has access to materials manufactured in South Africa and, thus, can avoid materials that must be ordered from North America or Europe. Fibreglass and brick, both of which can be produced in Botswana, are the main materials chosen for the stills introduced. The fibreglass unit is a modified Mexican still, which derives its name from the place it was first used.

Fibreglass is an ideal material for this application. It is strong, flexible, and does not corrode or leave a taste in the water. It can be made extremely resistant to damage from ultraviolet rays and is stable at temperatures up to 95° C wet and 185° C dry. The moulded surface is extremely smooth and hence can be easily kept clean. The basin can be coloured black, for optimum efficiency, the pigment being added to the resin so no amount of scraping will remove it. Other materials, such as steel bracing and nylon nipples can be bonded into the moulding without problems.

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Since first introduced in Botswana, the Mexican still has been developed into a very efficient and effective design. Performance is high and the stills are robust, easily installed, and easily maintained. If a sweet borehole is drilled in an area, the fibreglass units can be removed and reinstalled elsewhere, so the capital outlay is not lost.

Their one disadvantage is cost. Between 1985 and 1987 the price of fibreglass materials increased by 250%, so cheaper alternatives have been sought. Bricks and mortar - the brick still - proved acceptable, although much less durable and portable than the fibreglass unit. Trials with asbestos cement boards and ferrocement as the main materials were not successful.

Different configurations of stills were also tested, some of which performed well but were not practical for remote areas. For example, a "cascade" still, consisting of several basins like a set of steps covered by a single piece of glass, keeps the water surface close to the glass and, thus, has a minimum of air within it and is efficient. However, it cannot be cleaned easily and it uses an inconveniently large sheet of glass.

Basic survival stills can be made by covering holes in the ground with plastic sheet, but they are unsuitable for use in Botswana despite their low cost. They have to be dismantled for access to the distillate, and their performance depends on minor details. Although they were thought to be a means for pastoral peoples to obtain water while at sites other than settlements, the only sources of water, including brackish water, are settlements.

3 Designing stills for harsh conditions

A solar still consists of a basin with a sloping glass cover; the walls are low and it looks like a house with a glass roof. At the bottom edge of the glass, on the inside, runs a gutter. The bottom of the basin is black and is well insulated.

Salty water (30-40 mm. deep is optimal) is introduced in the basin, heats up when the sun shines, and evaporates. The heat is absorbed by the black surface, and the hotter the basin becomes, the faster the evaporation. The insulation prevents the heat from being lost to the earth.

The air inside the unit becomes saturated, and then water vapour condenses on the coolest available surface, the glass. The water flows down the inside of the glass as a thin film and collects in the gutter. From there, it is directed to a storage tank. The glass must be set at an angle, be kept clean and be free of cracks so that the water does not form droplets that fall back into the salt water.

Each still has access doors so that the inside can be properly cleaned. However, when the doors are closed, the unit must be airtight for optimal operation.

Mexican stills

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The Mexican solar stills (MK II) of the Rural Industries Innovation Centre in Kanye are made of fibreglass and resin mixtures. They are designed to withstand transport over unpaved roads and to operate under the harsh conditions in rural Botswana. They differ from the MK I models in that they do not have false bottoms packed with insulation and the gables are lower than the earlier model.

The moulded basin has 1.6 m^2 of evaporator area, two gutters for collection of the distillate as it runs down the glass, and gables that support the glass. The shape is like a tent with two pieces of glass for the roof (Fig. 1 and blueprint, pp. 16-17). The fibreglass is strong and resistant to salt, heat and sunlight; it is dyed black before it hardens.

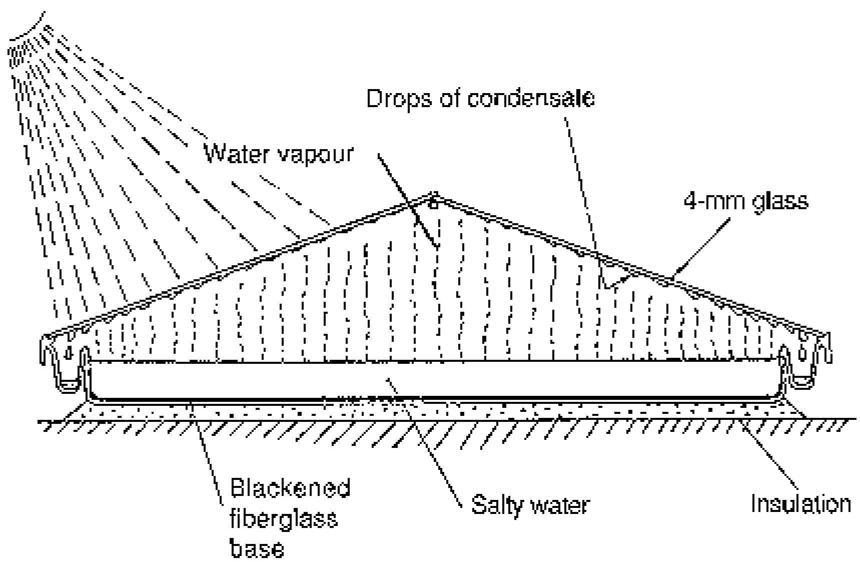

Fig. 1. The Mexican still is simple, reliable, and efficient.

The stills are relatively small and can easily be carried on Landcruisers ® or similar vehicles commonly used in the desert. A larger prototype (with 1.9-m^2 evaporator area) has been built because in Botswana most transport of such materials is on 7-t trucks. The high cost of making moulds, however, has put the larger types on hold. For easy transportation the stills are designed with recessed outlet and drain nipples and slightly sloping gables so that they can be stacked. Early models used to vibrate down until they nestled so tightly that the comers split. To prevent this, support blocks were incorporated into the mould.

Originally, the stills were tried with both glass and plastic glazing. The plastic used was "Tedlar" polyvinyl fluoride sheet. This was found to give about 15% less production because condensation occurred as drops rather than as a film, hence reducing the transmission of light. Tedlar was also very difficult to fasten to the still, and even harder to make taut. With time, it tended to stretch and flap in the wind, so drops of distillate fell back into the brine. To allow the condensate to run down the Tedlar under normal circumstances, the designers introduced a glazing angle of 20° . Once the problems of Tedlar had been identified, it was decided, in accordance with other literature (Durham 1978), to use only glass.

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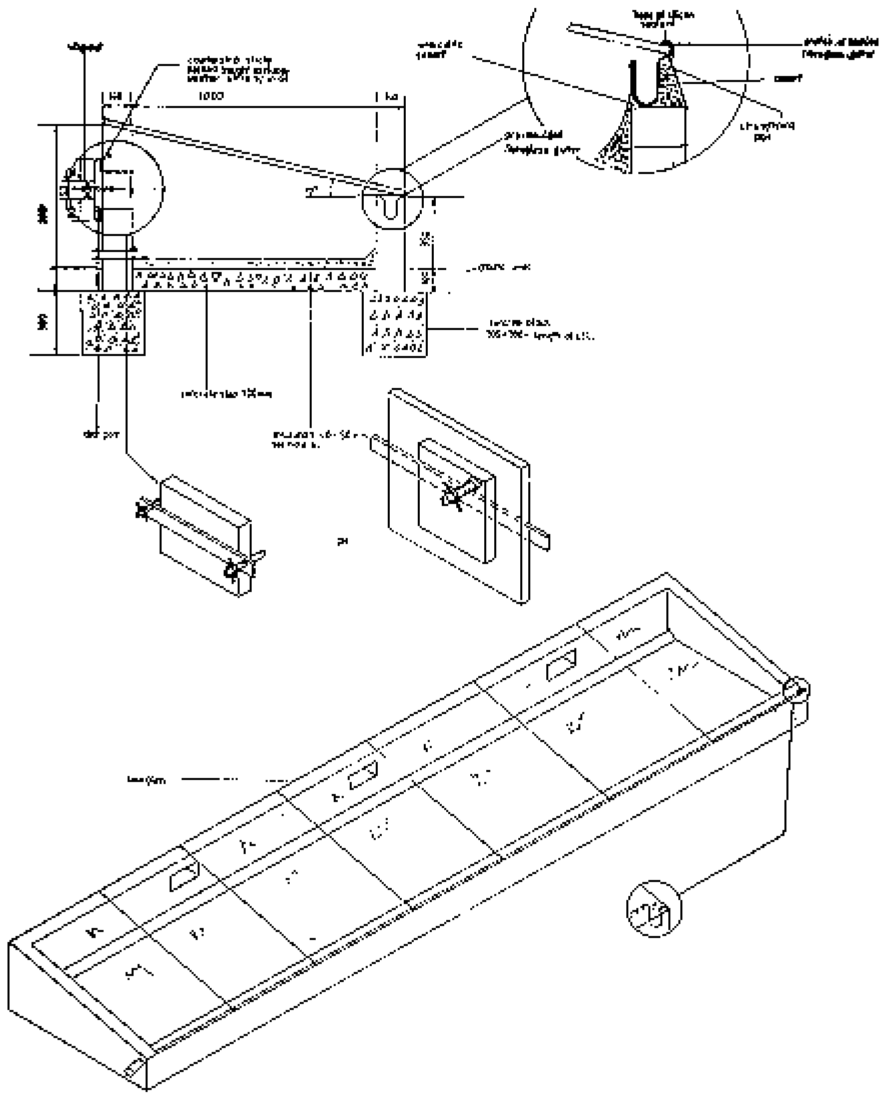

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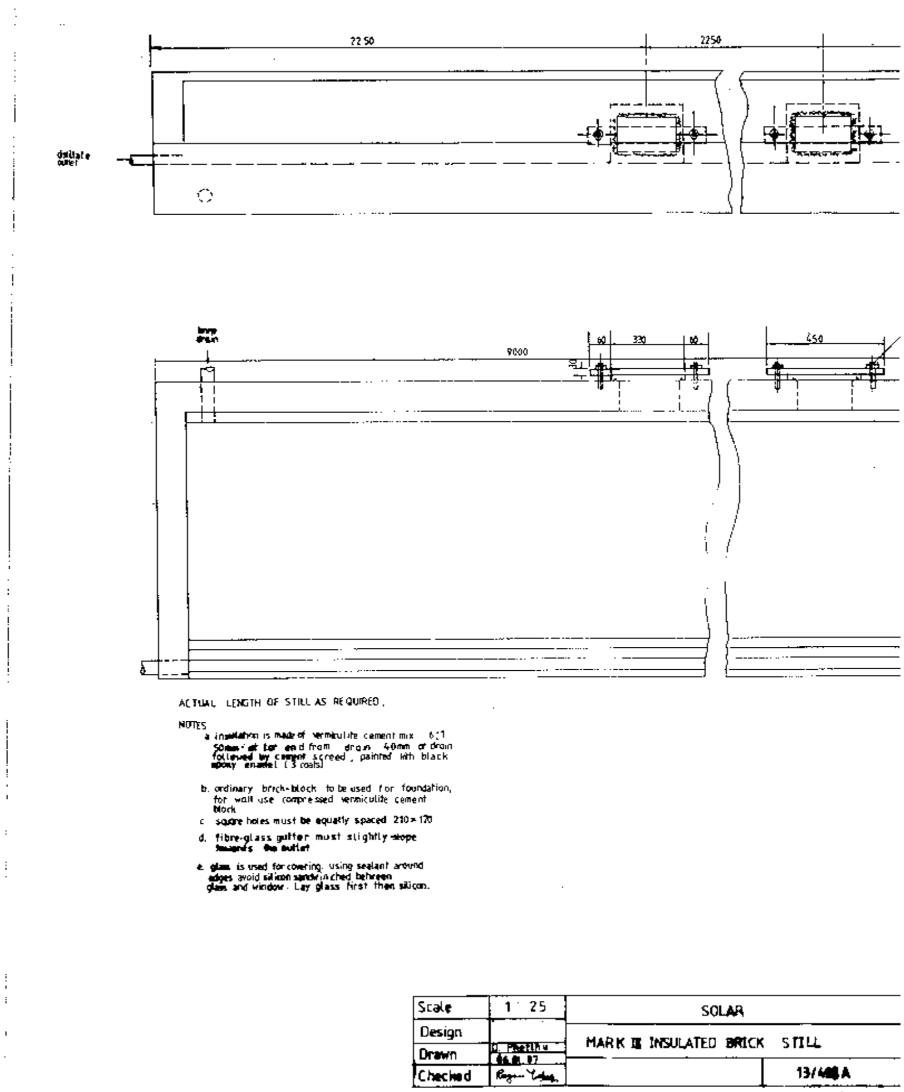

The glass could be kept at an angle of 15° , with an improvement in efficiency, possibly because the distance between the water surface and the glass was lower and, hence, the energy required to lift the water vapour to the glass was reduced. The reduction in angle also meant that a smaller piece of glass could be used. A standard 4-mm window glass is used and has been found to be satisfactory. It is easily obtained within Botswana and is strong enough to withstand hail storms. Thinner pieces (3 mm.) broke during hail storms and became brittle when the still was left dry and overheated. Originally, one sheet of glass was used on each side of the still, but this was increased to two each, half the size, to ease transport and replacement problems.

To transport the glass on bad roads, it was essential to carry it stacked on edge in a strong crate, padded underneath and fastened on top to prevent movement. The crate was stored as far forward in the vehicle as possible, and packed across, rather than along the chassis.

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When a site is ready for the still to be installed, the glass is fastened to the still with a silicone sealant. By putting the glass in place and then applying the silicone around it rather than sandwiching the silicone between the glass and the fibreglass, one can remove the glass later without breakage.

Outlets for distillate and a drain for brine (which could also be used for filling) are made by bonding nylon nipples into the mould. Galvanized iron nipples were used at first, but they soon corroded on their cut ends.

For efficient operation, good insulation is essential. Early attempts to make a polyurethane-filled false bottom in the stills failed because the false base did not bond properly to the moulded form. Polyurethane was found to be the most effective insulator. It could simply be laid under the still. However, it is very expensive and difficult to transport. So for normal installations, a 6:1 mixture of vermiculite and cement is recommended, 50 mm. thick. This is cheap and effective, serving as a foundation to hold the stills in place.

For access to the still basin, two holes exist in the gable ends and are covered with moulded plastic caps. The caps are held in place by fibreglass batons fastened with brass bolts. A seal is created by a stickybacked piece of foam weatherstripping.

If the fibreglass basin is pulled from the mould before it has fully cured, it tends to shrink and distort. The distortion, in turn, causes the lower glazing edges to bend inwards. The edges can be braced so that they remain straight, but the solution is to keep the stills longer in the mould. A fold of fibreglass has been incorporated into the design to further strengthen the edges of the still. Angle iron is bonded onto the base to hold it flat, because warps in the basin result in dry areas that reduce efficiency.

At Khawa, Botswana, brick (foreground) and Mexican stills have been installed.

A galvanized iron pipe is used as a ridge pole to support the apex of the glass. Although it reduces production slightly, as it heats the adjacent strip of glass and prevents condensation, no other material has been found to be as satisfactory and easily obtainable.

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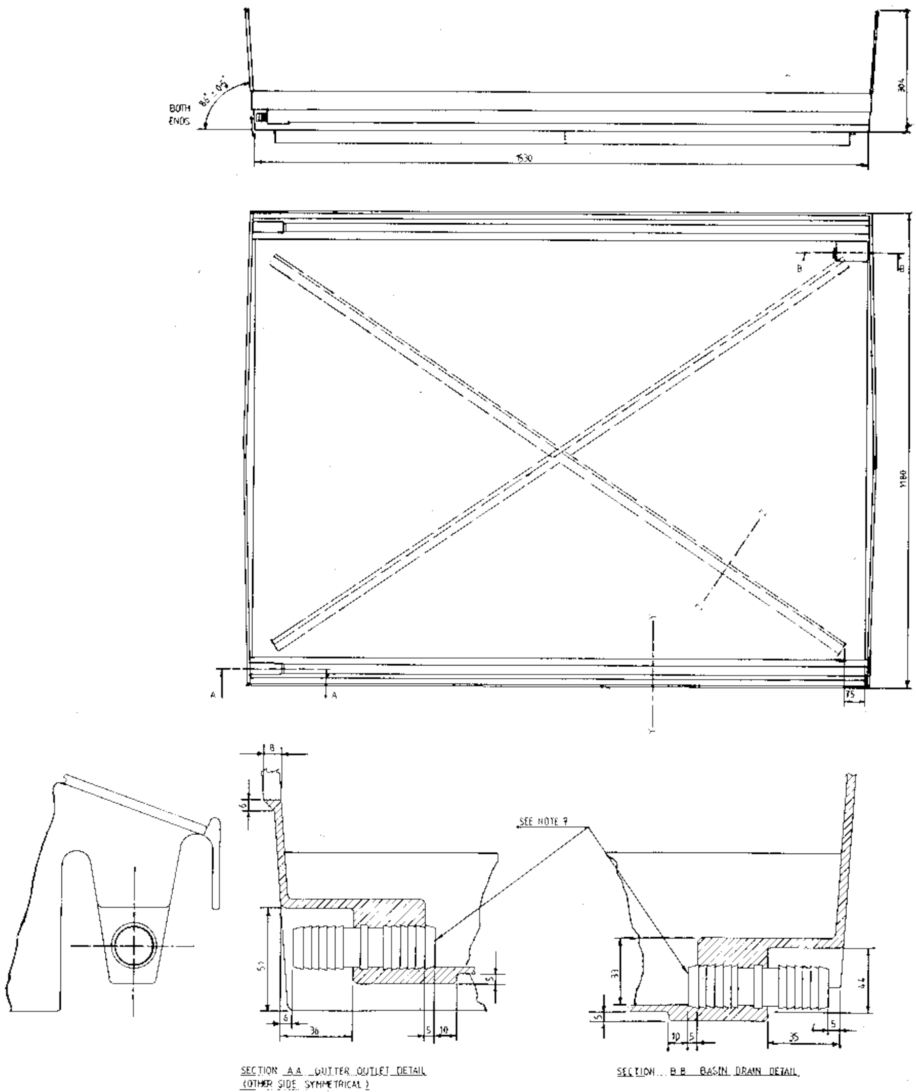
Brick stills

The brick stills consist of a long, insulated concrete basin covered with a single sloping glass roof that is supported on brick or block walls (blueprint, pp. 20-21, and Fig. 2). A single gutter runs along the bottom edge of the glass to collect the distillate. Large brick stills can be constructed much more cheaply than the fibreglass variety. The floor of the still is a reinforced concrete slab, topped by a 50-mm layer of vermiculite-cement insulation, and finished with a thin screed of strong cement mortar. The recommended maximum for the reinforced concrete slab is 5 m because of the risk of cracking. Brickforce reinforcement is used between each course. The basin (slab) is painted black with epoxy enamel, which is resistant to salt and heat.



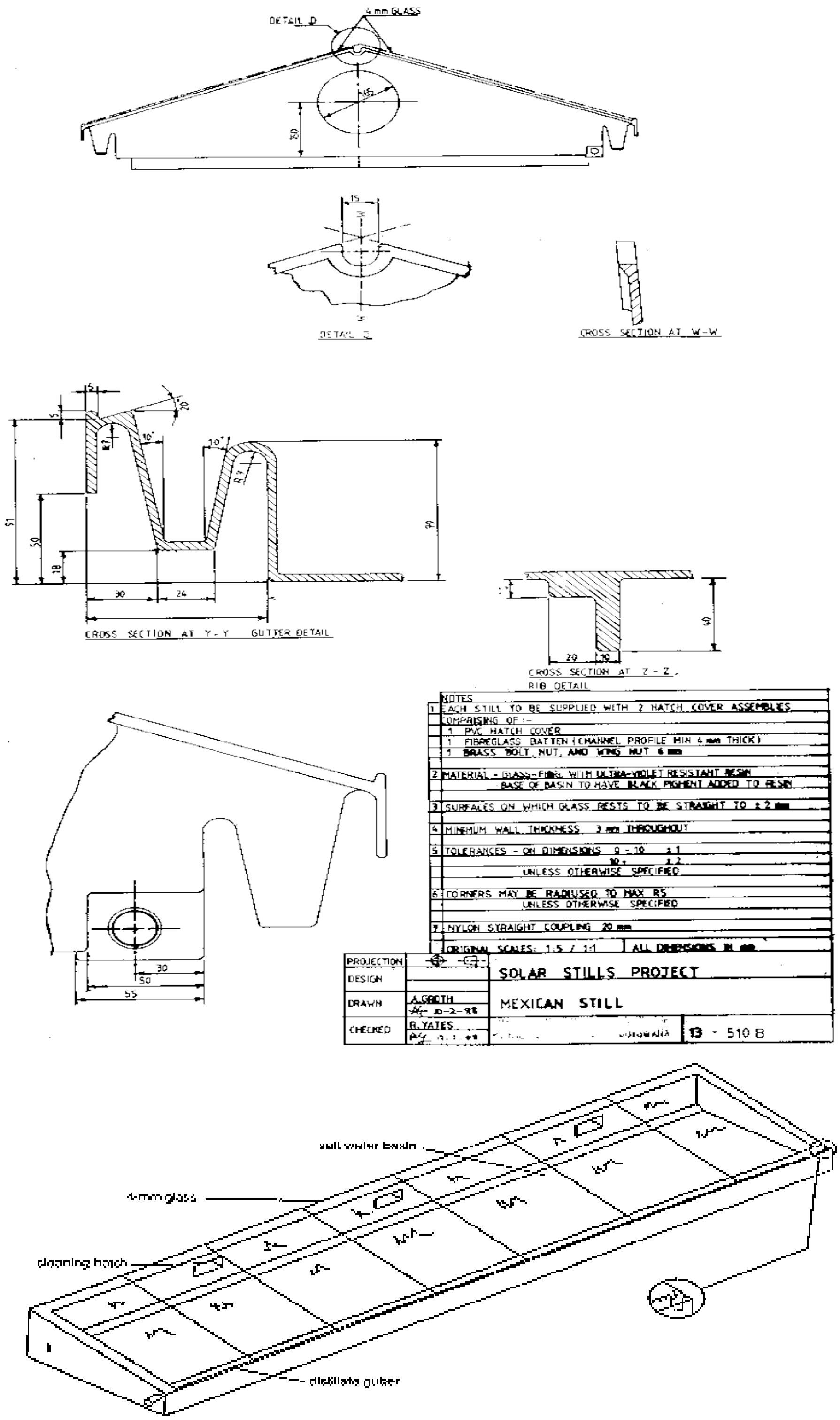


Fig. 2. Stills with walls of bricks and mortar are efficient but liable to crack near the cleaning hatches.

A single, north-facing glass has been used in the installations to date in Botswana. The span of the glass is 1 m, as experiments with a longer span have shown that the glass breaks. No extra supports are needed between each sheet of glass. As in the Mexican still, the glass is set at about 15° .

Bituminous black paint was tried but found to taint the distillate even 2 years after construction. It also was easily damaged during cleaning as it softened in the heat. Although more expensive, the epoxy enamel forms a strong smooth surface. It is easily cleaned and does not tear when scraped. Some chalking of the paint is caused by sunlight, although it does not seem to affect performance. The basin needs repainting after about 3 years. The still must be left for several weeks to cure before being painted. A fibreglass gutter with an integral lip to support the glass catches the distillate. The addition is expensive but effective. Attempts to form a cement gutter only led to problems with the poor quality of sand available in the field.

The walls are either standard cement/sand blocks or blocks made from vermiculite-cement. The latter give slightly improved performance but, if exposed to water, will absorb it. Hatches are constructed in the back wall for cleaning and filling purposes. The method of sealing is the same as for the Mexican stills. The spaces in the brickwork cause problems of cracking as the stresses in the wall concentrate at their comers. Precast concrete linters can be used over the spaces but, at this stage, cracking is still a problem. The walls inside need to be plastered before being painted, and the comers between walls and floor are rounded with cement to avoid leaks. The low quality of available sand in the field in Botswana has made plastering difficult and again cracking often occurs. Given skilled labour and a supply of reasonable sand, these stills can be recommended for long-term installation, but some further development is necessary before they can be more simply and reliably constructed. A butyl rubber lining in the basin and the gutter might overcome the problem of cracking.
