Low cost, small-scale charcoal production in the Western Cape

John Austin Clark, B.Eng(Chem) *Stell*

Submitted to the University of Cape Town in partial
fulfilment of the requirements for the degree of Master
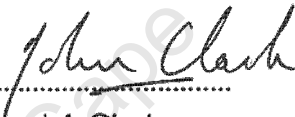of Science in Engineering.

Cape Town

May 1990

Declaration

I declare that this dissertation is my own original work. It is being submitted in partial fulfilment for the degree of Master of Science in Engineering at the University of Cape Town. It has not been submitted before for any degree or examination at any university.

J A Clark

3rd day of ....May...... 1990

Abstract

Low cost, small-scale charcoal production in the Western Cape

Domestic grade charcoal with a fixed carbon content of at least 80 % was successfully produced from the alien species *Acacia Saligna*. Carbonisation was effected using a Tongan drum kiln and average yields on a dry basis of 19.1 % (excluding fines production) were attained. With fines included, the yield increased to 31.4 %. It was shown that the earnings of woodcutters could increase by about 25 % if they opted for charcoal production using this technology. Three kilns examined in the Western Cape proved to be more financially viable than the Tongan drum kiln. The Tongan kiln was however shown to have advantages over other technologies in charcoal production from invasive alien vegetation by unskilled labour.

Keywords

Acknowledgements

I would like to offer thanks to Dr Anton Eberhard for guidance and inspiration for the duration of the project and for the supervision of the dissertation.

The van der Horst family enthusiastically took up the establishment of a charcoal producing site on their farm without which the project would not have been possible. I would like to thank them for their assistance and friendly hospitality.

I am also most grateful to the following:

Adre Malherbe and others involved in the local charcoal industry who willingly offered information and advice;

Staff in the departments of Materials Engineering and Survey at U.C.T. who lent time and equipment;

Philip Geerdts for assistance on the layout and presentation of the dissertation;

Bill Cowan, who at short notice, provided valuable advice at a critical stage;

Sasol for allowing deferment of work commitments to complete the degree;

To my parents for providing support, financial and otherwise, I would like to offer my warm thanks.

Finally, the general support of the staff and fellow postgraduates at the Energy Research Institute is kindly acknowledged.

Table of Contents

List of Tables

List of Illustrations

Chapter 1

INTRODUCTION

Certain invasive alien wood species have created an extensive problem for nature conservationists and landowners throughout South Africa. *Acacia Saligna* (Port Jackson) and *Acacia Cyclops* (Rooikrans) pose the greatest threat to the fynbos biome that occupies an area along the southern coastline. The bush clearing programs set up to curb the spread of these species in areas supporting indigenous vegetation and agricultural activity are expensive to maintain. The programs are also wasteful in that cleared bush is usually burned, destroying the biomass with no attempt being made to recover the energy in a useful form.

Two ways of offsetting bush clearing costs and making use of the wood are the harvesting of firewood or the production of charcoal. *Acacia Cyclops* is used as braai firewood and is widely harvested for this purpose. *Acacia Saligna*, on the other hand, is perceived to be a poor quality firewood and has little or no economic value. Conflicting reports in the literature exist as to the feasibility of using softwoods such as *Acacia Saligna* to produce a good quality charcoal.

Large scale commercial production of charcoal in South Africa is presently based on another invasive alien wood species *Acacia Mearnsii* (Black Wattle). Plantations of this species, cultivated for tannin production from its bark, produce large quantities of byproduct timber which provide a cheap and large source of raw material for a charcoal industry which is relatively capital intensive.

'The use of wood from the clearing of invasive bush is generally not suitable for large scale charcoal technology because:

- the present scale of clearing activities would not provide sufficient timber for a large scale operation;
- clearing activities are spread over a wide area where transport to a central facility would make the timber costs too high; and
- the irregular shape and size of the timber would generally reduce the efficiency of production.

Shaw (1989) thus proposed the use of low cost small-scale technologies along the lines of those used in other developing countries. The small scale would allow for operation on the "forest floor" as an integral part of bush clearing, following the receding bush and thereby eliminating costly timber haulage. In addition, if carbonisation is based on simple technology, unskilled labour could be given the opportunity of becoming involved in the production process. The low cost would also allow for ownership by unskilled labour and facilitate relatively easy entry to the charcoal market, thus creating new employment.

Shaw conducted a series of experiments using a variety of low cost small-scale production options and several alien wood species as raw material. A small community already involved in cutting of firewood from alien species was employed to clear bush and produce charcoal.

The most promising of these technologies in terms of the above criteria, the efficiency of the conversion process and the quality of charcoal produced appeared to be the Tongan drum kiln. The data obtained, although useful, was limited. Shaw showed that the wood cutters could double their income by producing charcoal rather than firewood. The community however reverted to firewood production whenever supervision was absent.

From these experiences it is clear that a more comprehensive study on both the technical and economic feasibility of this technology is necessary.

From the outset the study was limited to the Western Cape because of the extent of the infestation of alien species. The Western Cape also has a large potential charcoal market.

The technical assessment of the kiln therefore focuses on charcoal production from the most available species, *Acacia Saligna*, and involves an investigation into the following parameters:

- the yield obtained;
- the calorific value;
- density;
- proximate analysis of the charcoal; and
- the effect of raw material moisture content, size and carbonisation temperature on the above parameters.

An economic assessment of the technology involves assessment of a range of criteria. Shaw for example showed that the technology can facilitate wood cutters in earning increased income over firewood sales. The technology could be employment creating. Despite the existence of a large local charcoal market, the site set up by Shaw failed to produce charcoal on a continuous basis. It is therefore necessary to establish how competitive the technology is versus other methods of charcoal production. To assess this a commercial site with organised labour and a more formal infra-structure was established. The site facilitated an economic analysis under real production and market conditions.

A brief analysis of costs and income for a single road side operator is given. More detailed analyses are made for two production rates in the order of 3500 and 7000 five kilogram bags of charcoal per month. A distinction is drawn between two types of investor:

- a landowner who would already be in possession of several of the capital goods required for charcoal production; and
- an entrepreneur who would be starting out from scratch.

For each case the capital costs, fixed and variable costs, working capital and income are calculated. A cash flow diagram for a project life of five years is set up and the following investment indices are determined:

- the net present value;
- the discounted cash flow return;
- the payback period;
- the return on investment; and
- the breakeven cost of charcoal per bag.

In order to further assess the competitiveness of the Tongan drum kiln, comparative economic analyses of three sites in the Western Cape using different technologies are also made.

For each of the sites a sensitivity analysis is performed to explore the effects on the economic viability of the projects of changes in items contributing to cash flow.

The thesis is structured as follows:

- The literature on low cost, small-scale charcoal is reviewed with a focus on the production and use of charcoal in the developing world. The technologies associated with this production are identified. Included is a review of the characteristics of charcoal and the various factors that influence charcoal quality.

- This leads to the technical analysis of the Tongan drum kiln according to the parameters outlined above.

- Results from the experimental work and the technical analysis are then used to undertake an economic feasibility study of the kiln. This section includes a comparison with other charcoal producing technologies operating in a similar environment.

- Final conclusions evaluate the potential benefits of using the Tongan drum kiln for charcoal production in the Western Cape.

Chapter 2

LITERATURE REVIEW

2.1 Charcoal programmes in developing countries

Most applications of low cost, small-scale charcoal technologies are in developing countries and most of the literature on these technologies is focussed on case studies in the Third World.

Charcoal making is far from an exact science with most production methods in the developing world relying more on the art and skill of the charcoal makers than on any precise knowledge of the physics and chemistry of what is happening. Consequently even under reasonably good manufacturing conditions, it takes roughly four tons of wood to make one ton of charcoal. As a result, the cost of charcoal per unit weight will always be considerably higher than that of firewood in any particular location. All programmes in developing countries have focussed on decreasing this ratio thus improving the production rate and decreasing the cost.

This section reviews the scope and effect of charcoal programmes. A review of the technologies used in developing countries is given in section 2.2.
In all there are improved charcoal making programmes of one kind or another in 20-30 countries.

Nowhere have the efforts been greater or more persistent than in India where the Indian Forestry Service began promoting improved charcoal making techniques over a century ago.

It has however been recognized that the major difficulty in introducing new techniques is not technological. It is one of devising and implementing an organizational scheme that will offer employment using modern charcoal techniques on terms more attractive than those on which an individual can go into charcoal production using traditional means (Hughart, 1979).

2.1.1 Early initiatives

A paper written in India in 1884 describes an apparently improved design for a mound kiln. As is true of the vast majority of such reports, there was no follow-up account of what happened in practice.

Around the same time, interest was also roused in the use of steel kilns, while brick kilns were preferred by some foresters.

Another improved mound kiln which was said to be a considerable improvement on the crude though intelligent form of local charcoal making, was proposed by Indian foresters in 1908. Matters had not changed greatly by the 1920s and 1930s, despite encouraging results obtained from trials with imported steel kilns. Local charcoal makers continued resisting the improvements being urged upon them by foresters.

With the 1940s there came further efforts in India to introduce improved techniques. There also appear to have been sporadic efforts to improve existing charcoal making techniques or to introduce new kiln designs in a number of other countries. None however seems to have had any major impact (Foley, 1986).

2.1.2 Uganda in the 1960s

During the early 1960s, the Uganda Forest Department was engaged in a very active programme of forest management.

This involved selective logging for commercial purposes and the poisoning of non-commercial trees. This poisoning was expensive and caused problems when the dead trees collapsed. It became apparent that if the forest management was to be carried out on an economic basis the costs would have to be reduced.

In 1963, charcoal makers using traditional earth kilns were issued with licenses to make charcoal from the waste wood left from logging and sawing

operations. The scheme was popular with charcoal makers and their number rose within a year from 30 to 200.

In 1964, the charcoal makers were encouraged to cut down the dead trees and from 1965 onwards poisoning was stopped, with unwanted timber being felled by the charcoal makers.

In 1965, a small steel kiln was tested and showed promise. In 1966, a charcoal company was formed, making charcoal in portable steel kilns.

Without displacing the earth kiln the production using steel kilns grew and, by the middle of 1970, 32 commercial companies were using a total of 99 kilns. They produced half of the total Ugandan charcoal output.

The rise to power of Idi Amin in 1971 put an end to most of these imaginative efforts (Foley, 1986).

2.1.3 Programmes in the 1970s and 1980s

Experiments using a number of different types of kilns were carried out in Ghana in the mid 1970s. The most successful steel kiln was used in training people as charcoal workers. This did not gain wide acceptance and many kilns were abandoned. The main difficulties were the cost of the kiln and the need for skilled operators.

In the late 1970s, charcoal making was introduced into Subri Forest Reserve in the rain forest area of southern Ghana as part of a forest management strategy being developed there. The scheme relied upon the approach previously used in Uganda. After initial success, the continuation of this project by the end of 1982 looked extremely doubtful as a result of the country's financial position and the threatened withdrawal of support by foreign funding agencies.

Elsewhere, in West Africa a project to improve on the traditional pile technique of making charcoal was introduced which resulted in substantially higher yields with little extra capital outlay. The ensuing higher profits lead to its ready acceptance (Ellis, 1982).

Kawanguzi et al (1987) report that the Katugo kiln developed by the Uganda Forest Department and built from locally produced bricks produced good quality charcoal at a conversion efficiency of 2 to 3 times that produced from traditional kilns. The development of this kiln led to added benefits for the

local work-force which received training in the use and maintenance of modern hand tools, as well as skills in the construction and maintenance of the kilns.

The results of a survey on the use of the new kiln method were strongly in favour of permanent charcoal kilns, principally for the creation of employment in rural areas. The kilns attracted people from neighbouring districts, and educational and medical facilities received more emphasis. Local agricultural markets then expanded, in turn increasing the general level of prosperity.

Katugo kilns have been introduced throughout Uganda and many large scale commercial kilns have been constructed. Also many small industries have used the design.

Charcoal projects have been introduced to over 20 developing countries including Guyana, Jamaica, Fiji, Liberia, Dominica and Bangladesh. Few reports on these projects are available.

In Sri Lanka where large areas of forest were scheduled to be cleared for a dam and irrigation scheme, a project was undertaken in 1981 to promote the manufacture and use of charcoal. There have, however, been severe financial problems and progress on the project has been slower than anticipated.

The use of charcoal, which prior to 1978, was unknown in Papua New Guinea, was promoted because of its considerable forest reserves. A range of metal kilns were introduced for manufacture as well as a charcoal stove. The project had little practical impact. The demonstration programme was subsequently reorganized and the stoves redesigned. By 1982 charcoal industry and cooking had an established foothold in Papua New Guinea (Foley, 1986).

2.2 Charcoal technologies

One of the most common ways of comparing different charcoal making methods is on the basis of their yields, but the present position in the presentation of test results is far from satisfactory.

In the literature for example, it is common to find charcoal yields expressed in terms of the mass or volume of charcoal produced from a given stacked volume of wood. For the assessment of the relative yields of different charcoal making techniques, measurements by mass are essential and are used throughout this review unless otherwise stated. But even when mass measurements are used, the lack of agreed standards and methods of measurement leave room for considerable error.

One of the most basic problems is knowing what, in any given context, is meant by the charcoal yield. Reports rarely state whether charcoal fines are included as part of the charcoal product and what the moisture content of the product is. There is also no consistent method of dealing with the moisture content of the original wood. It is probable that in most cases the yield is expressed as a proportion of the wet mass of the wood (Foley, 1986). In other cases the yield is expressly based on the oven dry mass of the wood. The difference between the two methods can be quite significant.

It is important to realize that the yield obtained in a kiln is not the only, or necessarily the most important, factor determining the final cost of the charcoal (Foley, 1986). Transport, loading and packing can make up to 25% of the production cost. The investment capital and the amounts of labour involved in wood preparation and kiln management must also be taken into account. Lack of capital and surplus labour in the developing world make cheap, labour intensive production methods more attractive (Kristoferson et al, 1984).

2.2.1 Earth mound and pit kilns

One of the simplest methods of charcoal making is the earth covered mound kiln. In this the wood is stacked in a pile, on the ground, covered with vegetation and then a layer of earth. It is as old as charcoal making, and with pit kilns, is by far the most widespread method presently in use in the developing world (Baldwin, 1987).

The size varies from a few cubic metres to 100 m³ or more (Foley, 1986). Baldwin (1987) reports kilns of 200 steres (1 stere = 1 stacked cubic metre).

In many parts of the world charcoal is traditionally made in a pit dug into the ground. As in the earth mounds the pits are covered with grass and leaves and sealed with an earth layer. Sizes vary from 1-2 m³ to 30 m³. For a simple illustration of pit and earth mound kilns see figure 2.1 (1),(2) and (3).

(a) Yields

A large variation in yields is reported for the mound kilns varying from 10 to 30%. In some cases charcoal makers using mound kilns make a living with yields of 6% or less (Foley, 1986).

Pit kilns have an equally large variation with reports from 12-30%. In Malawi, production efficiencies range from 20-25% (Chamaere et al, 1984). Averages from various areas have been reported as 14,7-20%. Kristoferson et al (1984) report average yields according to mass as 15-17% for mound kilns and 5-15% for pit kilns.

(b) Technical choice factors

Pit and earth mound kilns can be built wherever required and adapted to size and shape of wood. They also require no capital investment and waste wood can be brought to productive use with a minimum of investment in equipment. However, high levels of skill in traditional charcoal making methods are only achieved with prolonged training and practice.
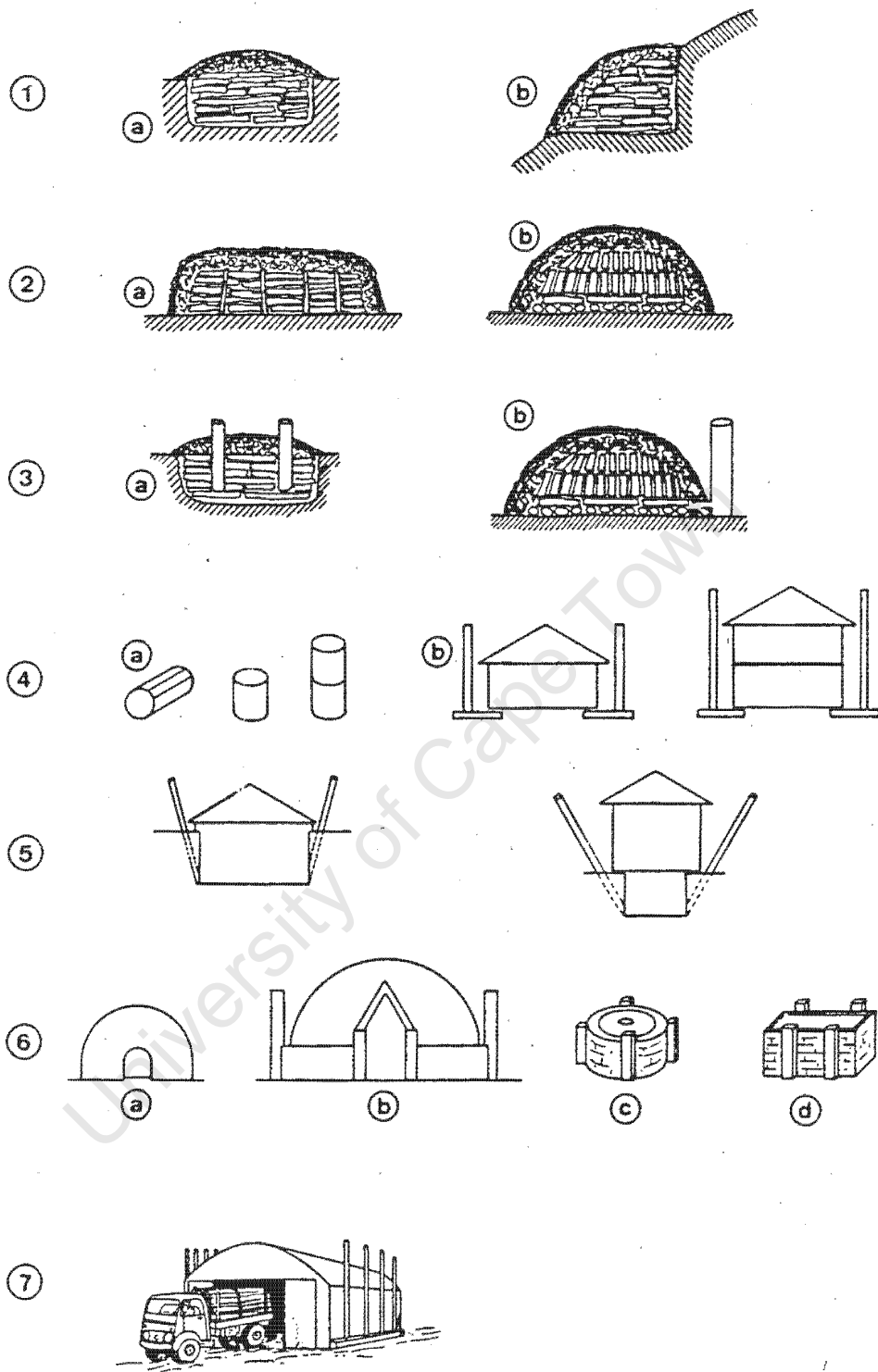
Figure 2.1 Different types of charcoal kilns

Source: ILO (1985)

2.2.2 Portable steel kilns

A large variety of steel kilns have been developed over the past two centuries. They were widely used in the wood distillation industry with the recovery of volatiles being the most important aspect of their operation. Portable types came into use mainly for charcoal making in forest areas. Their sizes vary from 3,5-10 m³ (Foley, 1986). See figure 2.1 (4) and (5). A garage type portable steel kiln used widely in South Africa is the Armco kiln (described in section 4.5.1). This kiln is made from individual steel plates that are bolted together.

(a) Yields

As with the previous kilns discussed a wide range of yields have been reported. Average yields vary from 22-34,1% with reported yields up to 37% (Foley, 1986). Kristoferson et al (1984) reports average yields as 20-25%.

(b) Technical choice factors

Portable steel kilns have a small output. They are not therefore particularly suitable for areas where there is a need for high volume production. Their ideal application is where the source of wood is dispersed and charcoal making is carried out on a relatively small scale.

It requires less labour than the small earth kiln and has a generally greater yield of more consistent and higher quality charcoal. It is also much quicker.

The major disadvantages of the portable steel kiln is its capital cost, even with local manufacture. Given a working life of 2-3 years, it can be very difficult to justify economically in areas where labour costs and charcoal prices are low.

2.2.3 Brick and concrete kilns

Kilns are built in various shapes and sizes from bricks, fired clay or cement. Sizes vary from 8,5-336 m³ (Foley, 1986). See figure 2.1 (6) and (7).

(a) Yields

Average yields from kilns used over a long period have been given as 26 to 30%. The Brazilian beehive kiln has a reported 25% efficiency using wood with a 30% moisture content (Huy, 1984). Other reported yields vary from 12,5-23,5%, with averages around 17% (Foley, 1986).

(b) Technical choice factors

These types of kilns are relatively simple and cheap to construct in areas where bricks and the necessary skilled labour is available. They have a lifespan of 5-8 years (Kristoferson et al, 1984). The kiln, however, is a permanent structure and must be situated near a readily accessible supply of wood.

It is therefore not appropriate for low intensity forestry operations carried out in different locations every year. It is however a most appropriate technology when situated close to a large supply of wood. It has a relatively quick carbonisation cycle and is much easier to operate than an earth kiln. For some kilns heavy investment costs make them difficult to justify when labour costs are low.

2.2.4 Retorts

The retort differs from the kiln in the manner in which in which the heat for carbonisation is generated. Kilns develop the heat required by combustion of a part of the charge packed into the equipment for carbonisation. The retort is heated from an external source until the wood gas generated is dry enough to burn. Thereafter heat is supplied by the gas combustion.

There are few reports of low cost retort designs appropriate to the developing world and no reports of their operation and efficiency. A low cost design is briefly examined in section 2.3.2.

2.2.5 A comparative look at various kilns

The following average conversion figures and relative costs were given by Openshaw (1983) for African conditions.

Table 2.1 Kiln efficiency and cost comparison

Kiln type	Tons of air dry wood (15% moisture) to produce 1 ton of charcoal	Relative cost
Earth	10	1
Portable steel	7	20
Brick	5-6	140
Retort	4.5-5	1000

The following characteristics of charcoal making devices were summarized by the National Academy of Sciences (1984) as follows:

Table 2.2 Kiln efficiency, operation and cost comparison

Kiln type	Capital cost ($US 1976)	Useful life (yrs)	Wood consumption (per ton charcoal)
Earth pile	none	one firing	8-12
Pit	small	1-2	7-8
Portable steel	1000	3	5-7
Brick	800	5	5,7
Retort	2 000 000	30	3,5

2.3 Charcoal production in South Africa

2.3.1 Commercial production

An estimated 370 000 tons of dried timber (10% moisture) was used for charcoal manufacture in 1982 (Bennie, 1982). Black wattle accounts for 92% of wood consumed. 75% of this is in the form of plantation wastes. Eucalyptus and pine account for 8% of charcoal produced.

Most manufacturing takes place in a relatively sophisticated and organized manner with the use of brick, cement and cylindrical steel tank kilns.

Manufacturing costs were given as R60,00 to R90,00 per ton of charcoal with labour costs at 24% of the total cost, and equipment accounting for 35% (Bennie, 1982).

Yields vary on average from 15.9-20,5% (Bennie, 1982). Cohen (1982) quotes yields from 12.5-25%.

2.3.2 Low cost small scale production options

Shaw (1989) undertook an investigation into the potential of using low cost charcoal production technologies to manufacture charcoal from biomass generated by the clearing of alien bush.

His work focussed on the use of the softwood, *Acacia Saligna*. It has been shown elsewhere that the carbon content and calorific values of charcoal produced from softwood are of the same order as that produced from hardwood (Yatim et al, 1987). He also evaluated the possibility of exploiting the perceived advantages that charcoal possesses over wood in transportation to open up unwanted stands of alien wood species as ready made woodlots to areas needing fuelwood.

Shaw selected four small scale technologies for evaluation. Selection was based on transportability, simplicity in construction and operation, cost and charcoal production yield. Three kilns and one retort design were selected: the TDRI kiln, the Tongan drum kiln, the CUSAB kiln and the Vita retort.

No experiments were conducted with pit kilns as the sandy soils in the Cape do not easily support construction of the pit. The kilns were evaluated and the following results were obtained.

(a) TDRI metal drum kiln

This kiln is made up of two cylindrical sections and a conical lid, fitting together to make up a steel container with a diameter of 2,3 m and capacity of 7,5 m^3 (see figure 2.2). Construction and materials cost were R3 100.
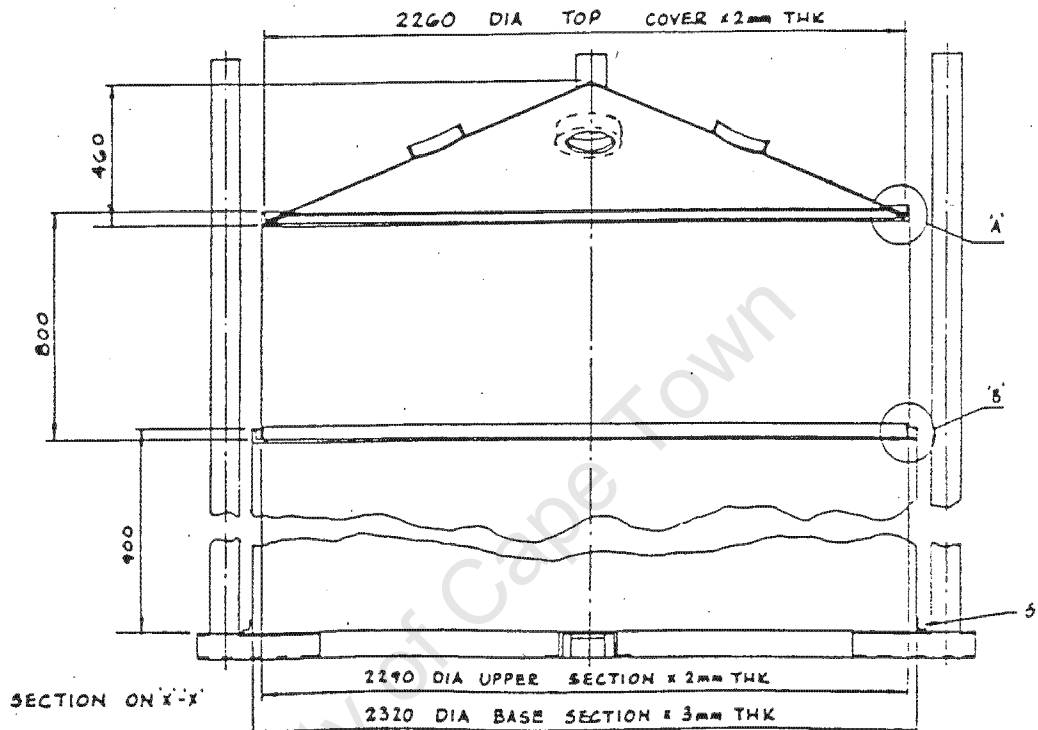
Figure 2.2 The TDRI metal drum kiln

Source: Paddon (1979)

A number of experiments were conducted, but the results proved to be inconsistent. This kiln has a 2-3 day turn around producing between 250 to 400 kg per run with yields of 17-31% on an oven dry wood basis. Experience in kiln operation appeared to play an important part in the results. As a result it is not well suited to unskilled labour. Manual cutting of timber would allow charcoal production at costs ranging between R150-R320/ton at labour costs of between R5-R10 per day.

(b) CUSAB kilns

Carbonisation of brush, 45% of the biomass produced during bush clearing, was found to be possible through use of a kiln design similar to the TDRI kiln (see figure 2.3). A very fine charcoal was produced with yields varying

between 5 and 44%. Briquetting of fines is a necessary, but expensive option for the production of a saleable product.
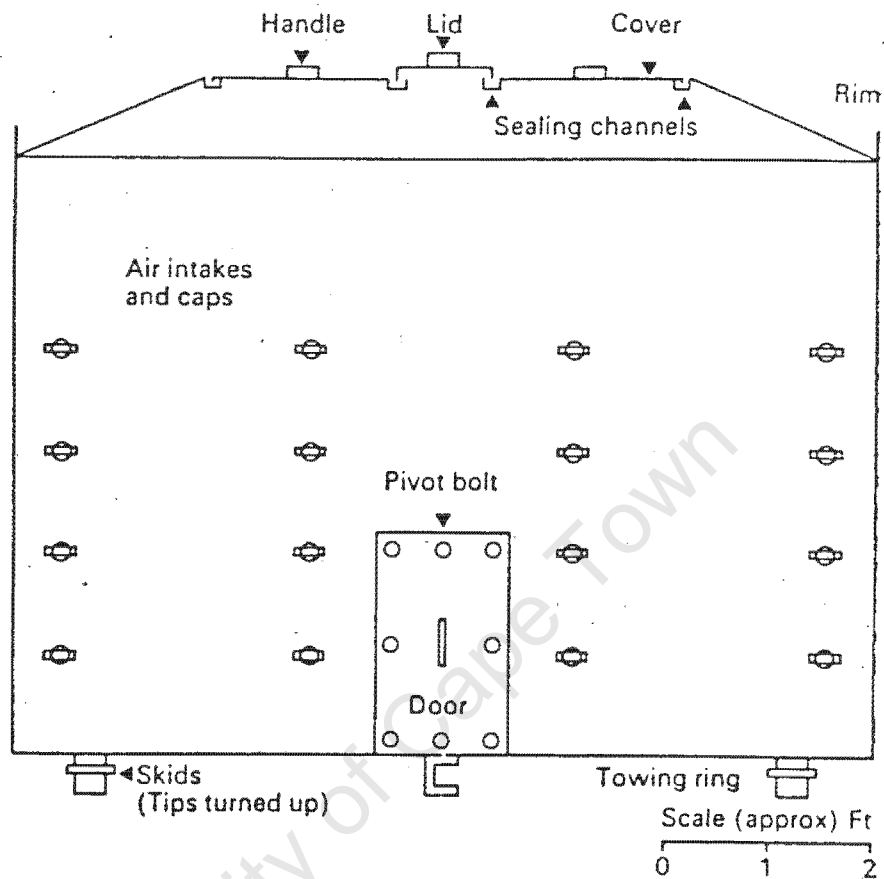
Figure 2.3 The CUSAB kiln

Source: Shaw (1989)

The cost of fine charcoal produced was found to be R30-R35 per ton at a R5 per day labour rate.

(c) Vita retort

An attempt was made to produce charcoal from a simple retort design similar to that illustrated in figure 2.4. The reason for selection was primarily because the technique could conceivably use both brush and timber from bush clearing. However, problems experienced with sealing of the vessel and buckling of metal walls after only two runs indicated a very short lifespan for this design. Low cost retort technology was therefore considered inappropriate for carbonisation of bush clearing residues.
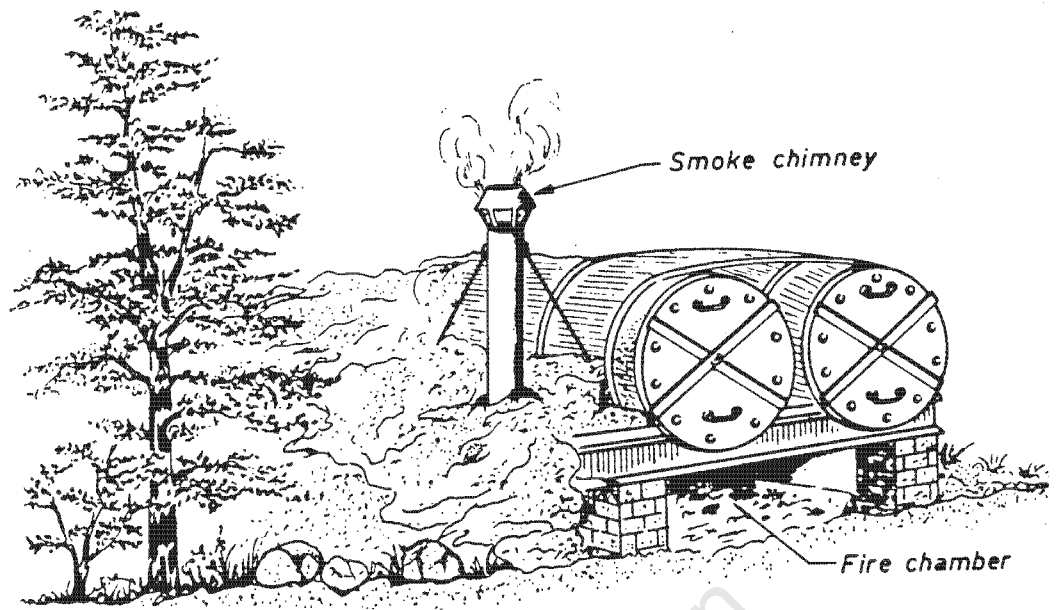
Figure 2.4 The VITA retort

Source: Emrich (1985)

(d) The Tongan drum kiln

As the name suggests, this kiln was developed in Tonga when the need arose for converting coconut shells and wood to a saleable product. Based on the 210 litre drum it is extremely versatile, mobile and ideal for small-scale operators (see figure 2.5).
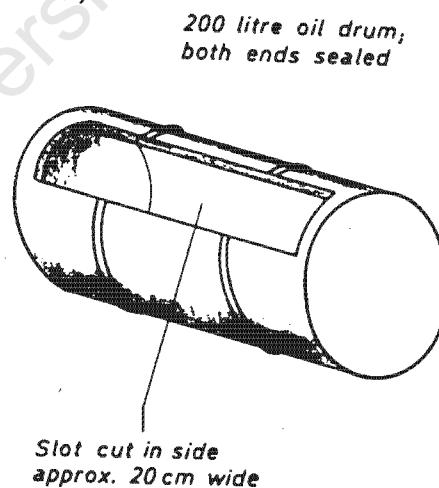
Figure 2.5 The Tongan drum kiln

Source: Emrich (1985)

The carbonisation cycle is typically 6 hours with cooling over night. Charcoal yields of 9% to 35% (including fines) were achieved, producing 8-30 kg per

drum (Shaw, 1989). Wood cutters operated the kilns extremely well, highlighting the suitability of this design for small scale entrepreneurs. Production costs ranged from R190 to R480 per ton for manual wood cutting at R5 and R10 per day.

Kristoferson et al (1984) report charcoal makers obtaining 12-15 kg per firing, with one person operating 10 drums. They quote a 4-8 hour cycle; a carbonisation period of 2-3 hours followed by a cooling period of 3 hours. Yields of about 23 % are reported, increasing to 27-29% with fines included.

Emrich (1985) reports a carbonisation time of 1 hour and a cooling period of 6-8 hours.

Oil drum kilns last for about six months and the capital investment of purchasing used drums can be recovered after one firing (Michaelis, 1986).

2.3.3 Integration of charcoal into bush clearing

As explained in Chapter 1, one of the options for clearing bush is through charcoal production. Two alternatives for use of charcoal production are open to the land owners requiring extensive clearing operations. The owner (or administrator) may invite small entrepreneurs to produce charcoal from alien wood species, or he may integrate a charcoal producing unit to an existing bush clearing operation.

The Tongan drum is ideally suited to small entrepreneurs because it allows entry in the market with very little capital outlay (R10 per drum). Earnings through sale of charcoal can be twice that earned from cutting firewood and require total capital costs of about R140 to clear 0,5-1,2 ha/month (Shaw, 1989).

The TDRI and CUSAB kilns are better suited to integrated bush clearing and charcoal production but with capital costs in excess of R6 000 associated with clearing 0,5 ha per month.

2.3.4 Charcoal as a fuel for underdeveloped areas

Prevailing labour rates and realistic charcoal production costs associated with alien wood utilization involve economic break-even distances of 20-60 kms, compared with firewood transport, implying that charcoal in many cases will be more cost effective than wood (Shaw, 1989).

Comparisons with the cost of coal in several areas in South Africa however, show that charcoal will generally be unable to compete unless produced from wood wastes obtained at zero cost. As a result, charcoal cannot be expected to provide a solution to the fuel shortages of the underdeveloped areas in South Africa (Shaw, 1989). If there is limited opportunity to develop charcoal production as a substitute to wood for underdeveloped areas, it is necessary to consider the broader commercial market in South Africa.

2.4 The charcoal market

2.4.1 The South African market

The charcoal industry in S.A. grew by 30% per annum in volume of charcoal produced from 1976 to 1982 (Bennie, 1982).

In 1980 the production of charcoal amounted to 80 000 tons. This was divided between briquettes(11 700 tons), fines(1 000 tons) and lump charcoal(67 300 tons) (Cohen, 1982).

By 1981/1982, the production had grown to 104 000 tons, with a forecast of 220 000 tons for 1985 and 500 000 tons for 1990 (Williams et al, 1987).

The charcoal production by mass is distributed geographically as follows:

Transvaal	44,5%
Natal	52,9%
Cape	2,6%

Charcoal consumption in various sectors is given as follows (Bennie, 1982):

Industry	36%
Braai Market	33%
Export	31%

2.4.2 Export markets

The estimated total quantity of imports by all countries in 1983 is 427 000 tons. See Table 2.3 for details.

Table 2.3 Principle countries importing and exporting charcoal

Importing Countries	Quantity [tonnes]	Exporting Countries	Quantity [tonnes]
Saudi Arabia	12 000	South Africa	10 000
Netherlands	14 000	Portugal	12 000
Sweden	16 000	Philippines	18 000
United Kingdom	21 000	Malaysia	19 000
Bahrain	27 000	Singapore	28 000
Japan	34 000	Sri Lanka	30 000
France	57 000	Indonesia	36 000
Malaysia	61 000	Thailand	70 000
West Germany	64 000	Spain	90 000

Source: Foley (1986)

Although figures do not appear in official records, information from local producers indicates that there is a substantial illegal export trade in East Africa to Arab countries. Kenya, for example, reportedly had a firm that exported 91 000 tons of charcoal to Qatar in a 6 month period in 1984, despite the existence of a government ban on charcoal exports (Foley, 1986).

2.4.3 Internal consumption patterns

(a) Domestic consumption

In South Africa there is no traditional use of charcoal in developing areas. The non-industrial use of charcoal is confined to urban areas and is restricted to the luxury braai market. However, charcoal is used widely by households in the rest of Africa.

In Zambia the annual consumption of urban consumers is estimated to be 168 kg/capita. For Malawi the average urban household consumption is given as 540 kg per year (Malawi Energy Studies Unit, 1984). The annual consumption for luxury purposes in Botswana is estimated at 40 tons (Alidi, 1984).

The total quantities of charcoal officially recorded as entering Dakar in 1978 indicated an average annual consumption per capita of about 100 kg. In Tanzania widely different annual consumption figures are reported from 170

to 353 kg per capita (Foley, 1986), while in adjacent Zaire a consumption of 36 kg per capita was reported (Development Assistance Corporation Proceedings, 1982).

A survey in the town of Bara in central Sudan in 1977/78 showed annual average consumption to be 420 kg/capita; surprisingly high for an arid area where wood supplies were reported to be growing scarce. Further westwards in Bamako, in Mali, average annual consumption was just 17 kg/capita in comparison with 370 kg/capita of firewood (DAC Proceedings, 1982).

As indicated earlier in the work of Shaw (1989) charcoal is unlikely to be used to alleviate fuel shortages in South Africa's developing areas.

(b) Small scale commercial and artisanal use

Charcoal is used in a variety of small industries and handcrafts. The association with metal working is very strong; blacksmiths, foundries and metal workshops are substantial users of charcoal in many places.

Charcoal is used in the working of precious and semi precious metals. Gold and silver smiths use it in India, Bangladesh, Ghana and other countries. It is also used in smelting and working of iron, tin, copper and in kilns for firing pottery.

Commercial enterprises such as tea and coffee shops, restaurants, hotels, laundries, street vendors use charcoal for its convenience. In Malawi it is used for drying fish, meat and other food products (Chamaere et al, 1984). A total non-household urban charcoal consumption of 400 tons was reported for Malawi in 1983 (Southern African Development Co-ordination Conference Energy, 1987).

Bara in the Sudan had an average annual consumption for its two blacksmiths of 3,6 tons per year; the town's seven tea shops used an average of 6 tons each. Sierra Leone records a total of 3 000 tons being used in metal working per year.

An estimated 309 000 tons of charcoal are used in restaurants, food vendors and temples in Thailand which is about 10% of the total estimated consumption (Foley, 1986).

(b) Large scale industrial use

The Brazilian steel industry used 4,1 million tons of charcoal in 1981 (Foley, 1986). In 1983 about 18% of energy used in the Brazilian steel industry came from charcoal (Baldwin, 1987). In addition, in 1981 the cement industry used 270 000 tons.

In Malaysia, the steel industry is a considerable user, and charcoal production for industrial purposes in 1980 was estimated at 132 000 tons. In the Philippines the steel industry used 210 000 tons in 1983.

In the Zambian copper belt 45 000 tons of charcoal are used per year for copper smelting (Foley, 1986).

2.4.4 Forecasts of future charcoal demands

There have been many projections of large increases in the domestic consumption of charcoal in line with the population growth.

Extreme caution is needed before demand projections are used as the basis for charcoal making programmes or creating tree plantations to supply them. The processes by which fuel demand changes with time in any given society tends to be complex and difficult to predict. It cannot be assumed that patterns of consumption remain unaltered as supplies become scarce, prices rise, cities become larger, and the economic circumstances of customers change.

Charcoal is however used predominantly in urban areas. With the present increase in urbanization the use of charcoal is thus likely to increase (Kristoferson et al, 1984).

As an example of forecasts of increased domestic demand, in 1980 the estimated production of charcoal in Zaire was 450 000 tons and the projected production by 2000 is given as 836 000 tons (DAC Proceedings, 1982).

2.5 Charcoal vs firewood

Charcoal has about twice the energy content of wood per unit mass. This means that its transport cost, per unit of energy, will be about half that of wood, assuming that mass is the limiting factor on the load being carried.

There are thus two counterbalancing factors determining the cost per unit energy of charcoal and firewood when they are delivered to a city market. At the point of origin, when they are being loaded onto the truck, the charcoal is substantially more expensive. However for each kilometre it is carried, there is a saving in its transport cost compared with that of the firewood.

The greater the distance the charcoal is carried, the more this is able to offset its higher initial cost. At a certain distance from the city, there is therefore a point at which, in principle, the combined transport and production costs of the two fuels, per unit energy, are equal.

Some writers have referred to this as the "break-even distance" for wood and charcoal transport. Using East African data for 1970, Earl (1975) calculated it to be 82 km. It is given elsewhere as 100 km (ASSET, 1981) and 95 km (Boutetie et al, 1984). Shaw's (1989) estimates for the Western Cape (see section 2.3.4) are 20-60 kms.

Leach et al (1987) show that with available data the maximum distances for which firewood and charcoal can be transported competitively are 170 km and 990 km respectively. This gives a distance ratio of 1 : 6. However, the area from which fuels can be transported competitively is in the ratio 1 : 36. As seen above, assessments put the distance over which wood can be transported economically at 82-100 km. The firewood supply area for a centre would thus be only 3% of the charcoal supply area.

Boutetie et al (1984) assert that this break-even point can be drastically reduced depending on the relative efficiency of charcoal and wood stoves. The break-even point is also dependent on the wood moisture content. They also show that for a West African situation, improving the efficiency of the production method, thus reducing the cost, can make charcoal a competitive fuel in urban areas.

Baldwin (1987) disputes this transport theory. Transport costs, he claims, are primarily due to vehicle depreciation and maintenance, therefore the cost of hauling wood or charcoal is the same per unit of energy carried.

Baldwin (1987) asserts (see Table 2.4 and Table 2.5) that one cannot follow the standard practice of expressing transport costs in terms of ton-km's. In the developing world transport is more often limited by volume than by mass. In the case of volume limited transport, 13% more energy can be transported per truck load of wood than of charcoal at a cost of a 21% increase in fuel use. When production costs are included, charcoal is more expensive than wood. He gives the price per GJ of charcoal as being typically twice that of firewood.

Despite its higher price, charcoal is a popular fuel. This is attributed to the following:

- it resists insect attack. It can therefore be prepared in
  advance of, for example, the rainy season when other fuels are
  unavailable.

- it is convenient to use. It is nearly smokeless allowing cooking
  to be done indoors. It also requires little attention when lit.

- it does not have to be cut up by the consumer and contains
  more energy than an equivalent mass in wood.

Charcoal production is made difficult by various inhibiting regulations in several countries (Boutetie et al, 1984). These regulations are however difficult to enforce as long as there is a demand for charcoal.

Table 2.4 Energy required to transport wood and charcoal

Factor	Wood	Charcoal
Assumed volumetric gravity	0.7	0.33
Assumed packing density	0.7	0.7*
Effective volumetric gravity	0.49	0.23
Energy content per truckload	390 GJ#	345 GJ **
Mass per truckload	24.5 MT##	11.5 MT ***
Transport energy per truckload-km	35.3 MJ/km	29.1 MJ/km
Transport energy per km/energy content of load	$91*10^{-6}$	$84*10^{-6}$

#GJ is a gigajoule; ##MT is a metric ton, 1000 kg

* Charcoal may have a higher or lower packing density depending on its size and whether or not it is bagged for transport. It is normally packed for transport.

** Assumed calorific value for wood, 16 MJ/kg; charcoal, 30 MJ/kg; both including moisture.

*** Based on a payload volume of 50 m^3. This is less than a standard tractor trailer, but was chosen so as to remain within the limits of the correlation of mass to transport energy, yet correspond to the case for most developing countries of volume limited transport for either wood or charcoal.

Source: Baldwin (1987)

Table 2.5 Transport costs of wood and charcoal

	Wood [% of total]	Charcoal [% of total]
Labour and management	12	12
Fuel	18	15
Maintenance and repair	40	30
Licence and tolls	1	1
Vehicle depreciation	42	42
Total costs	113	100
Energy hauled	113	100

Source: Baldwin (1987)

2.6 The physics and chemistry of charcoal

Charcoal can be made from virtually any organic material. Wood, straw, coconut shells, rice husks, bones and a variety of other substances have all been used. Wood is by far the most common raw material and generally yields the best charcoal. Among tree species, hardwoods are usually regarded as the most suitable.

Charcoal is normally produced in kilns. Part of the wood is used for the initial combustion after which sufficient heat is produced by the carbonisation process itself. In retorts wood is heated by an outside source of heat.

The basic steps by which wood is converted to charcoal are the same.

2.6.1 The charcoal making process

Three distinct phases can be distinguished.
- Drying
- Pyrolysis
- Cooling

In practice there is often a considerable overlap between these; thus pyrolysis may be well advanced in one area of the kiln before drying is complete in another.

(a) Drying phase

Before wood can be carbonised, the water it contains must be driven off. This happens in two distinct stages.

The first is when the water in the pores of the wood, the free water, is expelled at a wood temperature of about 110°C. When this is complete, the temperature rises to 150°C, and the more tightly bound or absorbed water is released. This continues and the temperature rises to 200°C.

(b) Pyrolysis phase

With the continued application of heat, the temperature of the wood rises further. At around 270-280°C the pyrolysis reaction begins to occur. Pyrolysis is a term which is loosely applied to describe the set of processes which take place when the chemical structure of wood breaks down under high temperature and in the absence of air.

The breakdown of the wood cellulose, hemicellulose and lignin during pyrolysis results in the evolution of a complex series of chemical substances referred to as the pyrolysis products. Because most of these are driven off in the form of gas or vapour, they are often described as the volatiles. The presence of the volatiles causes the colour of the smoke coming from the charcoal kiln to darken, thus indicating that pyrolysis is underway.

The temperature reached during pyrolysis depends on the size of the charge of wood being carbonized, the geometry of the kiln, the degree to which the manufacturing process is insulated against heat loss, the ambient temperature, the original moisture content of the wood and a variety of other factors. In most small-scale traditional methods of manufacture, the maximum temperature reached tends to be about 400-500°C, but in some types of kilns, temperatures of up to 600-700°C are obtained.

(c) Cooling phase

As the pyrolysis reaction draws to completion, the temperature in the charge of wood begins to fall. The amount of smoke given off from a charcoal kiln drops substantially and its colour changes to a pale blue.

The kiln must be kept tightly sealed at this stage. If air is admitted before the charcoal has fallen below its ignition temperature, there is a danger of the whole load bursting into flame and being lost.

When it has cooled sufficiently, the charcoal is ready to be packaged and transported.

2.6.2 The properties of charcoal

One of the key properties of charcoal is the amount of pure carbon it contains. This determines, for example, whether it will be suitable for domestic or industrial use.

Other important properties of charcoal include its moisture content, ash content and calorific value. They depend on both the raw material from which the charcoal was made and the manufacturing method used.

(a) Fixed carbon content

The pure carbon content of a sample of charcoal is obtained by deducting the moisture, volatile and ash contents from the total mass. It is usually expressed as a percentage and is referred to as the fixed carbon content.

The proportion of carbon in the final charcoal depends principally on the maximum temperature reached during carbonisation and the length of time spent at that temperature. Figure 2.6 shows the relationship between the carbonisation temperature and the charcoal composition.

The fixed carbon content of the charcoal produced by traditional methods of manufacture is usually in the range of 70-80% (Foley, 1986).

The optimum fixed carbon content depends on the end use to which the charcoal is being put. Charcoal required for industrial or metallurgical uses should have a fixed carbon content of 80-90%.

(b) Volatile content

The volatile content is determined by heating a sample of dry charcoal in the absence of air at a temperature of 900°C until it reaches constant mass.

Under most working conditions the minimum volatile content is about 10%. Foley (1986) quotes results from charcoals made by traditional methods as having volatile contents from 8% up to a maximum of 47.3%, with an average of 22%.

When charcoal is intended for domestic cooking, a higher volatile content is required. This makes the charcoal less friable and easier to light. A minimum volatile content of 20-30% is usually desirable.

(c) Calorific value

The gross calorific value of a particular charcoal depends on the proportion of fixed carbon and volatiles which it contains. Most of the substances contained in the volatiles have a lower calorific value than carbon and, as a general rule, the higher the volatile content the lower the calorific value. For most charcoals, the gross calorific value falls within the range 28-33 MJ/kg.

The net calorific value also depends on the water content of the charcoal. A net calorific value of 30 MJ/kg is frequently taken for calculation purposes; a value of 28 MJ/kg is probably more realistic for the charcoal used as a domestic fuel (Foley, 1986).

(d) Ash content

This consists of mineral matter such as calcium and magnesium oxides. The ash content varies in accordance with the tree species used. In most cases, the ash content is in the range 0.5-5.0%, with a figure of 3% being fairly typical.

(e) Moisture content

Freshly made charcoal has a zero water content but rapidly absorbs moisture from the air. The equilibrium moisture content of charcoal with a low volatile content tends to be 3-5% by mass. With increasing volatiles the absorptive capacity becomes greater and the equilibrium moisture content may be as high as 15%.

2.6.3 Factors influencing charcoal yields

A large number of factors affect the yield of charcoal obtained from a particular manufacturing method. Two of the most important of these are the maximum temperature reached during carbonisation and the moisture content of the wood.

(a) Carbonisation temperature
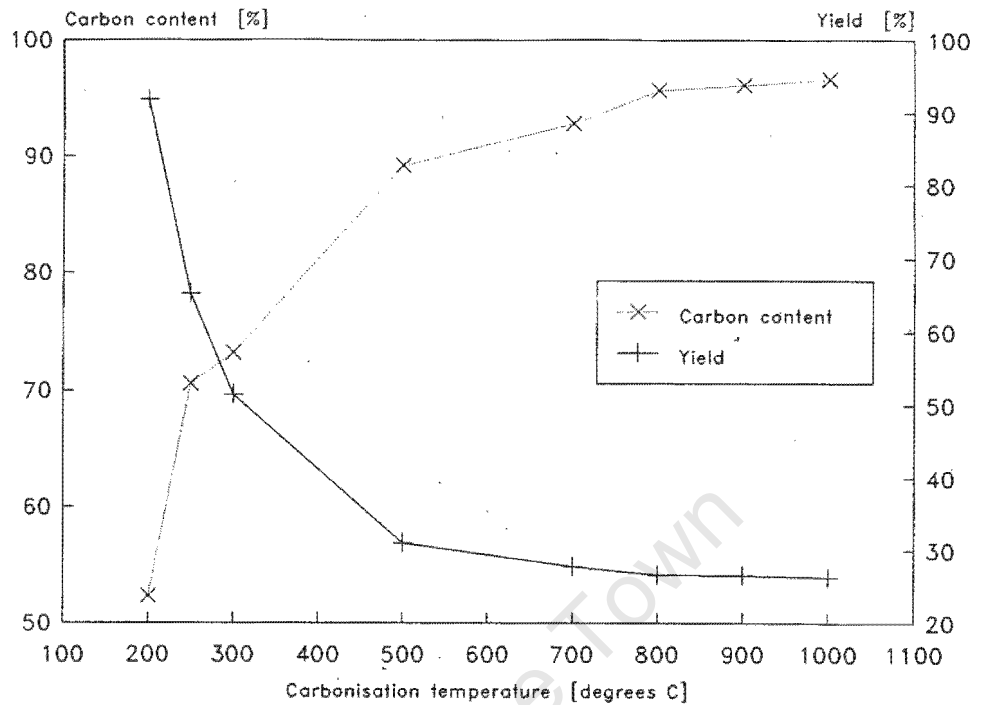
Figure 2.6 The effect of carbonisation temperature on yield and fixed carbon content of charcoal (carbon content and yield on a dry basis)

Source: Gore (1982a)

The effects of carbonisation temperature on the yield and fixed carbon content when charcoal is made in a retort are shown in figure 2.6. These figures, being based on laboratory tests using a retort, cannot be used to predict the exact yields obtained in practice. In general, the yields from kilns operated under practical conditions will be considerably lower than those shown (Foley, 1986).

(b) Moisture content

The water content has a bearing on the final yield because it determines the portion of the charge which has to be burned during the drying phase. This is shown in figure 2.7 for wood with a range of moisture contents.

A high initial moisture content also reduces the maximum temperature reached during carbonisation. In addition, it extends the carbonisation time.
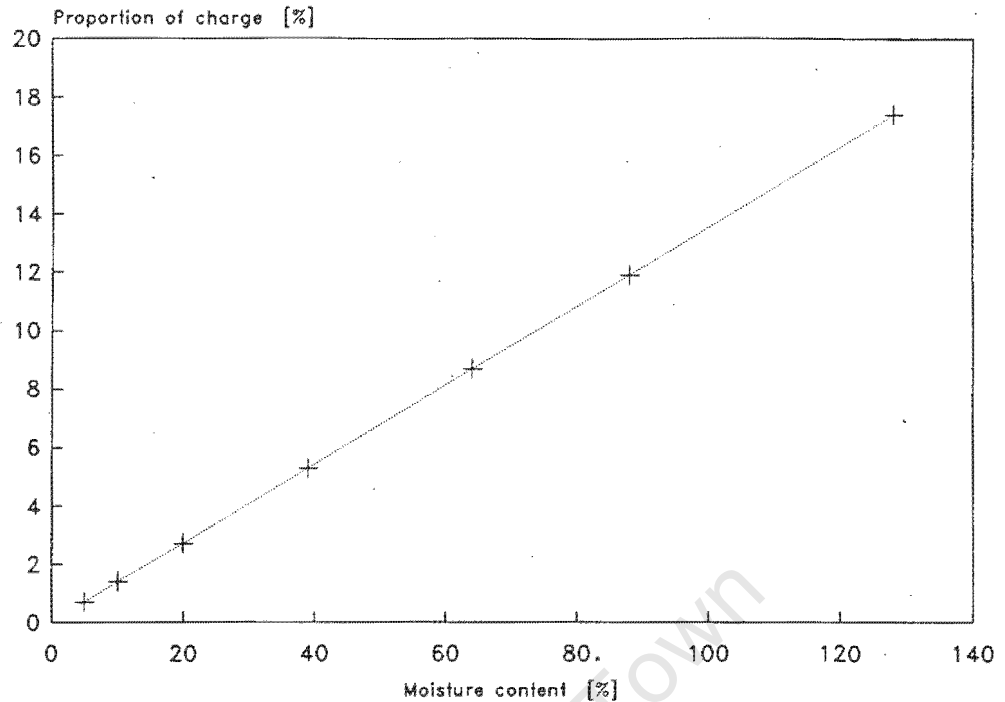
Figure 2.7 The proportion of wood charge required to evaporate water contained in wood during charcoal making (moisture content on a dry basis; wood charge as a percentage of oven dry mass)

Source: Gore (1982a)

The influence of moisture content on the final yield is therefore very complex. There is no doubt that when carbon of a high fixed carbon content is required, the use of dry wood leads to a higher yield. Low moisture content also reduces the time needed for carbonisation, which is a particularly important factor when charcoal making equipment with a high capital cost is being used. In such cases, it usually makes considerable technical and economic sense to reduce the water content of wood before converting it to charcoal.

But the same does not necessarily apply when traditional methods are being used to produce charcoal for the domestic market. In this case, the charcoal can have a reasonably high volatile content which means that low temperature manufacturing methods are acceptable. The use of green wood is one way of keeping the kiln temperature relatively low. This is a method used by traditional charcoal makers in some areas (Foley, 1986).

2.7 Conclusions

Research work in the field of traditional or small-scale production techniques is characterised by poor data concerning yields, production rates and technology choice. Conflicting reports as to the viability of using softwoods for charcoal production also occur.

Work undertaken by Shaw (1989) in the Western Cape shows that low cost technologies can be incorporated into a bush clearing or small business operations.

There is widespread traditional use of charcoal and charcoal making techniques throughout Africa, the most notable exception being South Africa. Shaw (1989) has shown that charcoal cannot compete with coal as a domestic fuel in South Africa. However, there is a growing local braai and export market.

The yields achieved by Shaw using the Tongan drum kiln and *Acacia Saligna* vary greatly. Kristoferson et al (1984) report yields for the kiln that are consistently high in relation to other low cost production options. With the limited data available it would appear as if the Tongan drum kiln warrants further local technical and economic evaluation.

Chapter 3

TECHNICAL ASSESSMENT

3.1 Rationale

3.1.1 Technology

Work done by Shaw (1989) indicates that the Tongan drum kiln is the most appropriate method of low cost charcoal production due to its simplicity of construction and operation. For any charcoal producing technology the most important technical qualifications are the yield obtained and the quality of the charcoal produced.

The major problem of assessing the Tongan drum kiln is the lack of data available on expected charcoal yields under local conditions, and the extent to which various factors influence these yields. The technical assessment of the Tongan drum kiln facilitates quantitative forecasts on the maximum yields expected from kilns.

3.1.2 Raw material

The encroachment of indigenous Fynbos areas in the Western Cape by the alien species *Acacia Saligna* and *Acacia Cyclops* poses an expensive problem for municipal councils and other land owners. *Acacia Cyclops* is used as braai firewood in most urban areas and is widely harvested for this purpose. *Acacia Saligna* on the other hand is perceived to be a poor quality wood and has little or no economic value.

For this reason the experimental work on the Tongan drum kiln makes sole use of *Acacia Saligna* as the raw material.

3.1.3 Variables

From the literature it is seen that the most significant factors that influence the yield and quality of charcoal are:

- The moisture content of the raw material, and
- The temperature at which carbonisation takes place.

An additional variable, the diameter of the raw material, was introduced to assess what preference, if any, should be shown by the producer to variation in wood size.

3.2 Kiln Construction and Operation

3.2.1 Construction

The kiln consists of a used 210 litre drum which is closed on both ends, and has both screw caps intact. A 20 centimetre wide opening is marked on the drum adjacent to the large screw cap. Three holes are knocked in the drum on each side of the marked line. The marked section of the drum is then cut out with a hammer and chisel, or a gas cutting torch. If the drum contained flammable liquids and is still contaminated, it is filled with water and kept full while it is being cut open.

The section of the drum that has been removed is then attached to the edge of the opening with three pieces of wire which act as hinges for the lid. The 210 litre drum is now a Tongan drum kiln, and is ready to be used for making charcoal. The kiln with the lid intact is illustrated in figure 3.1.
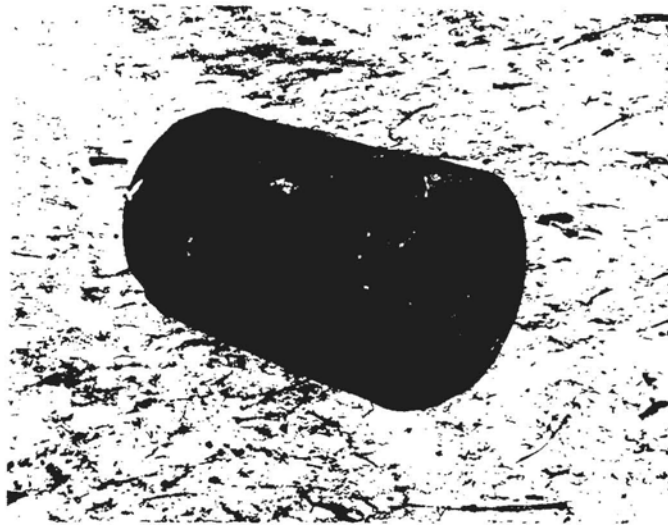
Figure 3.1   Tongan drum kiln

3.2.2 Operation

A wide range of sizes of *Acacia Saligna* can be used - from 30 to 40 millimetre diameter branches and stems to 160 mm diameter tree trunks. If the branches are thinner than 30 mm the charcoal will be too small. If the tree is thicker than 160 mm the wood will not carbonise completely in the kiln. If possible these bigger trees should be split in half. Most stem and branch diameters fall within the range of 40 to 120 mm. The usable pieces are cut into 0.8 metre lengths to fit into the kiln.

The kiln is positioned on its side with the opening facing the wind (if there is any). A small fire is lit in the bottom of the kiln with paper and twigs as illustrated in figure 3.2 (i). As more wood is gradually added the kiln is turned until the opening is facing upwards and the kiln is full of wood.

As the wood settles in the kiln more wood is added. The kiln will eventually be full of coals (see figure 3.2 (ii)). The lid is then closed. If there are half burnt pieces of wood in the kiln, these can be removed at a later stage. The kiln is then rolled upside down and sand packed around the entire opening to prevent any air from entering. (see figure 3.2 (iii)).

The kiln is allowed to cool overnight and the charcoal extracted the next morning.

(i)

(ii)

(iii)

Figure 3.2 Tongan Kiln Operation

3.3 Experimental Methodology

3.3.1 Raw material moisture control

Trees were felled and the wood cut into 0.8 m lengths and left to air dry in the veld in batches for periods of 39, 63, 104, 161, and 205 days respectively.

3.3.2 Temperature control

The temperature in the kiln varies according to the availability of oxygen in the area where combustion is taking place. This can be controlled by varying the rate at which wood is added to the kiln after the initial charge is burning strongly.

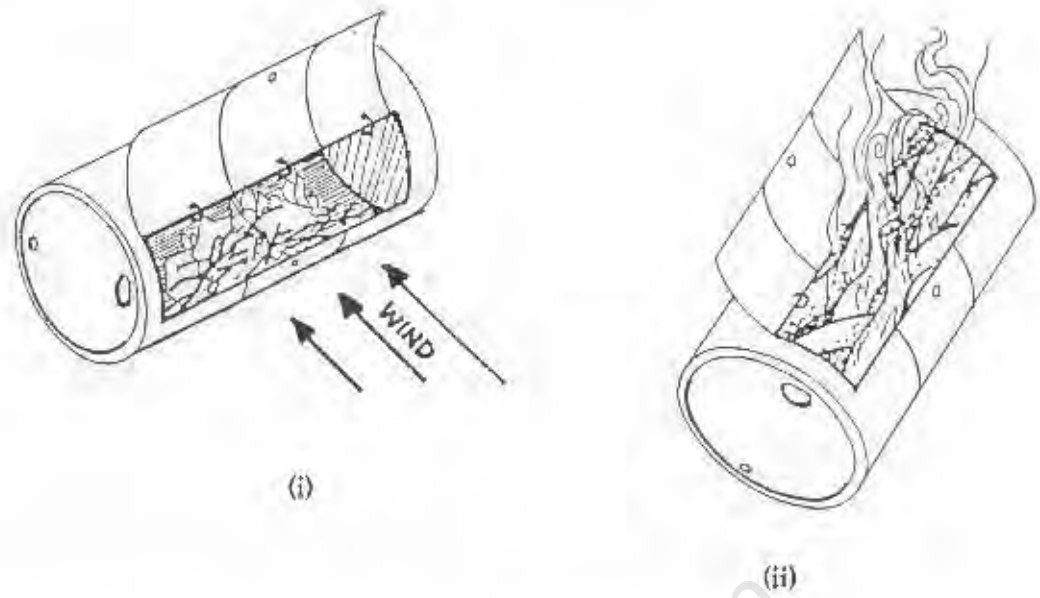To effect a **cold** burn, wood is added quickly and packed tightly into the kiln. Wood is also packed up over the opening of the kiln concealing the flames for most of the operation.

To effect a **medium** burn, the kiln is loaded to capacity, but the kiln opening is not covered as completely as for the cold burn. No flames should be visible.

To effect a **hot** burn, the kiln is loaded slowly and loosely with flames always being visible to the operator.

It must be emphasised that the simplicity of the technology does not allow for accurate and effective temperature control. This division into temperature ranges must at best be seen as broad temperature tendencies, with the sharpest division being between the cold and medium burns on the one hand and the hot burn on the other.

The temperature of the gasses leaving the kiln was measured at the centre of the kiln opening by means of a thermocouple. Readings were taken at regular intervals during the carbonisation cycle.

3.3.3 Raw material sizing

Two ranges of wood size were used. The smaller being wood with diameters from 40 to 80 mm, the larger with diameters from 80 to 120 mm.

3.3.4 Number of experimental runs

Experiments were done, in duplicate, for each wood moisture content, wood size and temperature tendency, the exception being experimental runs with wood having dried for 161 days where only one run with each variable was possible.

3.4 Kiln performance

This is measured in terms of the yield obtained on a dry basis and is defined as follows.

$$\text{yield} = 100 * C_m/W_m \quad [\%]$$

with:

C_m = mass of moisture free charcoal produced

W_m = mass of moisture free wood fed to the kiln

The mass of moisture free charcoal is obtained by weighing the charcoal produced immediately after the kiln has been opened and before moisture can be absorbed.

An average moisture content (dry basis) is calculated for each wood drying time and for both wood size ranges. This is done according to ASTM Designation D 2016-74. Having measured the mass of wet wood added to each kiln it is then possible to calculate W_m.

A further distinction is made between the yield that includes fines and a yield excluding fines. From a survey of the local charcoal producing industry a definition of fines is charcoal which passes through 15 mm "chicken wire" mesh. This distinction between fines and lump charcoal is used throughout the report.

3.5 Charcoal Quality

3.5.1 Calorific value

Two samples from each kiln were used to determine experimentally the higher heating value, or gross calorific value of the charcoal.

3.5.2 Density

Two samples from each kiln were cut into a symmetrical shape using a diamond edged cutting tool. The volume of each sample was measured using a reflex microscope coupled to a microcomputer. The mass was determined on an accurate balance.

3.5.3 Proximate analysis

Four samples were taken from each kiln at random so as to be representative of the kiln contents. The preparation of the samples was performed according to SABS 1399-1983. From these four samples, two were prepared for analysis. The moisture, volatile, ash and fixed carbon content were then determined using SABS Methods 925, 927, 926 and 928 respectively.

3.6 Results

3.6.1 Wood moisture content

The moisture content of wood at various drying times is given below. The apparent contradiction in the wood moisture content of wood having a drying time of 63 days being less than wood with a drying time of 104 days is attributed to the drying period of the former falling in the summer months and the latter in winter.
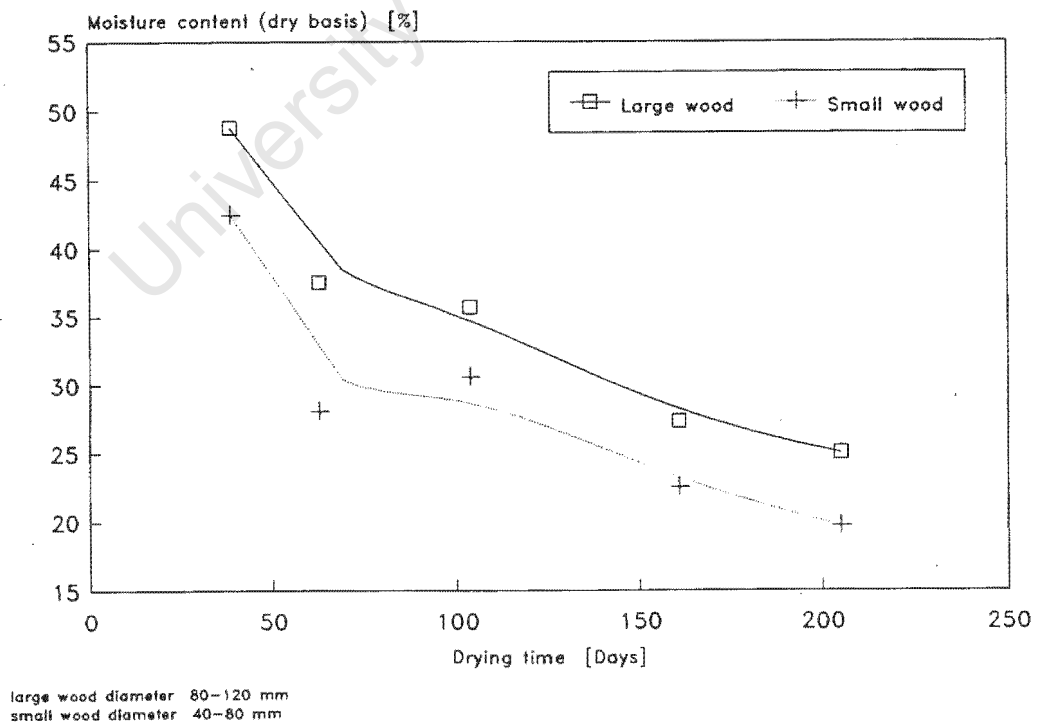
Figure 3.3 Wood moisture content (dry basis)

3.6.2 Temperature tendencies

The measurement of kiln temperature proved to be unsatisfactory. Considerable temperature variations were experienced within a single cycle with all three temperature tendencies. It also proved impossible to standardise any measurement position in the kiln where comparative readings between kilns could be taken effectively. Only a rough indication of average temperatures of the flue gasses is given below.

Table 3.1   Average temperatures

Wood diameter	Temperature [°C]		
[mm]	Cold	Medium	Hot
40-80	374	382	555
80-120	260	370	541

3.6.3 Length of burn

The average time taken from start-up until complete termination of the oxygen supply is given below. The variation in the length of any particular cycle was markedly more dependent on weather conditions than on other influences. A strong wind on a hot day resulted in a shorter cycle and no wind on a rainy, overcast day resulted in a longer cycle.

The turn around time of the kiln however remains constant at 24 hours.

Table 3.2   Average length of burn

Wood diameter	Length of burn [hours]		
[mm]	Cold	Medium	Hot
40-80	4.4	4.4	4.6
80-120	5.3	5.2	5.1

3.6.4 Yields

A: Yield excluding fines
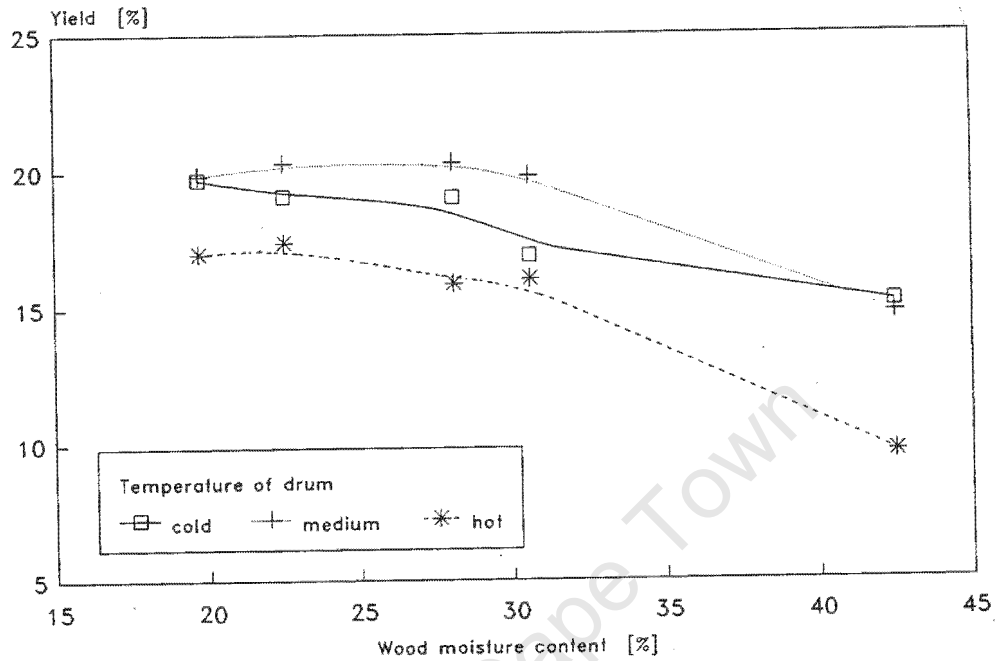
Figure 3.4 Yield excluding fines (dry basis; wood diameter 40-80 mm)
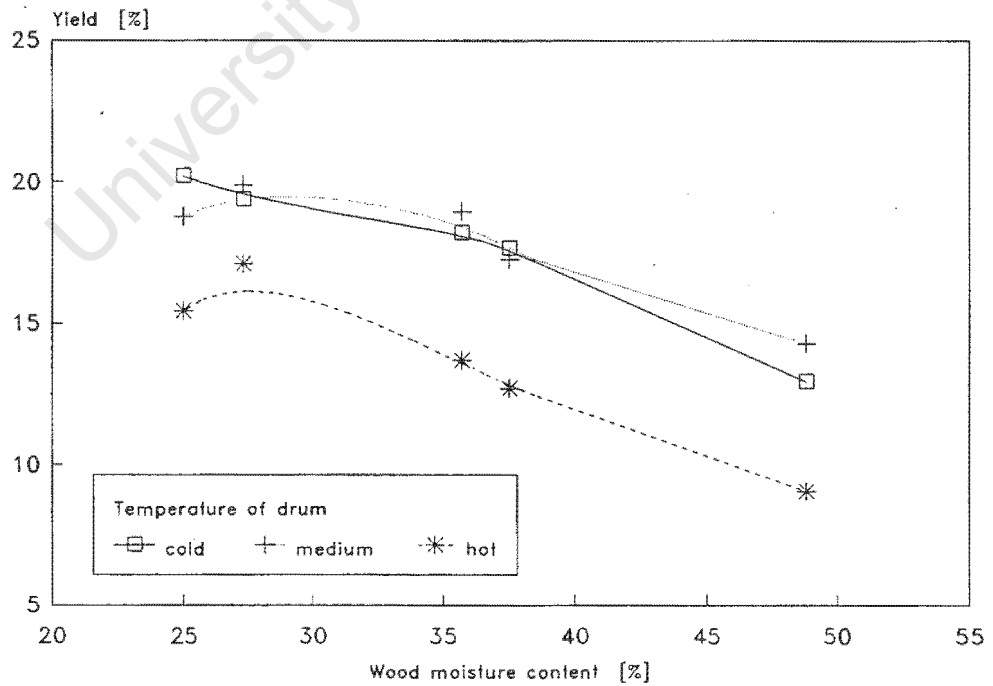
Figure 3.5 Yield excluding fines (dry basis; wood diameter 80-120 mm)

B: Yield including fines
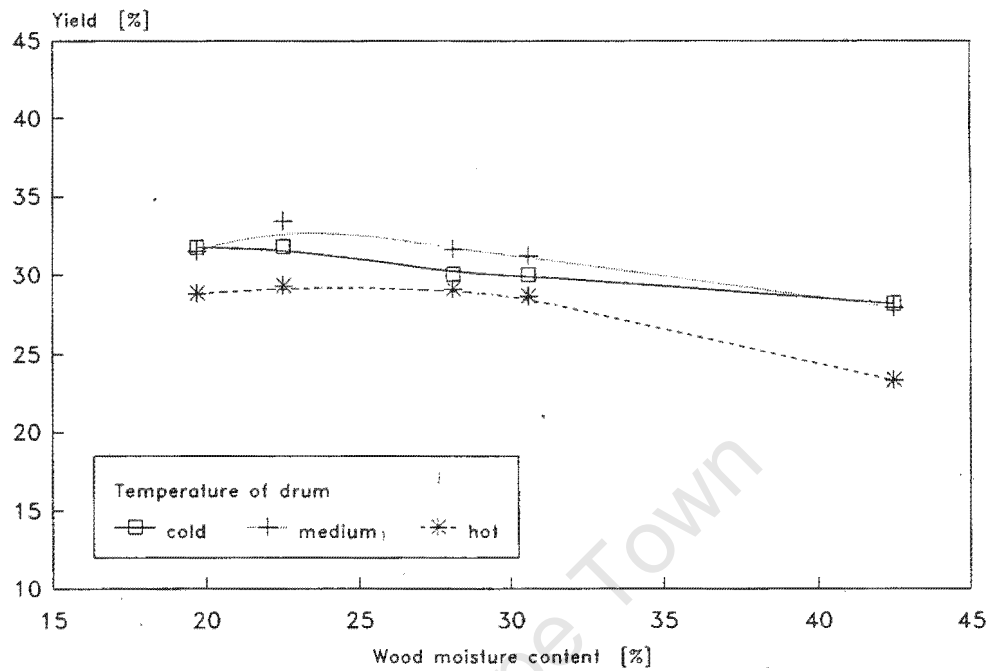
Figure 3.6 Yield including fines (dry basis; wood diameter 40-80 mm)
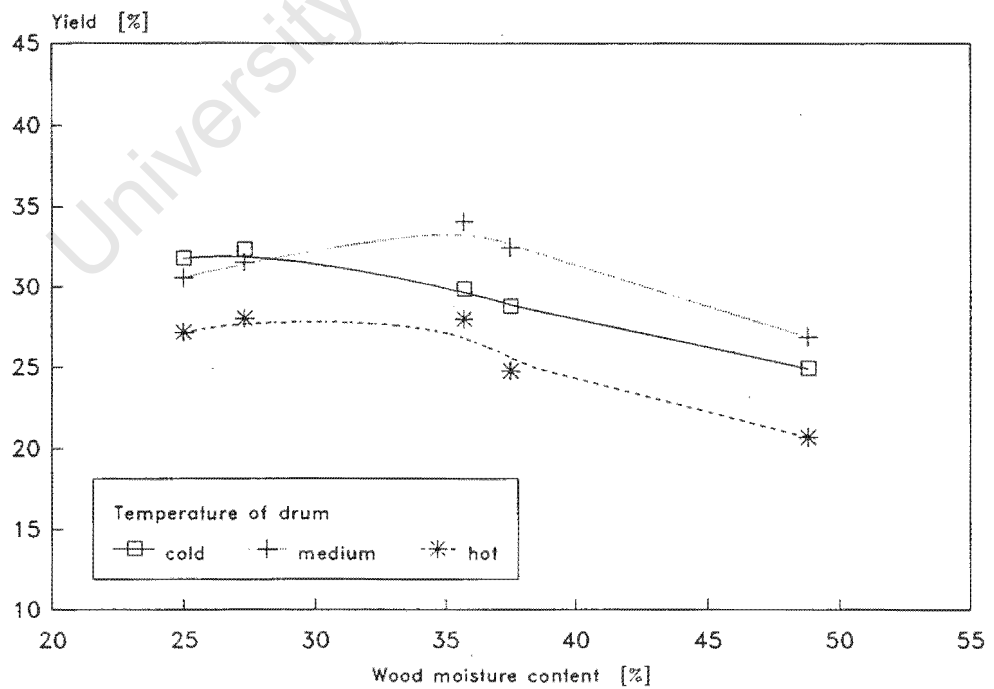
Figure 3.7 Yield including fines (dry basis; wood diameter 80-120 mm)

3.6.5 Charcoal calorific values
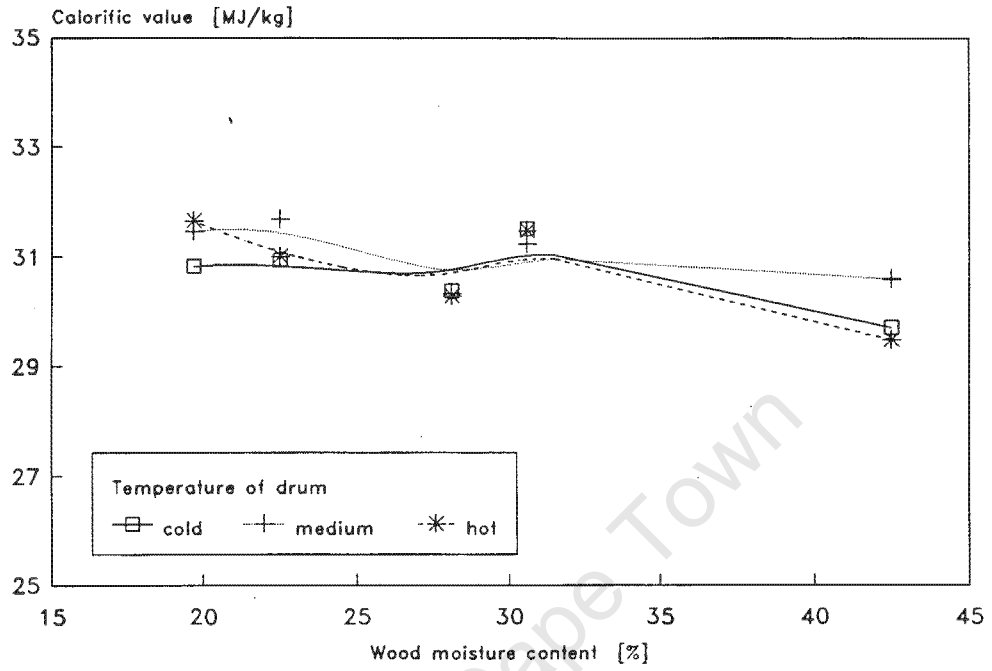
Figure 3.8 Calorific values (wood diameter 40-80 mm)
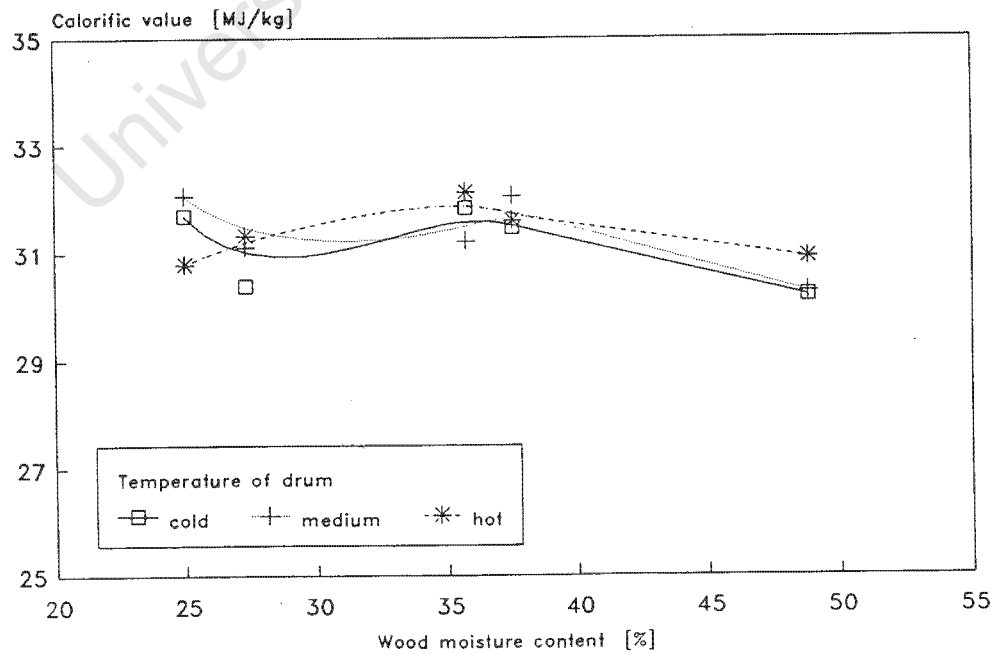
Figure 3.9 Calorific values (wood diameter 80-120 mm)

3.6.6 Charcoal Density
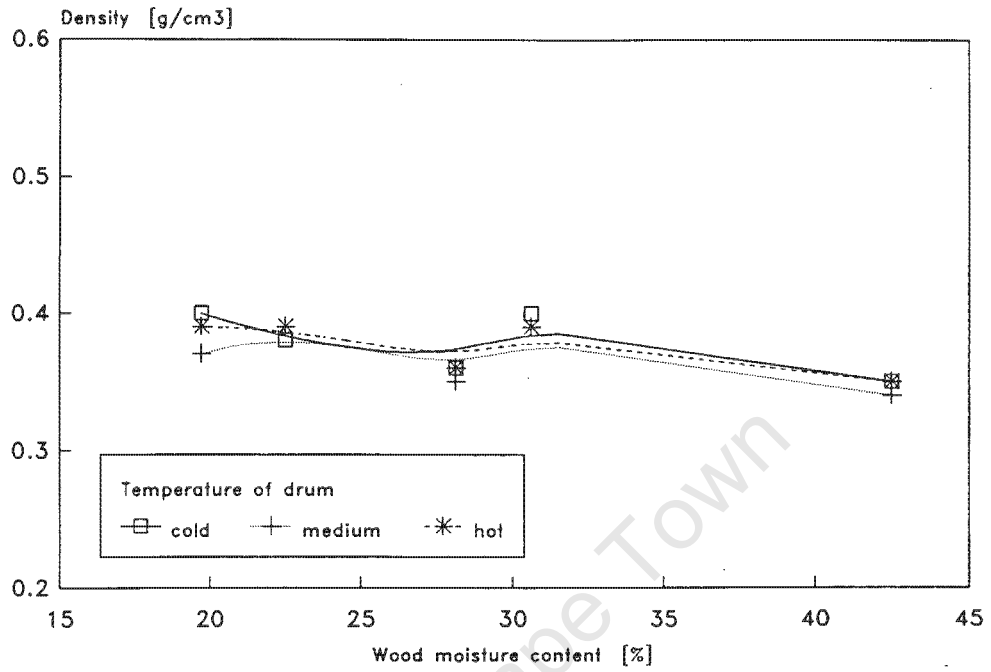
Figure 3.10 Density (wood diameter 40-80 mm)
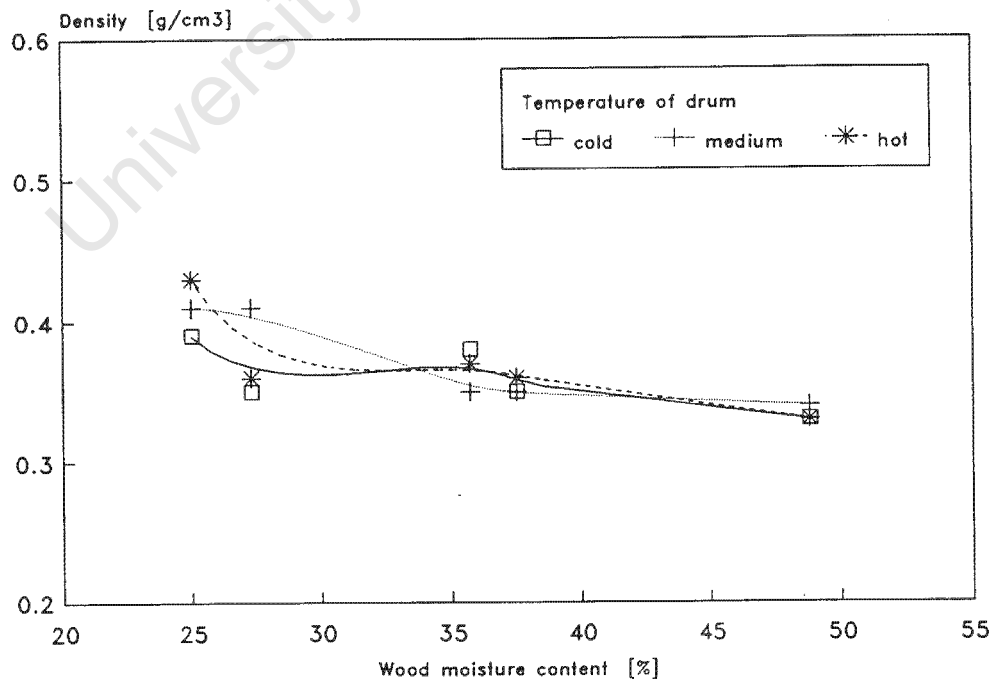
Figure 3.11 Density (wood diameter 80-120 mm)

3.6.7 Moisture content
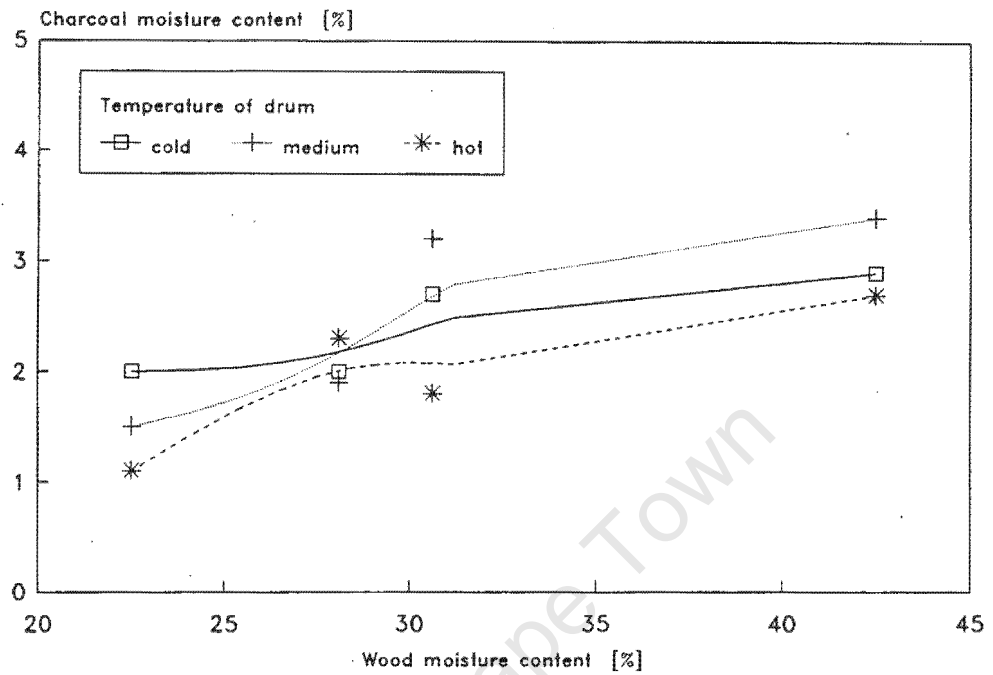
Figure 3.12 Charcoal moisture content (wood diameter 40-80 mm)
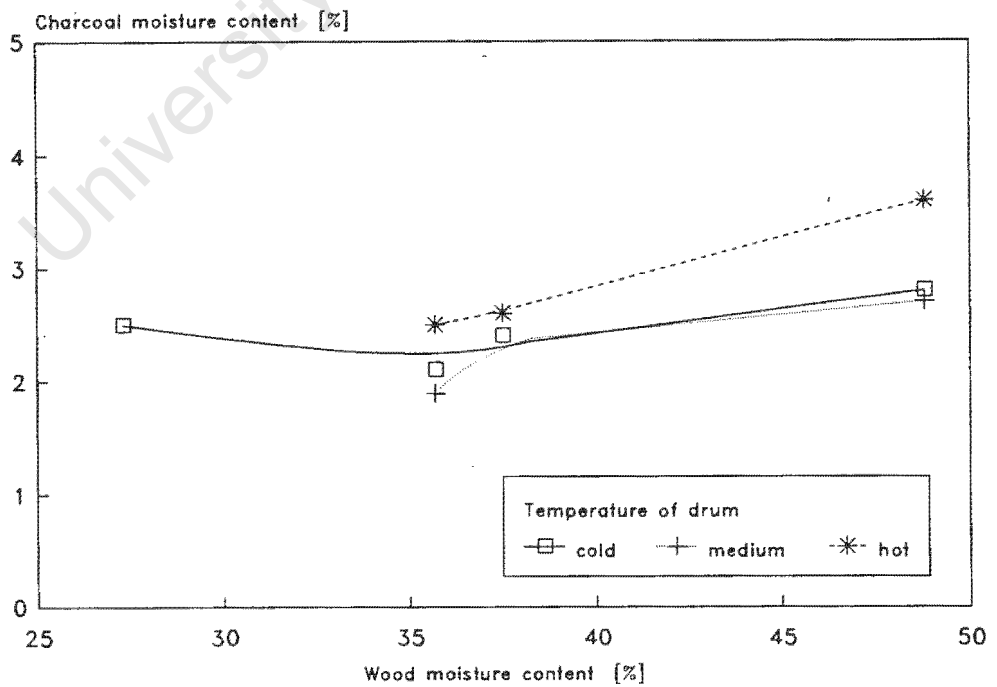
Figure 3.13 Charcoal moisture content (wood diameter 80-120 mm)

3.6.8 Ash content
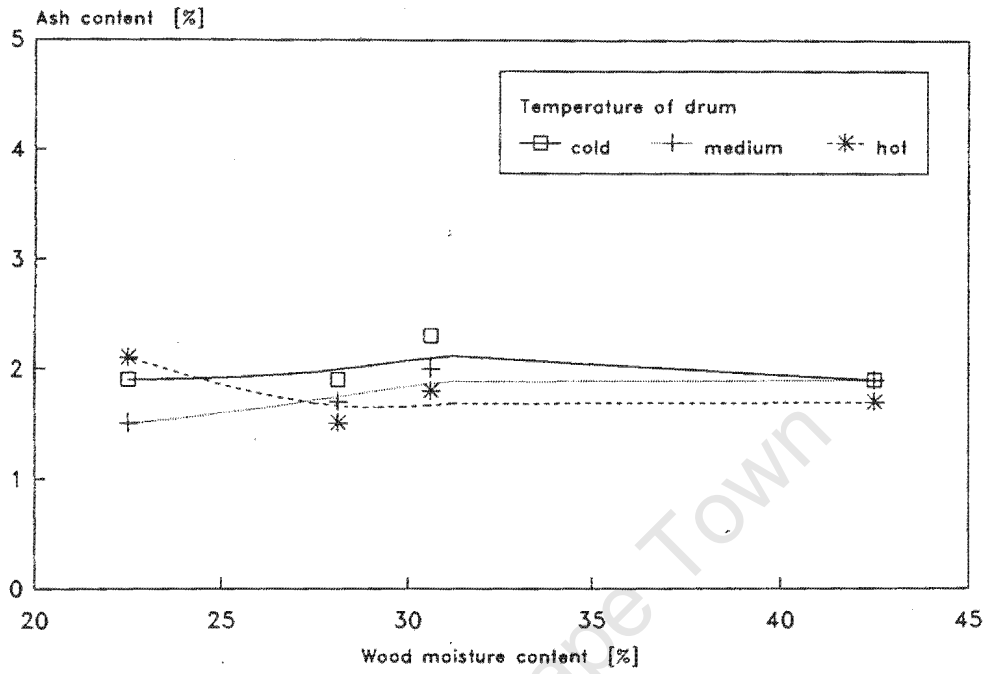
Figure 3.14 Ash content (wood diameter 40-80 mm)
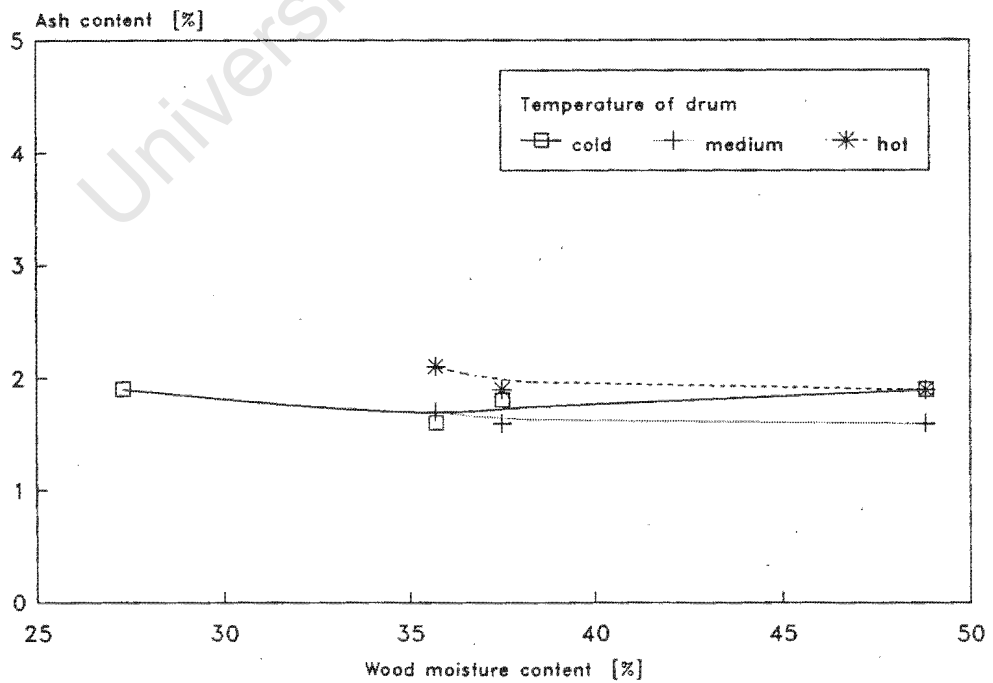
Figure 3.15 Ash content (wood diameter 80-120 mm)

3.6.9 Volatile content
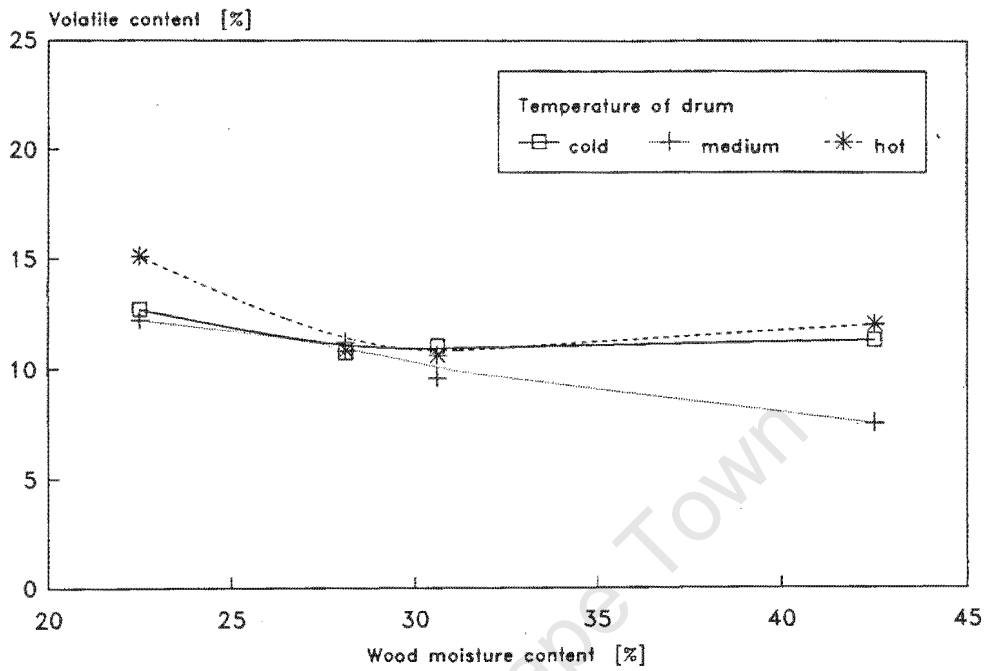
Figure 3.16 Volatile content (wood diameter 40-80 mm)
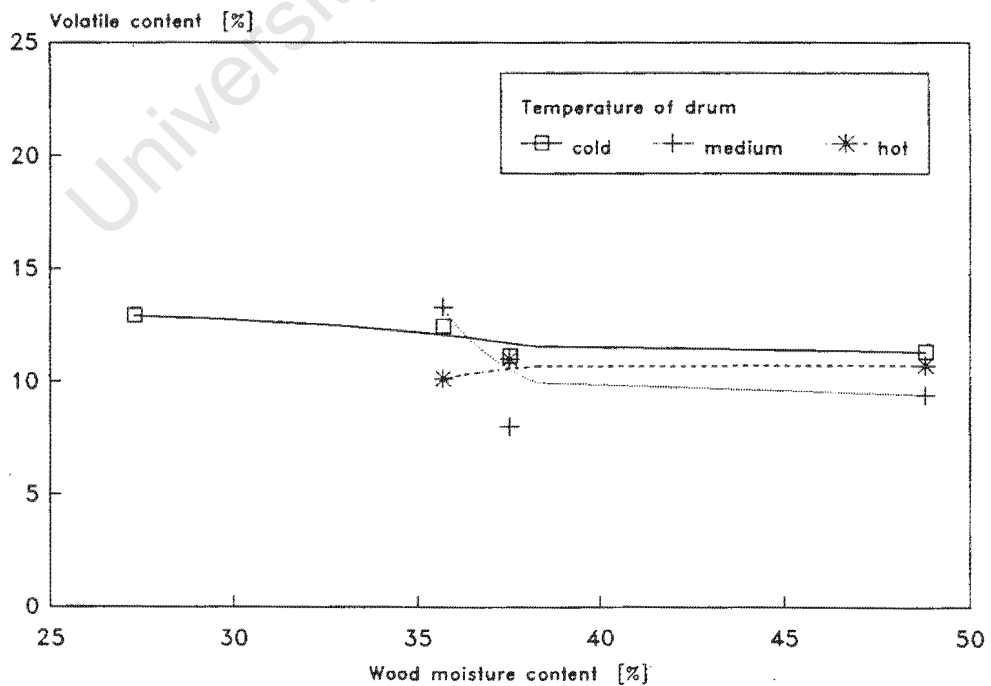
Figure 3.17 Volatile content (wood diameter 80-120 mm)

3.6.10 Carbon content
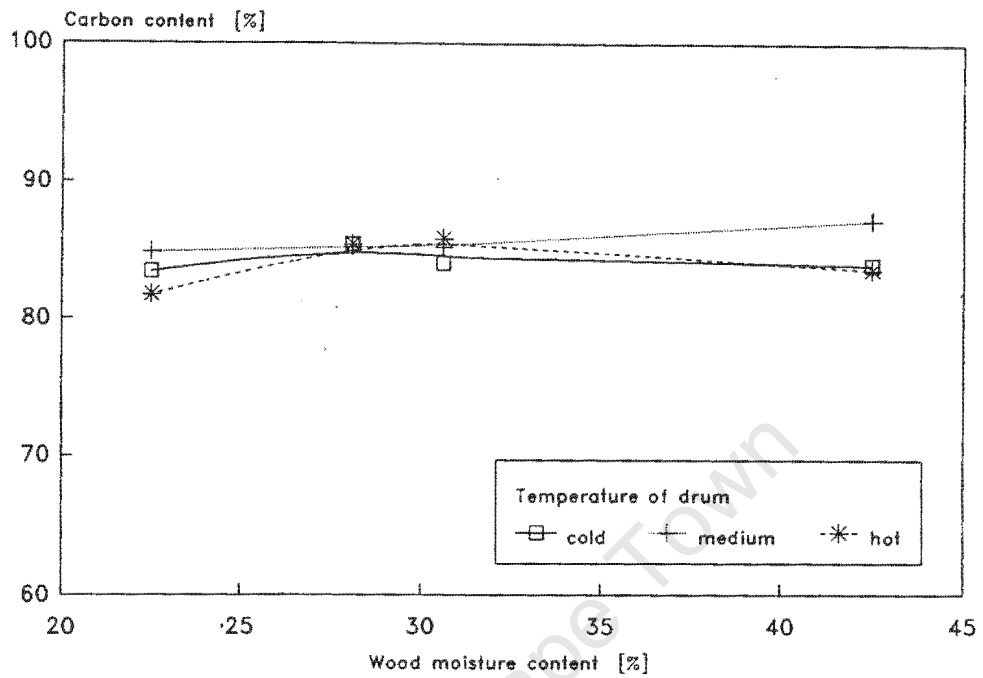
Figure 3.18 Carbon content (wood diameter 40-80 mm)
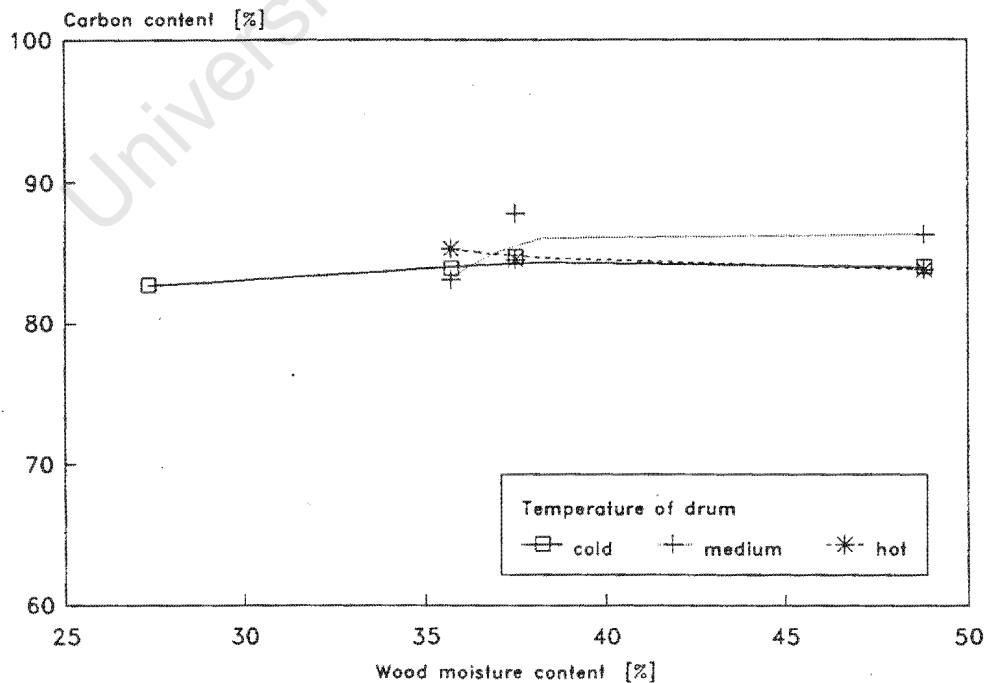
Figure 3.19 Carbon content (wood diameter 80-120 mm)

3.7 Discussion

For wood of both sizes dried for two months and longer (i.e. moisture content less than 38% on a dry basis) and carbonised under medium and cold conditions, the average charcoal yield excluding fines is 19 % on a dry basis. The corresponding yield including fines is 31 %. These yields are in the same order of magnitude as those achieved using the Tongan drum kiln by Shaw (1989) and those quoted by Kristoferson et al (1984) (see section 2.3.2). They also compare favourably to average charcoal yields of 16 and 20 % achieved in the Transvaal and Natal respectively using hardwood (Bennie, 1982). For 'portable steel kilns of various designs,' Bennie reports an average yield of 22.2 %.

From figures 3.4 to 3.7 it is concluded that wood with at least two months drying time should be used to produce charcoal. Leaving the wood to dry for longer periods has only a marginal effect on the yield. It is also clear from these figures that the yield shows a significant decline when carbonisation occurs under hot conditions. This is as expected (see section 2.6.3, figure 2.6).

The calorific values are all in the range of 30 to 31 MJ/kg and are not affected much by initial moisture content or temperature of operation. The standard specification for charcoal for household use (SABS 1399-1983) does not give a required minimum calorific value. Gore (1982b) specifies that it should not be less than 23 MJ/kg for use as a domestic fuel or for metallurgical reduction.

No formal specification exists for charcoal density. Typical figures given by Gore (1982a) are 0.7 to 0.8 g/cm^3 with values as low as 0.51 g/cm^3 quoted. The density of charcoal however varies directly with the density of the raw material used (Gore, 1982a). This would explain the relatively low density values in the order of 0.35 to 0.40 g/cm^3 obtained using *Acacia Saligna*. There appears to be a very slight increase in density when using a dryer wood charge (see figures 3.10 and 3.11). This is possibly explained by there being consequently less water escaping from the wood during the initial stages of carbonisation with a less porous, more dense charcoal being produced.

The moisture content of the charcoal varies in relation to the moisture content of the wood charge and is in the order of 2 to 4 %. Measurements were also affected by humidity conditions in the laboratory.

The ash content of charcoal varies in accordance with the tree species used. These are in the order of 1.5 to 2.0 %. Gore (1982a) gives a figure of 1.10 % as being typical for *Acacia Saligna* while Shaw (1989) shows results of 1.5 to 4.0 % ash content.

The volatile content of the charcoal produced varies from 7 to 15 %. This is considerably less than the average value of 22 % quoted by Foley (1986) for traditional charcoal methods. The standard specification for domestic charcoal (SABS 1399-1983) requires that the volatile content be less than 20 %.

The fixed carbon content on a wet basis is consistently higher than 80 %. This is well above the minimum specification for domestic grade charcoal (SABS 1399-1983) of 65 %. Gore (1982a) gives a minimum required for metallurgical reduction as 78 % by mass on a dry basis.

In conclusion, charcoal produced from *Acacia Saligna* in the Tongan drum is of a high quality. Calorific value, moisture, ash, volatiles and carbon content are all within acceptable limits, even for industrial use. No major improvements in these parameters are obtained by varying operating temperatures, drying time or the diameter of wood charges. However, yields are considerably affected by temperature and the optimum range appears to be around 370-400°C. Yields are also improved by drying the wood to less than 40 % moisture content. *Acacia Saligna* makes a very low density charcoal. There has, however, been a good response from those who have used it.

Chapter 4

ECONOMIC APPRAISAL

4.1 Introduction

A major factor in determining the appropriateness of the Tongan drum kiln is its economic viability. Shaw (1989) assessed the economic potential for small-scale individual operators, working informally and selling lump charcoal on the side of the road. He found that it was possible for such operators to double their income by producing charcoal with the Tongan drum kiln instead of selling firewood. The present study, for reasons outlined in Chapter 1, has focussed on more formalised production, and the detailed economic appraisal is for such a situation. However, it is useful first to include estimates of the potential expenses and income from roadside operation, for comparison with Shaw's findings, and to provide further indications of the viability of this technology for small-scale informal production.

4.1.1 Road side operation

This level of production is similar to that experienced in developing countries. Local woodcutters who at present sell firewood at the side of the road report erratic sales, making it difficult to assess the earnings generated by the firewood preparation. Also typical of developing countries, however, is a producer who sells in bulk to a middleman or wholesaler who then packages and transports the charcoal to the market (Foley, 1986). From local experience in the field it is not uncommon that this arrangement is established for firewood as well as charcoal production. The estimates which follow assume that this is how the firewood or charcoal would be sold.

To establish the earnings of woodcutters several wood wholesalers were consulted and on average R35 was paid per 1000 sticks. The price that charcoal wholesalers are prepared to pay for charcoal bought in bulk was found to be R2.20 for five kilograms.

It is generally expected that woodcutters provide their own equipment. From Shaw (1989) equipment costs for woodcutters are estimated at R1.50 per 1000 firewood sticks produced. From Shaw (1989) and field work, equipment costs for producing 0.8 metre lengths of wood suitable for the Tongan drum kiln are R1.30 per stere (stere = stacked cubic metre). Old 210 litre oil drums can be bought for R5.00 and it is assumed that all other equipment required for charcoal production (wire mesh and wood for a sieve; wire to attach the lid to the kiln) can obtained at no cost. The oil drums have to be replaced every 6 months.

From field work, wood production rates are estimated at 2 200 sticks per week for woodcutters and 5.0 steres per week for charcoal producers. One person operating 12 drums would require one day to carbonise and sieve a weeks wood production and would produce 290 kilograms of charcoal. Based on the above assumptions, the earnings of wood cutters and charcoal producers taken over a period of six months (1 month = 4.33 weeks) can be obtained as follows:

(a) Woodcutters

Expenses = 1.50*(2200/1000)*4.33*6
= R86

Income = 35*(2200/1000)*4.33*6
= R2002

Therefore:

Net income per day = (2002-86)/(5*4.33*6)
= R14.7

(b) Charcoal producers

$$\text{Expenses} = 1.30*5*(5*4.33*6)/6 + 12*5$$
$$= R201$$

$$\text{Income} = 2.20*(290/5)*(5*4.33*6)/6$$
$$= R2564$$

Therefore:

$$\text{Net income per day} = (2564\text{-}201)/(5*4.33*6)$$
$$= R18.2$$

The estimates show there is some potential for local woodcutters to improve their income from charcoal production, but by a smaller percentage than Shaw's (1989) study suggested.

4.1.2 Commercial production

While the above estimates are made for a level of production typical of underdeveloped areas elsewhere in the developing world, it must be remembered that South Africa has a more developed industrial sector than most developing countries. Charcoal production in the developing sector thus has to compete with production in the developed sector. Charcoal technologies found in the Western Cape are fairly primitive, larger steel kilns. The viability of the Tongan drum technology was tested against these by setting up a similar scale operation with a Cape Peninsula land-owner and monitoring costs and output over a period of about a year. Other existing sites were visited and calculated data formed the basis of the economic analysis, with the comparisons based on common assumptions.

The approach taken is one of viewing the establishment of a charcoal producing site from the perspective of two types of investors:

(i)   The first type of investor has no assets required for producing
       charcoal. All equipment has to be bought, a site established
       and labour acquired. This is called the stand alone case.

(ii)   The second type of investor is a land owner, typically a farmer
       or a town council. This investor will already be in possession
       of various capital goods and have an established labour force

as well as an available site. This is called the supplementary case.

For each case, the following are determined:

    (i)   The capital costs incurred at the start of the project as well as those incurred during the project lifetime.

    (ii)   Fixed and variable operating costs.

    (iii)   Working capital.

    (iv)   Income.

A net income for each year and the cumulative income for the project life is calculated.

In addition to this a sensitivity analysis is performed so as to pinpoint areas which are most critical in terms of uncertainty and to assist in indicating where confidence in estimates is most vital.

4.2 General assumptions

The following assumptions hold for all sites:

4.2.1 Charcoal production rate

An appraisal for each site is performed looking at two rates of production in the order of 3500 and 7000 five kilogram bags of charcoal per month. The actual production at each site differs according to the maximum production rate of the particular technology used. These rates fall within the range of equipment considered. The higher production also allows for the size of site that is easily manageable. Any larger site would require more mechanization than considered, and falls outside the scope of this report.

4.2.2 Project life

A project life of 5 years is assumed for all cases. This is the typical length of planning used in the local charcoal industry. It is also the length of time after which major capital equipment will have to be replaced.

4.2.3 Capital costs

In most cases the given costs of capital goods are for those obtained second-hand. It is assumed that the buyer searches the market thoroughly so as to obtain materials at the lowest cost.

4.2.4 Inflation

It is assumed that all components of project cash flows will inflate in step at the same rates throughout the life of the project. Forecasts and estimates of future cash flows are expressed in terms of current rand. To include inflation would thus involve inflating all future cash flows at the inflation rate and then deflating them again at the same rate. This would be superfluous and the evaluation is thus based on costs and prices in current (1990) rand values.

4.2.5 Salvage value

This is assumed to be insignificant at the end of the project life and is excluded from all assessments.

4.2.6 Taxes

As indicated above, the possible investor ranges from a private entrepreneur to a town council. This includes a wide range of possible tax rates with the lowest being zero. To facilitate comparisons on an equal basis no tax levies are included in the appraisal.

4.2.7 Depreciation

In light of the above no depreciation tax concessions are considered.

4.2.8 Working Capital

The following expenses have to be provided for at the start of the project:

    (i)   the cost of two months supply of wood,

    (ii)   the production costs of one months' stock,

(iii)   half of sales income for first 15 days. All other income is immediately receivable.

The working capital is recovered at the end of the project.

4.2.9 General sales tax

All cash flows include general sales tax.

4.2.10 Working month

It is assumed that all labour works a 8 hour day and a 5 day week. The length of a month is taken to be 4.333 weeks.

4.2.11 Project startup

As indicated in Chapter 3 the best results are obtained from wood that has been allowed to dry for at least 2 months. It is thus assumed that in the first year of operation only ten months of production takes place. It is further assumed that the construction and delivery of all equipment will be completed within this time.

4.2.12 Investment Indices

(a) Net Present Value

The net present value of a project is the sum of the present values of each individual cash flow. In this case the "present" is taken as the start of the project. It is assumed that all money invested is borrowed at an interest rate of 25 per cent. The cost of capital to the investor is therefore 25 % and all future cash flows are discounted at this rate per year to obtain the net present value (NPV).

(b) Discounted Cash Flow Return (DCFR)

The discounted cash flow return is defined as the discount rate which makes the NPV of a project equal to zero.

(c) Payback time

Payback time measures the time needed for the cumulative project investment and other expenditure to be exactly balanced by the cumulative income.

(d) Return on Investment (ROI)

This is expressed as the percentage ratio of average yearly profit (net cash flow) over the life of the project, divided by the total initial investment. For this project it is calculated for the discounted net cash flow (ROId) as well as for the net cash flow (ROI).

(e) Breakeven Cost of Charcoal (BCC)

This is defined as the cost of charcoal per bag that results in a NPV of zero.

4.3 Site A : Tongan Drum Kiln

4.3.1 Production Rates

A   The lower production rate requires 48 kilns to be operated per day. Each kiln can produce an average of 3.35 bags of charcoal per day. The mass of each bag is 5 kg. Thus 3484 bags are produced each month.

B   The higher production rate requires 96 kilns and will deliver 6968 bags per month.

4.3.2 Stand alone case

PRODUCTION RATE A: 3484 BAGS PER MONTH

(a) Capital costs

The following capital goods are required and are paid for in 1990 unless otherwise specified:

(i)   48 two hundred and ten litre oil drums. They need to be replaced every 6 months. The cost of transporting the drums to the site, as well as minor adjustments to the drum are considered negligible. Cost: R5 per drum.

(ii)   A tractor and trailer. Cost: R22 000.

(iii)   A four ton truck. The truck must have high sides and will require a tarpaulin cover. Total cost: R27 000.

(iv)   A sieve with a 15 mm diameter aperture. 15 mm 'chicken wire' is ideal. See figure 4.1 for a typical design. Cost: R1 200.
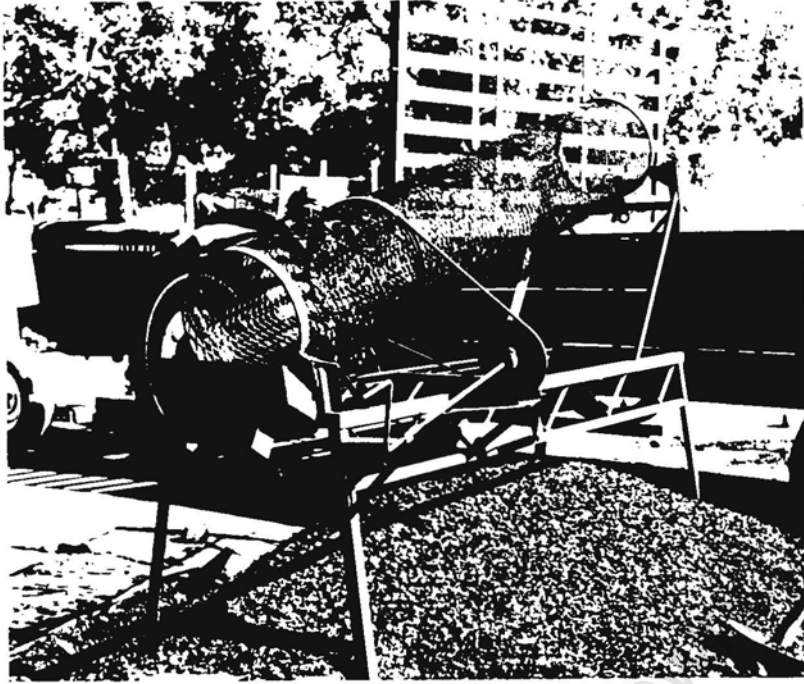
Figure 4.1 Typical sieve design

(v) A platform scale capable of weighing accurately a 5 kg bag.
     Cost: R1 300.

(vi) A blade saw. This should be driven independently by a diesel
      motor and will be used for cutting the felled trees into 0.80 m
      lengths. (see figure 4.2) Cost: R8 000.
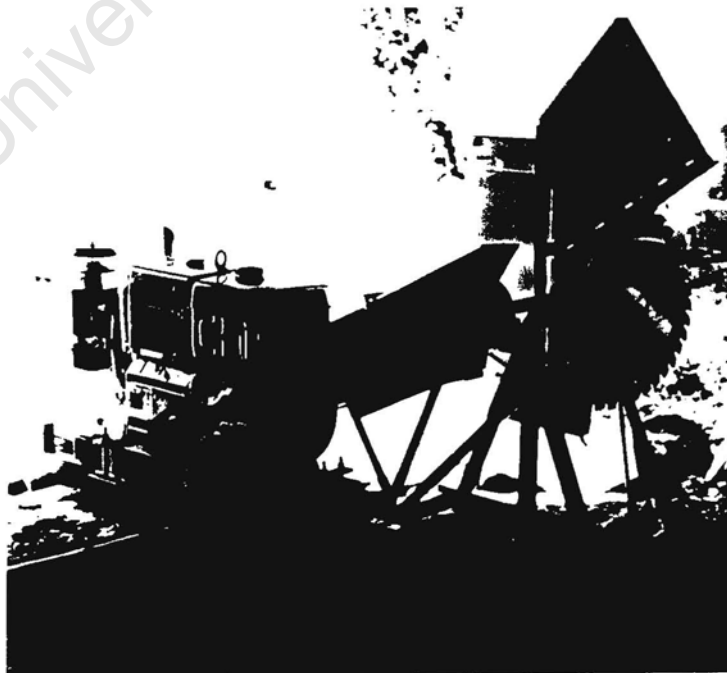
Figure 4.2 Blade saw

(vii) A stitching machine to stitch bags. Cost: R1 700.

(viii) A printing die so as to have bag designs printed. A single die can be used for the length of the project if the bag design remains unchanged. Cost: R2 500.

(ix) Bags of charcoal will typically have to be temporarily stored on or near the charcoal site before being transported closer to market. This will require the erection of a shelter or the purchase of a tarpaulin to protect the bags from getting wet. The cost involved for a 35 m^2 shelter is estimated at R2 100.

(x) An allowance of R500 is made for miscellaneous equipment needed at the start of the project.

(b) Operating costs

Fixed Costs

(i) Labour. A wage of R20 per labourer per day is assumed. The operation of this site has the following labour requirements (excluding wood harvesting):

> 4 labourers to operate 12 kilns each per day.
> 3 labourers to sieve, weigh and stitch each day's production.

It is assumed that the charcoal has to be transported from the forest face to a site where electricity is available to stitch the bags. This distance would typically not be more than 5 km. The above estimate makes allowance for time taken to load and transport the charcoal. Where electricity is not available close to the site the bags are assumed to be delivered unsealed to the warehouse.

(ii) Licence and insurance of truck and tractor. R324 per month.

(iii) Telephone: R150 per month.

(iv)   It is assumed that the producer will manage the distribution of
        charcoal to the retailer. This will require a warehouse close to
        the market. Warehouse rental: R1 000 per month.

(iv)   Miscellaneous expenses: R100 per month.

Variable Costs

(i)   **Wood.** It is particularly difficult to establish the cost of wood
        to the charcoal producer. This is principally due to three
        factors:

        - Harvesting of wood is labour intensive. A wide range of
          salaries are paid in the Western Cape depending on the
          distance from Cape Town and the type of employer. If
          farm labour is used, the benefits received by the labourer
          and thus the cost of wood is not necessarily reflected in a
          salary.

        - Method of wood harvesting. In some cases dry wood is
          collected over a wide area with no felling of trees
          involved. In other cases green trees are felled and the
          wood is left to dry.

        - Efficiency of the labour. For the purposes of this study the
          following costs will be used based on data obtained from
          a site situated 40 km from Cape Town where the labour
          is not housed by the employer:

        Wood is felled by the labourer with a bow saw, the small
        twigs (<30 to 40 mm diameter) and leaves are removed and
        the rest is cut to 0.8 m lengths on a blade saw. This saw is
        fueled and maintained by the employer. The wood is neatly
        stacked and the labourers are paid R15 per stere (stere =
        stacked cubic metre). The diameter of wood harvested varies
        from 30 to 130 mm. Output per labourer can vary from 5 to
        12 steres per week.

        From wood dried for at least two months, it is possible to
        produce on average 57.58 kg of saleable charcoal per stere.
        This is based on an average yield of 19.09 % (dry basis) for

cold and medium experimental burns using the Tongan drum kiln. Therefore:

$$\text{wood cost per bag} = R15/(57.58/5)$$
$$= R1.30$$

Note 1: A couple of producers consulted perceive a time of 2 to 3 weeks as sufficient drying time for freshly harvested *Acacia Saligna*. From experience gained in operating the Tongan drum kiln this is seen as an optimistic assumption. For all sites it is assumed that the wood is cut to the required operational length and air dried for two months.

Note 2: A further option in wood harvesting is to make use of chainsaws where bow saws would otherwise be used. This increases the rate of harvesting by a factor of 3 to 5. The cost (labour and equipment) per ton of wood produced does not however change significantly (Shaw, 1989). The choice of harvesting method would thus depend on the availability of labour.

(ii) **Blade saw operating costs.** The fuel consumption given by a manufacturer is 1 litre of diesel per hour. It is assumed that maintenance of the engine and sharpening the blade together cost an equivalent amount. To produce the required amount of wood, the saw will operate for 4 hours per day. Diesel is priced at R1.04 per litre. Therefore:

$$\text{saw cost per bag} = (R1.04*4hrs/day*5*4.333)*2/3484$$
$$= R0.052$$

(iii) **Packaging.** All charcoal is assumed to be packaged in 5 kg bags. A cost of R0.645 per bag is used throughout. This includes a plastic handle that is bought attached to the bag. The bags are stitched closed at a cost of R0.015 per bag for thread and stitching tape. Labour costs for packaging are included elsewhere.

(iv) **Vehicle costs.** Most exploitable woodlots are situated at distances of 20 to 200 km from the potential market. Typically

charcoal will have to be brought from the production site to warehouse and then distributed from the warehouse to the retailer.

The cost of maintaining a vehicle depends on the age of the vehicle, the distance and type of roads used and the load carried. Costing performed by a producer within 50 kms of the market and a producer 170 km from the market give the cost to be R0.20 and R0.30 per bag respectively. This is in the range of R0.40 to R0.80 per kilometre.

The same difficulty in calculating costs exists for the tractor as for the truck. The terrain over which wood or charcoal must be transported varies to a greater extent than with the truck. The distances travelled are however typically shorter. For the purposes of this study a truck operating cost of R0.25 per bag of charcoal sold is assumed. A tractor operating cost of R0.15 per bag of charcoal produced is given by a producer as a reasonable assumption.

Both these estimates include fuel, servicing and occasional repairs. They do not include a replacement cost for the vehicles.

(v) **Regional services council (RSC) levies.** On turnover: 0.115%. On wages and salaries: 0.25 %. For the purposes of this appraisal this includes the cost of wood, but excludes any funds withdrawn from the project by the initiator.

(c) Benefits

The only benefit considered is income received from the sale of charcoal and is taken as R3.90 per bag.

Two additional benefits are realised by the implementation of a charcoal project:

- In all cases charcoal is made from *Acacia Saligna* and occasionally from *Acacia Cyclops*. Both these species are invasive aliens. A substantial benefit is that farm land or ecologically sensitive areas are cleared at no extra expense.

- At certain times of the year farmers have a surplus of labour. This labour can then be utilized in charcoal production.

PRODUCTION RATE B: 6968 BAGS PER MONTH

Most of the costing assumptions made for the production rate of 3484 bags per month hold for this production rate. Only the deviations are listed below.

(a) Capital costs

(i)   96 two hundred and ten litre oil drums. Cost: R5 per drum.

(ii) An 8 ton truck is needed instead of a 4 ton truck.
       Cost: R31 000.

(iii) A shelter on the site twice the previous size is required.
       Cost: R4 200.

(b) Operating costs

(i)   Labour requirements:

       8 labourers to operate 12 kilns each per day.
       5 labourers to sieve, weigh and stitch each days
           production.

(ii) Licence and insurance of truck and tractor. R500 per month.

(iii) Telephone: R200 per month.

(iv) Miscellaneous expenses: R150 per month.

The effect of the production rate and discount rate on the cumulative income is shown in figure 4.3.
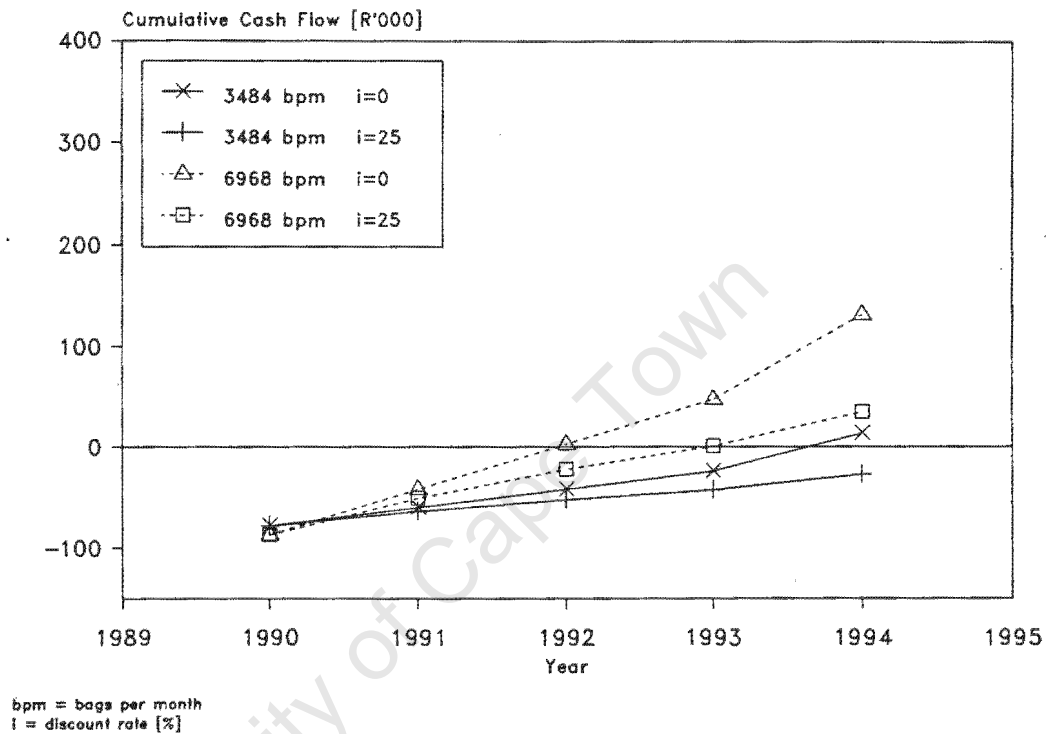
Figure 4.3 Cumulative project cash flows: Site A - Stand alone case

4.3.3 Supplementary case

For a typical supplementary study the initiator is assumed to be in possession of the capital goods listed below.

(i)   A tractor and trailer,

(ii) A suitable truck, and

(iii) A shelter close to the site.

Licence and insurance costs for the vehicles are assumed to be already paid.

PROJECT CASH FLOWS

The effect of the production rate and discount rate on the cumulative income is shown in figure 4.4.
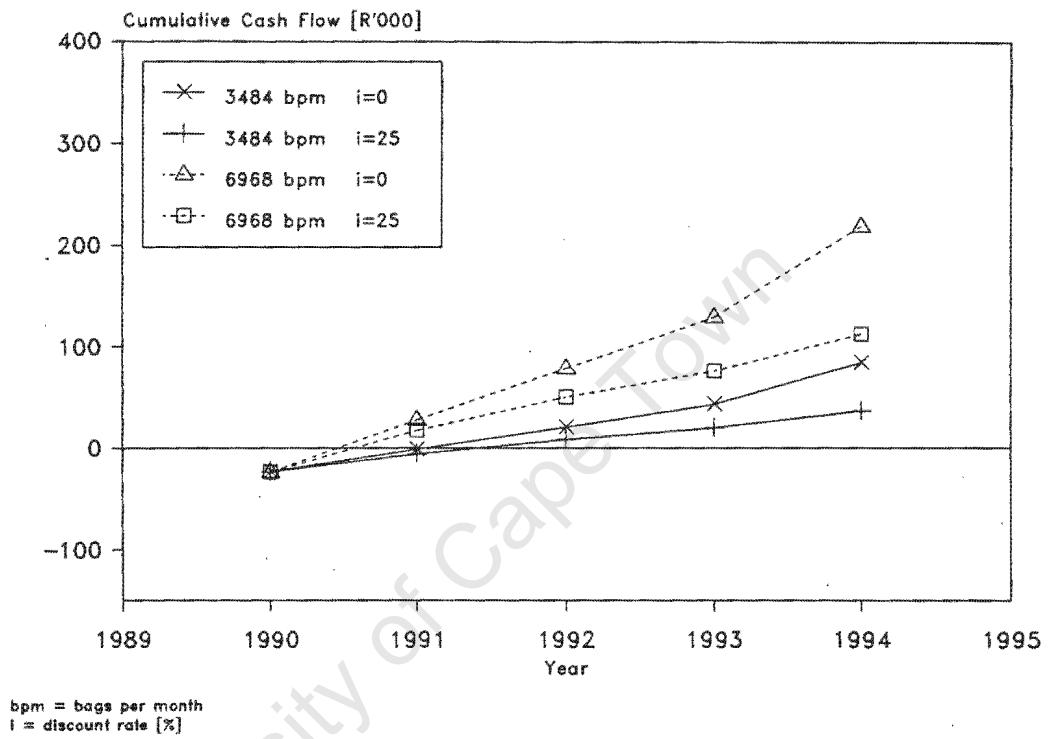
Figure 4.4 Cumulative project cash flows: Site A - Supplementary case

4.4 Site B : Petrol Storage Tank Kiln (PST Kiln)

4.4.1 Kiln description

The main component of the PST Kiln is a used 23 m^3 underground petrol storage tank. These are typically of the type used at petrol stations and reconditioned tanks are available at several outlets. The required modifications to the tank are indicated in figure 4.5. The cladding on the tank seen in figure 4.5 (i) is insulation to reduce heat loss during operation. The kiln is permanently sited close to an electric power source.
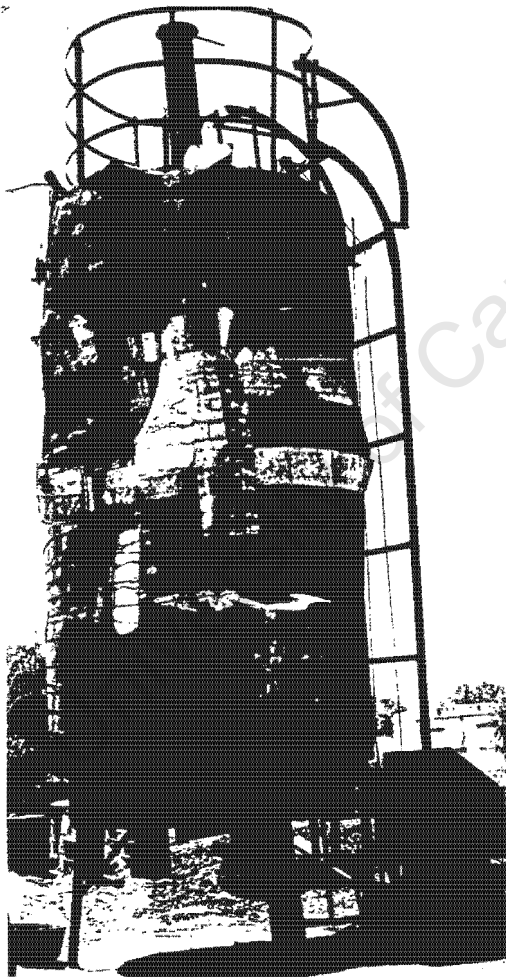
(i)
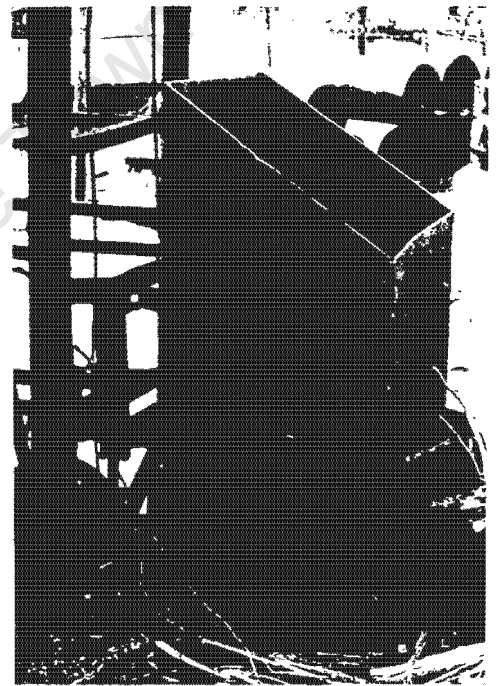
(ii)

Figure 4.5 (i) PST Kiln (ii) Wood box

4.4.2 Operation

The PST kiln can be batch operated or can run continuously. The kiln is loaded from the top using a motor driven winch and wood box. It is fired

from the bottom and then sealed with only three ports at the top remaining open until carbonisation is completed. When operated continuously the charcoal product is drawn off from the bottom at approximately hourly intervals. Charcoal from both operation modes is put into 210 litre drums which are sealed and allowed to cool over night.

4.4.3 Production Rates

A   When batch operated the kiln has a 24 hour cycle. This includes a period of cooling in the kiln after carbonisation, and can produce 180 bags of charcoal per batch. This amounts to a production rate of 3900 bags of charcoal per month.

B   Continuous operation for five days per week allows for a production rate of 7800 bags per month.

4.4.4 Specific assumptions

Assumptions concerning equipment and costs made for Site A hold for the corresponding cases and production rates on Site B. Only deviations are referred to in this section.

4.4.5 Stand alone case

PRODUCTION RATE A: 3900 BAGS PER MONTH

(a) Capital costs

(i)   A petrol storage tank can be cleaned and delivered for R800, with structural adjustments costing R9 000. The motor and gearing cost a further R4 300. Transporting and establishing the kiln cost R1 000. This gives a total kiln cost of R15 100.

(ii)   30 two hundred and ten litre oil drums. These have a lifetime of 1 year. Cost: R5 per drum.

(iii)   An electric motor driven blade saw can be used in the place of the diesel driven saw. The cost of the saw is assumed to be equivalent to that of the diesel saw.

(b) Operating Costs

Fixed Costs

(i) Labour.

> 4 labourers are required to load and empty the kiln.
> These labourers also sieve, weigh and stitch each
> day's production.

Variable costs

(i) Wood.
The PST kiln examined used mainly wood dried for
longer than 4 to 6 months and no wood that had been air
dried for a period shorter than 3 weeks. The length of each
piece was approximately 0.5 metres.

The yield proved difficult to asses as accurate measurements
of the mass of wood loaded and the wood moisture content
were not made by the operators. After much consultation and
personal observation the following figures appeared to be
reasonable, and if anything conservative:

> 4000 kg of wood at 20% moisture content (dry basis)
> added per batch. 900 kg of lump charcoal produced
> per batch. This excludes fines which for the PST kiln
> are minimal (< 3% by weight). This gives a yield on a
> dry basis of 27.0 %.

The average yield on Site A for cold and medium burns with
wood that had been air dried for at least two months was
19.1 %. The PST kiln shows an increase in yield of 41.4%. The
related increase in charcoal output per stere is assumed to be
the same. This gives an output per stere of 81.42 kg. From
Shaw (1989) it is estimated that there is a 4 % increase in
production cost to produce 0.5 metre lengths rather than 0.8
metre lengths. Therefore:

$$\text{wood cost per bag} = 1.04 * R15/(81.42/5)$$
$$= R0.957$$

(ii) **Blade saw operating cost.** The electricity, maintenance and blade sharpening costs are assumed to be half that for the diesel saw. Therefore:

$$\text{saw cost per bag} = \text{R0.052}/2$$
$$= \text{R0.026}$$

This includes the electricity cost of loading the kiln.

(iii) **Vehicle costs.** This kiln is not easily transportable. From observation it is estimated that the costs for transporting wood to the production site is double that estimated for on-site charcoal transport at Site A. A tractor operating cost of R0.30 per bag is thus assumed for Site B.

PRODUCTION RATE B: 7800 BAGS PER MONTH

(a) Capital costs

(i) 60 two hundred and ten litre oil drums. Cost: R5 per drum.

(b) Operating costs

(i) Labour requirements.

Two shifts of 4 labourers each are required to load and empty the kiln. These labourers also sieve, weigh and stitch each days production.

It is assumed that the night shift earn 1.5 times the day shift i.e. R30 per labourer per shift.

PROJECT CASH FLOWS

The effect of the production rate and discount rate on the cumulative income is shown in figure 4.6.

Figure 4.6 Cumulative project cash flows: Site B - Stand alone case

4.4.6 Supplementary case

PROJECT CASH FLOWS

The effect of the production rate and discount rate on the cumulative income
is shown in figure 4.7.

Figure 4.7 Cumulative project cash flows: Site B - Supplementary case

4.5 Site C : Armco Kiln

4.5.1 Kiln description

This is a commercially available portable steel kiln built from corrugated plates. The kiln examined was a slightly modified version of that normally used and is illustrated in figure 4.8 below. It is 6 metres long and has a volume of 36 m^3.
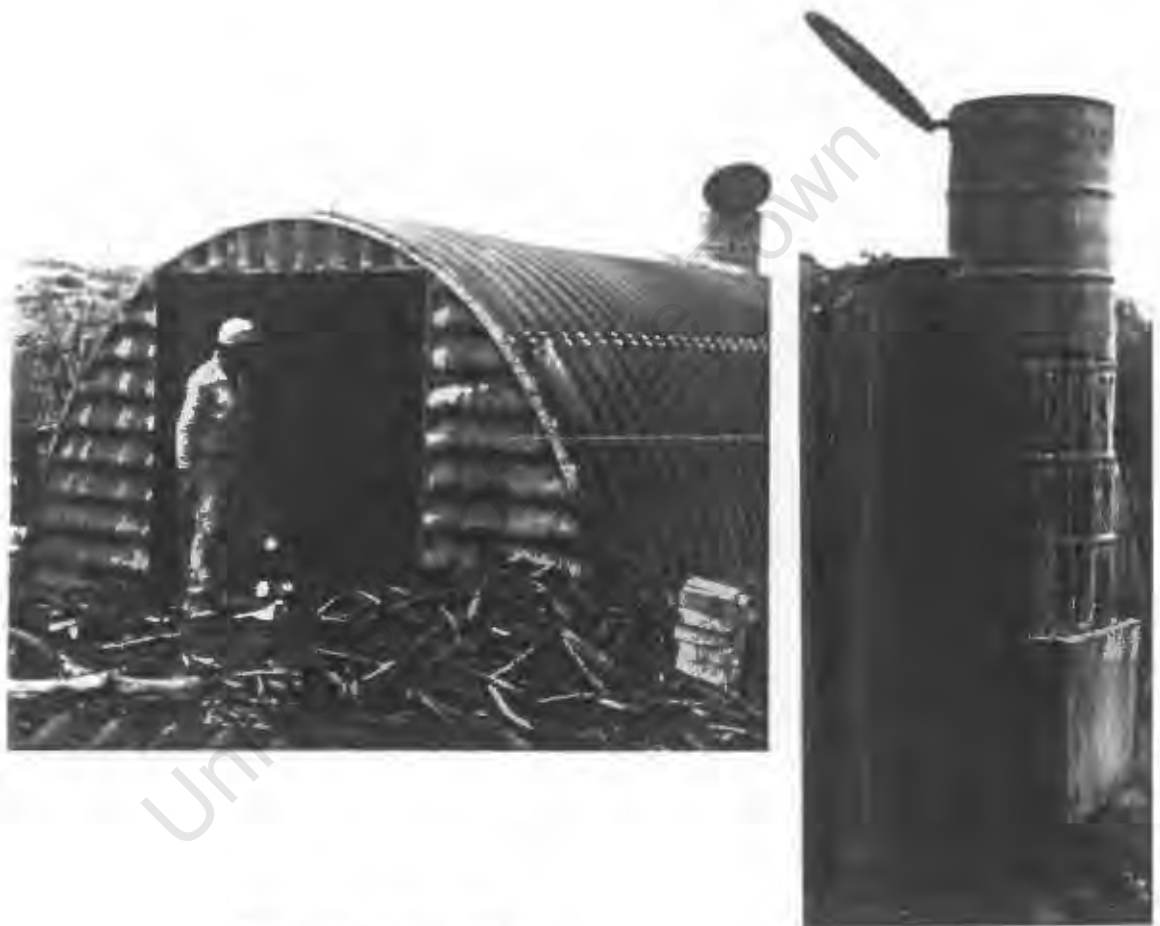
Figure 4.8 Armco Kiln

4.5.2 Operation

As can be seen in figure 4.8, the end closure of the kiln can be removed to facilitate loading and unloading. The wood is tightly packed so as to fill the entire volume. The kiln is fired at the end furthest from the chimney. Air inlets are opened and closed in succession until the entire charge has been carbonised. This can take between 8 and 10 hours. Unloading and loading the kiln takes 8 hours and cooling a further 14 hours.

4.5.3 Production rates

    A   It is possible to fire one kiln 3 times per week to produce 300 bags of charcoal per cycle. This gives a production rate of 3900 bags per month.

    B   Using 2 kilns it is possible to increase this production rate to 7800 bags per month.

4.5.4 Specific assumptions

Assumptions concerning equipment and costs made for Site A hold for the corresponding cases and production rates for Site C. Only deviations are referred to in this section.

4.5.5 Stand alone case

PRODUCTION RATE A: 3900 BAGS PER MONTH

(a) Capital costs

    (i)   A kiln can be bought, delivered and established on a site for R17 000.

(b) Operating costs

Fixed Costs

    (i)   Labour.

> 3 labourers to load and unload the kiln and sieve the charcoal.
> 2 labourers to weigh and stitch the bags.
> 1 labourer to work three nights a week at 1.5 times normal salary.

Variable costs

(i) **Wood.** Wood of various moisture contents was used to charge the kiln with most of the wood having been slightly charred by a recent veld fire and cut into 1.5 metre lengths. Various outputs per firing were thus reported which lead to the following yield estimate:

> Taken over a period of a few months the operator of the kiln gave an average of 300 bags per firing as an acceptable figure. Observation of the density of packing and the wood diameter gave an estimate of two thirds the density of packing as for Site A. An estimate yield of 20% on a dry basis was made by the previous operator of a similar kiln using *Acacia Saligna* and *Acacia Cyclops*. This gives an improved yield of 4.7 % to that at Site A.

An average of the above two estimates is used to calculate a charcoal output per stere of 61.40 kg. From Shaw (1989) a decrease in cost of 5 % to cut 1.5 rather than 0.8 metre lengths was estimated. Therefore:

$$\text{wood cost per bag} = 0.95 * R15/(61.40/5)$$
$$= R1.16$$

PRODUCTION RATE B: 7800 BAGS PER MONTH

(a) Capital costs

(i) If a producer is in possession of an Armco kiln it is possible to have a second one made partly from Armco plates and partly from locally purchased materials. The additional cost for a second kiln is R9 000. The cost of the two kilns is R26 000.

(b) Operating costs

(i) Labour requirements.

6 labourers to load and unload the kiln and sieve the
charcoal.

3 labourers to weigh and stitch the bags.

1 labourer to work three nights a week at 1.5 times
normal salary.

PROJECT CASH FLOWS

The effect of the production rate and discount rate on the cumulative income
is shown in figure 4.9.

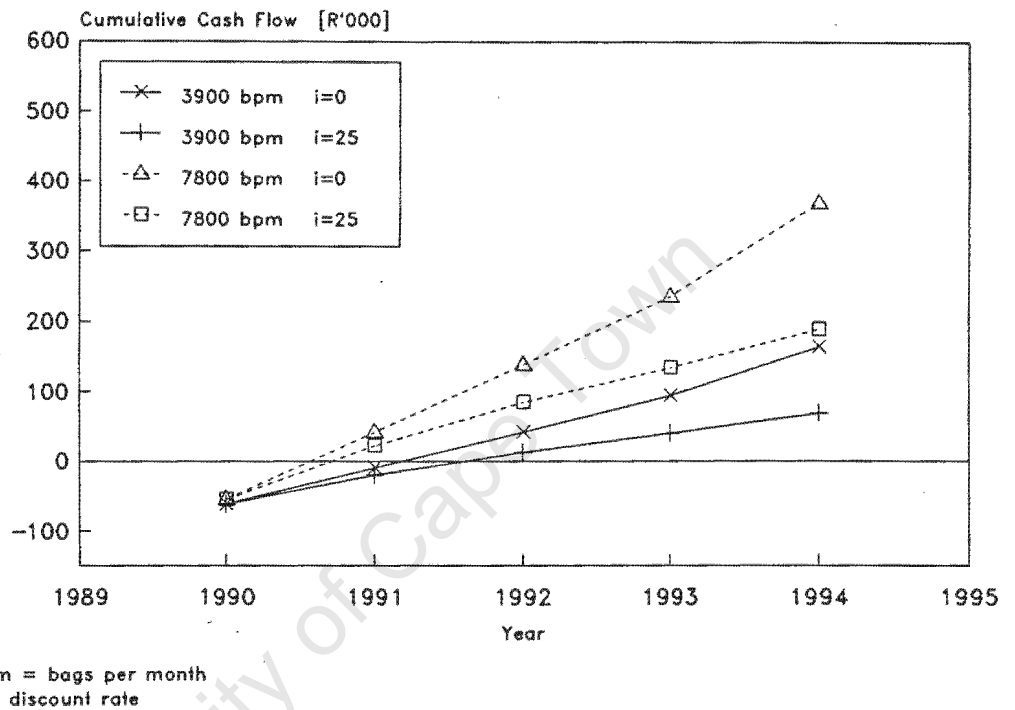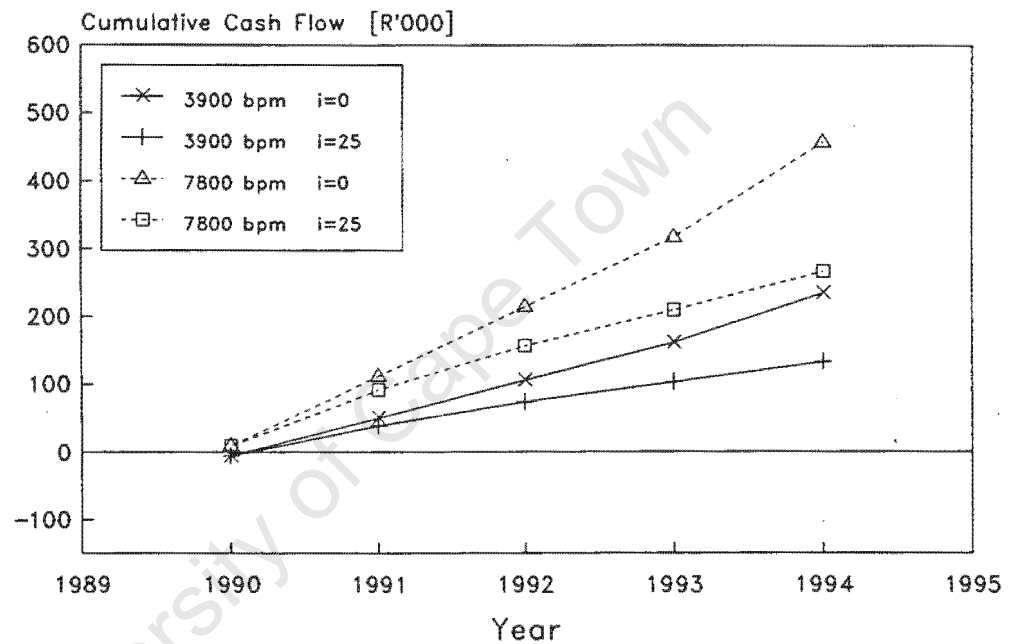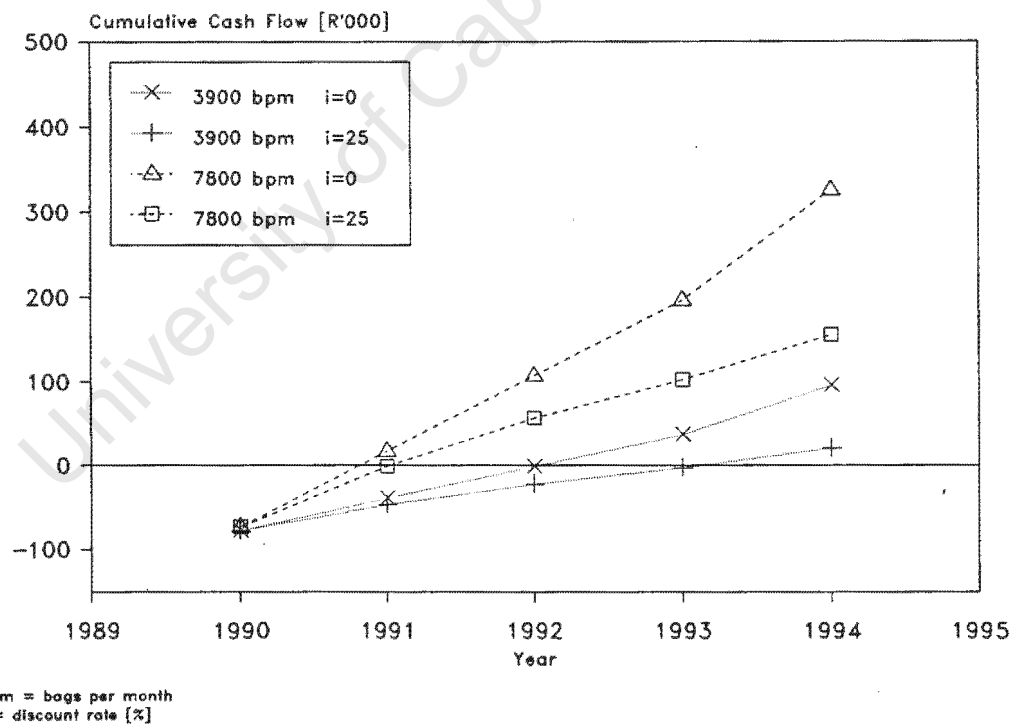Figure 4.9 Cumulative project cash flows: Site C - Stand alone case

4.5.6 Supplementary case

PROJECT CASH FLOWS

The effect of the production rate and discount rate on the cumulative income is shown in figure 4.10.
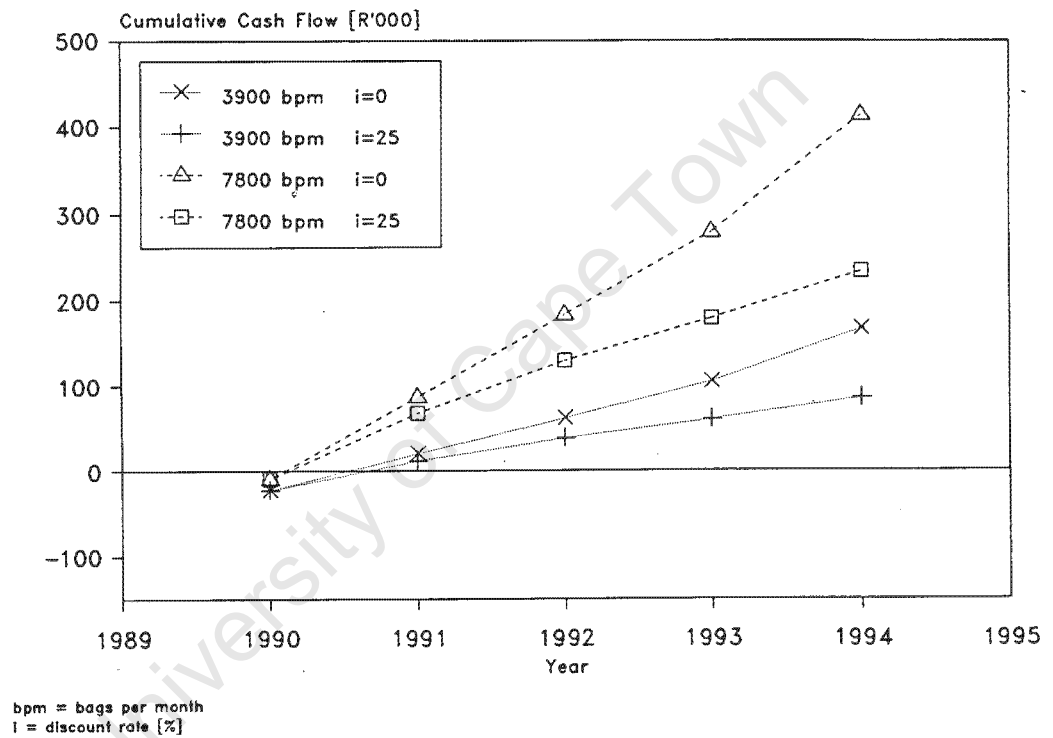
Figure 4.10 Cumulative project cash flows: Site C - Supplementary case

4.6 Site D : Gevers Kiln

4.6.1 Kiln description

Gevers kilns are made from the same 23 m³ petrol storage tanks as used for the PST kiln. Three Gevers kilns can be cut from one tank with each kiln having a volume of 7.6 m³. A typical kiln is illustrated in figure 4.11 below.
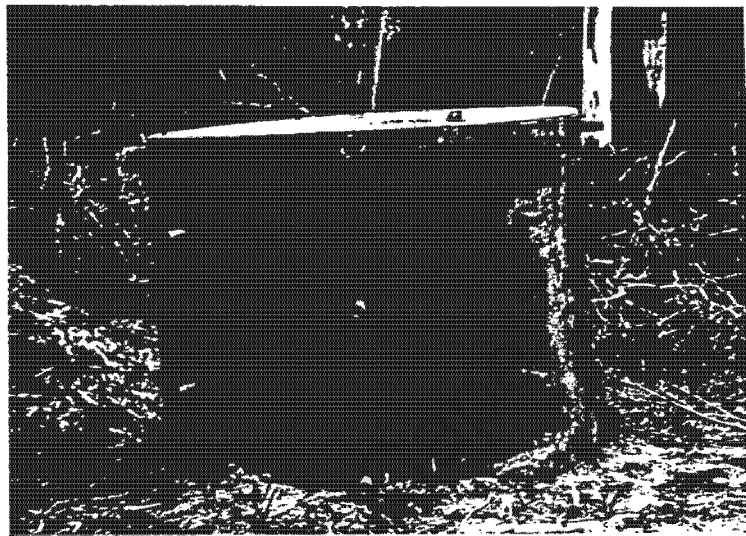
Figure 4.11 Gevers Kiln

4.6.2 Operation

Wood is stacked on a metal frame in the shape of the kiln. The kiln is then lifted using a light overhead gantry with a hand operated chain hoist and placed over the stacked pile. The kiln is fired and usually requires 8 hours to complete the burn. All air inlets are then sealed and the kiln is allowed to cool over night. The kiln is lifted the next day and the process repeated giving a 24 hour cycle.

4.6.3 Production rates

A It is possible to fire one kiln five times per week with each firing producing 50 bags of charcoal. Using 3 kilns a production rate of 3250 bags per month is possible.

B Using 6 kilns it is possible to increase this production rate to 6500 bags per month.

4.6.4 Specific assumptions

Assumptions concerning equipment and costs made for Site A hold for the corresponding cases and production rates for Site D. Only deviations are referred to in this section.

4.6.5 Stand alone case

PRODUCTION RATE A: 3250 BAGS PER MONTH

(a) Capital costs

    (i)   To purchase, degass and manufacture and deliver 3 kilns costs R2 000.

    (ii)   The light hoist can be constructed for R2 000.

(b) Operating costs

Fixed Costs

    (i)   Labour.

        3 labourers to sieve weigh and stitch each days' production as well as to assist where necessary in loading and unloading the kiln .
        1 labourer to operate the kiln.

Variable costs

    (i)   Wood. Information given by a producer who has operated this kiln as well as a Tongan drum kiln indicates that similar yields of saleable charcoal can expected using wood of the same moisture content. The length of wood used is 0.8 metres. The cost per bag of charcoal is thus assumed to be the same as that for Site A.

PRODUCTION RATE B: 6500 BAGS PER MONTH

(a) Capital costs

    (i)   6 kilns are required and the cost is double that for 3 kilns.
          Cost: R4 000.

(b) Operating costs

    (i)   Labour requirements.

          5 labourers to sieve weigh and stitch each day's
          production as well as to assist where necessary in
          loading and unloading the kiln.
          1 labourer to operate the kiln.

PROJECT CASH FLOWS

The effect of the production rate and discount rate on the cumulative income
is shown in figure 4.12.
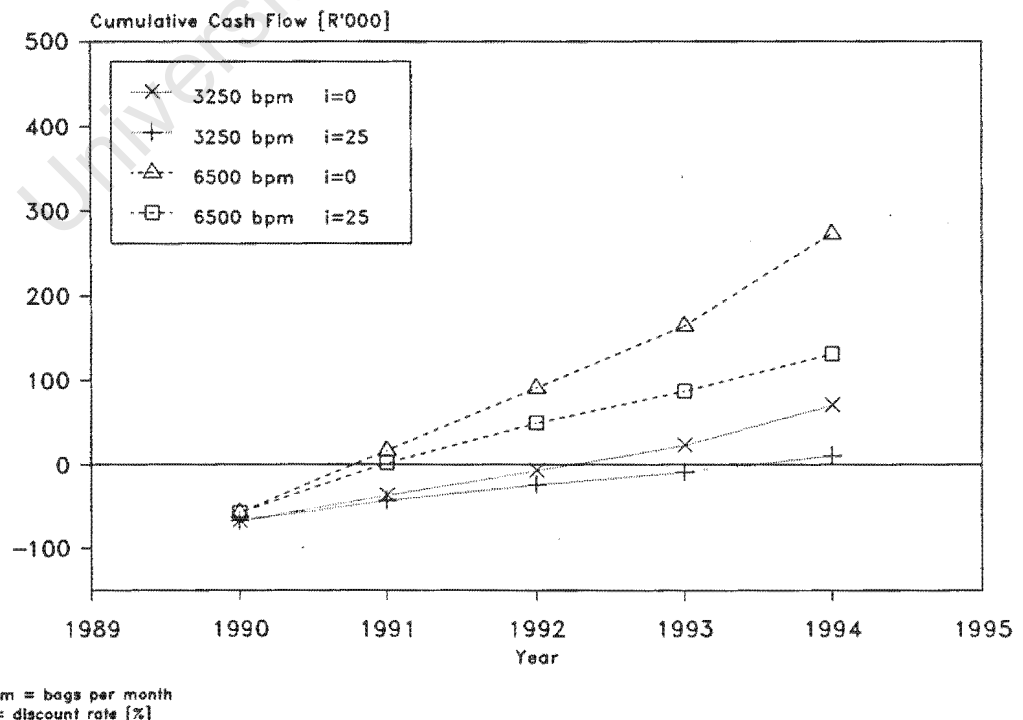
Figure 4.12 Cumulative project cash flows: Site D - Stand alone case

4.6.6 Supplementary case

PROJECT CASH FLOWS

The effect of the production rate and discount rate on the cumulative income is shown in figure 4.13.

bpm = bags per month
i = discount rate [%]
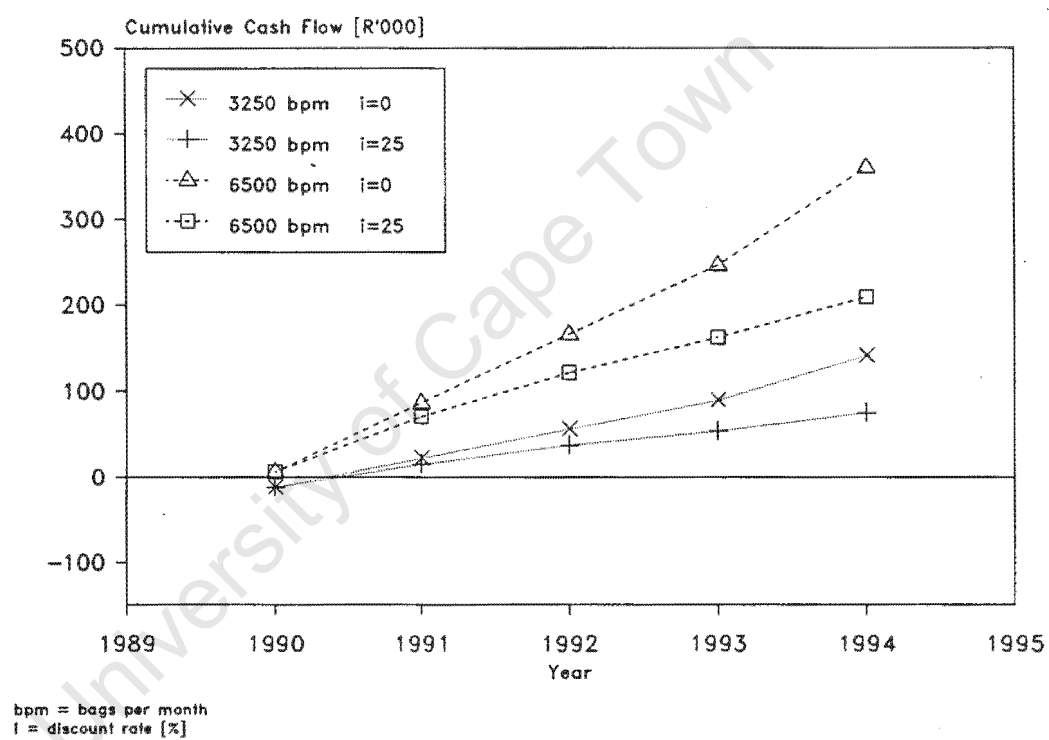
Figure 4.13 Cumulative project cash flows: Site D - Supplementary case

4.7 Investment indices

The investment indices for all cases are shown in tables 4.1 and 4.2 below:

Table 4.1 Investment indices: Stand alone cases

Site	A		B		C		D	
Production rate								
[b.p.m.]	3484	6968	3900	7800	3900	7800	3250	6500
NPV [R'000]	-27.8	34.6	68.2	188.3	20.5	155.1	10.5	131.0
DCFR [%]	6	44	78	174	38	120	33	126
Payback period [yrs]	>5	4.0	2.6	1.7	4.1	2.0	4.5	2.0
ROId [%]	-8.3	9.4	16.7	42.9	4.9	31.5	3.0	33.4
ROI [%]	4.1	35.8	40.2	83.9	22.8	66.2	19.9	69.5
BCC [R']	4.11	3.77	3.44	3.26	3.76	3.38	3.81	3.37

b.p.m. = bags per month
NPV = Net Present Value
DCFR = Discounted Cash Flow Return
ROId = Return on Investment (discounted net cash flow)
ROI = Return on Investment
BCC = Breakeven cost of charcoal per bag

Site A - Tongan drum kiln
Site B - PST kiln
Site C - Armco kiln
Site D - Gevers kiln

Table 4.2 Investment indices: Supplementary cases

Site	A		B		C		D	
Production rate [b.p.m.]	3484	6968	3900	7800	3900	7800	3250	6500
NPV [R'000]	36.6	112.3	132.6	266.0	84.8	232.8	74.9	208.7
DCFR [%]	93	216	913	/	184	992	278	/
Payback period [yrs]	2.4	1.6	1.1	0.8	1.7	1.1	1.4	0.9
ROId [%]	46.7	139.0	87.1	173.8	52.7	113.0	78.0	169.9
ROI [%]	107.3	270.4	153.9	297.9	102.9	200.5	146.5	339.1
BCC [R']	3.63	3.48	3.01	3.01	3.33	3.12	3.30	3.06

b.p.m. = bags per month
NPV = Net Present Value
DCFR = Discounted Cash Flow Return
ROId = Return on Investment (discounted net cash flow)
ROI = Return on Investment
BCC = Breakeven cost of charcoal per bag

Site A - Tongan drum kiln
Site B - PST kiln
Site C - Armco kiln
Site D - Gevers kiln

4.8 Sensitivity analysis

The relative effects on the economic viability of the project of changes in items contributing to cash flow is explored. In this project the change in viability will be assessed in terms of a change in breakeven cost per bag of charcoal. The cash flow items to be used are the following:

- a 20% increase in capital costs
- a 20% decrease in capital costs
- a 20% increase in labour costs (excluding wood preparation)
- a 20% decrease in labour costs (excluding wood preparation)
- a 20% decrease in maximum production

The effect of variation in wood harvesting costs is analysed in more detail as follows:

- a 20% increase in wood costs
- a 20% decrease in wood costs
- a 50% decrease in wood costs

The vehicle running costs are analysed in similar detail as follows.

- a 20% increase in running costs
- a 20% decrease in running costs
- a 50% decrease in running costs

The results of the sensitivity analyses for all cases are shown in tables 4.3 and 4.4 below.

Table 4.3 Sensitivity analysis: Stand alone cases

Site	Change in BCC [%]							
	A		B		C		D	
Production rate [b.p.m.]	3484	6968	3900	7800	3900	7800	3250	6500
+20% Capital	2.5	1.5	3.0	2.0	3.0	2.0	3.1	2.0
-20% Capital	-2.5	-1.5	-3.0	-2.0	-3.0	-2.0	-3.1	-2.0
+20% Labour	4.6	4.6	2.8	3.8	3.8	3.5	3.2	2.6
-20% Labour	-4.6	-4.6	-2.8	-3.8	-3.8	-3.5	-3.2	-2.6
-20% Production	9.9	8.5	8.6	8.0	9.5	7.7	8.8	6.6
Wood costs:								
+20%	6.6	7.2	5.8	6.4	6.5	7.1	7.2	8.1
-20%	-6.6	-7.2	-5.8	-6.4	-6.5	-7.1	-7.2	-8.1
-50%	-16.5	-17.9	-14.4	-15.1	-16.0	-17.8	-17.6	-19.9
Vehicle costs:								
+20%	2.0	2.2	3.3	3.7	2.3	2.3	2.3	2.4
-20%	-2.0	-2.2	-3.3	-3.7	-2.3	-2.3	-2.3	-2.4
-50%	-5.0	-5.4	-8.2	-8.4	-5.4	-6.1	-5.2	-6.0

b.p.m. = bags per month
BCC = Breakeven cost of charcoal per bag

Site A - Tongan drum kiln
Site B - PST kiln
Site C - Armco kiln
Site D - Gevers kiln

Table 4.4 Sensitivity analysis: Supplementary cases

	Change in BCC [%]							
Site	A		B		C		D	
Production rate								
[b.p.m.]	3484	6968	3900	7800	3900	7800	3250	6500
+20% Capital	0.6	0.3	1.3	0.5	1.3	0.9	0.8	0.6
-20% Capital	-0.6	-0.3	-1.3	-0.5	-1.3	-0.9	-0.8	-0.6
+20% Labour	5.0	4.9	3.1	3.8	4.2	3.7	3.3	2.7
-20% Labour	-5.0	-4.9	-3.1	-3.8	-4.2	-3.7	-3.3	-2.7
-20% Production	7.7	7.0	6.2	6.1	7.4	6.1	6.0	4.6
Wood costs:								
+20%	7.3	7.7	6.6	6.5	7.3	7.6	8.0	8.7
-20%	-7.3	-7.7	-6.6	-6.5	-7.3	-7.6	-8.0	-8.7
-50%	-18.8	-19.4	-16.6	-16.7	-18.1	-19.4	-20.6	-22.1
Vehicle costs:								
+20%	2.1	2.3	3.7	3.7	2.5	2.5	2.3	2.6
-20%	-2.1	-2.3	-3.7	-3.7	-2.5	-2.5	-2.3	-2.6
-50%	-5.8	-6.0	-9.3	-9.4	-6.2	-6.6	-6.3	-6.7

b.p.m. = bags per month
BCC = Breakeven cost of charcoal per bag

Site A - Tongan drum kiln
Site B - PST kiln
Site C - Armco kiln
Site D - Gevers kiln

4.9 Discussion

A road side operator can increase earnings by an estimated 24 % through producing charcoal rather than firewood. This is less than the doubling in earnings for charcoal production at this level predicted by Shaw (1989). The calculations in section 4.1.1 are performed for a single operator whereas Shaw (1989) assumed that a team of workers would be involved in wood harvesting and charcoal preparation. This is a possible explanation for the discrepancy in results.

As a commercial site the Tongan drum kiln does not fare well against the other technologies examined.

Despite requiring the lowest capital investment for the kilns, the net present value is substantially less that at the other sites. This is ascribed to the kiln cost in all technologies being a relatively small percentage of the overall costs. The kiln is however the least sensitive to an increase in capital costs.

All the investment indices follow more or less the same trends as the NPV with the PST kiln being the most attractive investment option. It does however have to be sited at an electric power source, and is not easily transportable. Wood has to be transported to the kiln and this is reflected in the relatively high sensitivity of the PST kiln to changes in vehicle costs.

The profitability of the PST kiln is followed by the Armco kiln, the Gevers kiln and the Tongan drum kiln in that order. This order appears to be directly related to the yields obtained and thus to the cost of wood. The Gevers kiln, although having the same yield as the Tongan drum kiln has more favourable investment indices because of the lower labour input required. The Tongan drum kiln is consequently more sensitive to an increase in labour costs.

The sensitivity of all the technologies to a change in wood costs is high. Wood costs are related to the kiln yields and the efficiency of wood harvesting. To ensure profitability, both these aspects of production will have to closely monitored and optimised.

A decrease in production also has a substantial effect on the breakeven cost per bag of charcoal. It appears important to ensure a minimum of down time with all the technologies. The production rate is also related to the yields obtained.

The supplementary case Gevers kiln shows a breakeven cost per bag of charcoal second only to the PST kiln. This is probably due to the low capital cost of the Gevers kiln relative to that of the Armco kiln. The Gevers kiln is easily transportable and appears to be a viable alternative to the Tongan drum in more inaccessible areas. For all investment indices however, there are only marginal differences between the Gevers and the Armco kilns.

It is however noteworthy that the supplementary case Tongan drum kiln at the higher production rate produces the least, but nevertheless, substantial return on investment and discounted cash flow return. The nature of the Tongan drum kiln allows it to be very easily used at different production rates by buying more drums as labour becomes available. This type of production lends itself to a typical farm set up where labour surpluses are experienced at various times of the year.

Chapter 5

CONCLUSIONS and RECOMMENDATIONS

5.1 Conclusions

It is possible to offset the costs of bush clearing by producing charcoal with the Tongan drum kiln. This project has shown that it is technically viable.

The most important qualities of this technology proved to be the following:

- It is capable of producing at a consistent yield when operated by unskilled labour. The yields and charcoal quality are shown to compare favourably with both small scale and large-scale charcoal producing technologies in the developing world.

- The quality of charcoal produced is well within the standards set for the braai market. It also falls within the specifications required for industrial use.

- The ease with which the kilns can be transported to the wood source thereby eliminating costly transportation of wood.

- It is the simplest kiln to construct and operate of those examined. It is also the smallest scale technology, allowing easy entry to the charcoal market at minimal cost.

The most significant disadvantage of the Tongan drum kiln is its inability to effectively carbonise wood with a diameter larger than 160 mm. This however is largely negated in that most *Acacia Saligna* forest does not reach this size.

The excessive production of charcoal fines by the kiln is not seen as a serious disadvantage as the yields obtained excluding these fines remain high.

But is the Tongan drum an economically viable charcoal production technology? In many senses, this is an academic question for those involved in the informal sector. It is the only technology they can afford, and we have shown that charcoal production using this kiln can increase earnings above that generated by the sale of firewood. This increase is however only marginal and any spontaneous shift from firewood to charcoal production is unlikely.

The Tongan drum kiln can however not compete with large scale operations. This is primarily due to the lower yields obtained and higher labour inputs required relative to other options. The investment indices indicate that the PST kiln is the most viable charcoal production technology for both landowners and entrepreneurs. It is also the least sensitive to changes in items contributing to cash flow. The disadvantage of this kiln is that it has to be sited at an electricity source.

The only investment index where the Tongan drum kiln performs better than any of the other options is the return on investment for the supplementary case (landowners) where it is superior to the Armco kiln.

It must however be noted that all cases are sensitive to an increase in wood costs. The wood cost per bag of charcoal is directly proportional to the charcoal yields obtained. Gore (1983c) gives the yield for an Armco kiln as being 15.5% whereas a yield of 20 % was assumed for the Armco kiln operating on Site C. This illustrates the variation and uncertainty that exists when estimating charcoal yields. The same holds true for the PST and Gevers kilns.

Although the investment indices indicate favourable returns for these technologies, they are seldom attained by local producers. This is attributed to the following typical characteristics of the sites examined:

- The process from harvesting the raw material to the production of the charcoal is labour intensive and requires long working hours under unpleasant conditions.

- The work is consequently performed by a largely unskilled and unmotivated labour force.

The local charcoal industry is also characterised by:

- Stiff competition between local producers.

- Serious competition from charcoal products imported from the Transvaal, Natal and Namibia.

Any investment in the charcoal industry should therefore be preceded by careful consideration of factors that have been shown to affect the profitability of each technology.

On the other hand the Tongan drum kiln has been shown to deliver a consistent yield when operated by a variety of operators and in all weather conditions. This charcoal yield increases substantially when the fines are included, and results in a higher overall yield than obtained when using the larger scale kilns.

Possible advantages of the Tongan drum kiln are:

- The kilns are small resulting in only a small wastage if a kiln is badly operated. With the larger kilns it is possible to lose an entire charge due to indifferent operation.

- Each labourer operates several kilns individually. It is thus possible to closely monitor the production rate and to remunerate each labourer pro rata for each days production. A similar remuneration system was installed at Site A for wood harvesting resulting in an increase in harvesting rates by a factor of 2 to 3.

- The Tongan drum kiln is the most labour intensive of all the production options. Given the high unemployment of unskilled workers in the Western Cape, this is an important factor in determining the appropriateness of the technology

- The nature of the kiln also allows for cheap and easy
  expansion of the production output.

5.2 Recommendations

The Tongan drum kiln has been shown to produce a greater overall yield than the other charcoal producing technologies found in the Western Cape. On average 35-40 % of the yield is in the form of fines. This cannot be sold as lump charcoal and an alternative market is required. The most attractive option for a charcoal producer would be to briquette the fines thereby offering an alternative product to clients. Most charcoal briquetting technology is however large scale and capital intensive, not suitable to the scale of operation practised in the local charcoal market. It is therefore recommended that low cost, small-scale briquetting technologies be investigated.

The economic appraisal has shown that one of the most critical factors affecting the profitability of the technologies is the yield obtained. It is also the factor around which the greatest degree of uncertainty exists. A closer monitoring of these technologies is required to reduce this uncertainty. It is therefore recommended that this be done for the PST, Armco and Gevers kilns operating under local conditions.

References

Alidi, F S (1984). Botswana: Investigation - Demand on woodfuel. <u>SADCC Energy</u>, No.6, Oct.-Dec.

Allen, D H (1980). A guide to the economic evaluation of projects. The Institution of Chemical Engineers, Rugby.

ASSET (1981). UNCNRSE conference news section. United Nations conference on new and renewable sources of energy, Nairobi.

ASTM Designation D 2016-74 (Reapproved 1983) (1987). Standard test methods for moisture content of wood - Oven dry method. Annual book of ASTM Standards, Philadelphia.

Baldwin, S F (1987). Biomass stoves: Engineering design, development, and dissemination. Volunteers in technical assistance, Arlington, Virginia.

Bennie, G (1982). Survey of the charcoal manufacturing industry in the Transvaal and Natal. National Timber Research Institute, CSIR Special Report: Hout 255, Pretoria.

Boutetie, M and Karch, G E (1984). Charcoal: Small scale production and use. Braunschweig.

Chamaere, W and Nkaonja, R S (1984). Woodfuel and charcoal in Malawi. <u>SADCC Energy</u>, No.6, Oct.-Dec.

Cohen, R (1982). Charcoal market in South Africa. CSIR Special Report: Hout 269, Pretoria.

Duvigneau, J C and Prasad, R N (1984). Guidelines for calculating financial rates of return for DFC projects. World Bank Technical paper No.33, Washington D.C.

Development Assistance Corporation (1982). Proceedings of workshop on energy, forestry and environment Vol.3. Washington D.C.

Dixon, W J and Massey, F J (1969). Introduction to statistical analysis. Third edition, McGraw-Hill.

Earl, D E (1975). Forest energy and economic development. Clarendon Press, Oxford.

Ellis, G (1982). Issues in African energy development. Development Assistance Corporation, Proceedings of workshop on energy, forestry and environment Vol 2. Washington D.C.

Emrich, W (1985). Handbook of charcoal making. Solar Energy R&D in the European Community, Series E, Vol.7, Energy from biomass, Dordrecht.

Foley, G (1986). Charcoal making in developing countries. Technical Report No.5, Energy Information Programme, International Institute for Environment and Development, London.

Gore, W T (1982a). Charcoal production and properties. CSIR Special Report: Hout 262, Pretoria.

Gore, W T (1982b). The analysis of wood charcoal. CSIR Subject Survey: O/Hout 42, Pretoria.

Gore, W T (1983). Charcoal and retorts. CSIR Special Report: Hout 292, Pretoria.

Hughart, D (1979). Prospects for traditional and non-conventional energy sources in developing countries. World Bank, Washington D.C.

Huy, V R (1984). "Can charcoal help to overcome the urgent need for firewood". Energy for Underdeveloped Areas Conference, Energy Research Institute, Cape Town, 9-10 Feb.

International Labour Office (1985). Fuelwood and charcoal preparation. Geneva.

Kawanguzi, A C and Merrikum, P (1987). New kiln offers more and better charcoal - and employment. Ceres, No.116, Vol29, No.2.

Kristoferson, L, Bokalders, V and Newham, M (1984). Biomass energy: production, conversion, utilisation. The Beijer Institute, Stockholm.

Leach, G and Gowen, M (1987). Household energy handbook: An interim guide and reference manual. World Bank Technical paper No.67, Washington D.C.

Malawi Energy Studies Unit (1984). Malawi urban energy survey. Energy Studies Unit, Ministry of forestry and Natural Resources, Lilongwe.

Michaelis, L A (1986). Survey of wood based energy technologies. Cambridge Energy Research Group, Cambridge.

National Academy of Sciences (1984). Diffusion of biomass technologies in developing countries. Washington D.C.

Openshaw, K (1983). Measuring fuelwood and charcoal. Wood fuel surveys, Food and Agriculture Organisation of the United Nations, Rome.

Paddon, A R and Harker, A P (1979). The production of charcoal in a portable metal kiln. Tropical Products Institute, London.

SABS Standard 1399 (1983). Standard specification fo wood charcoal and charcoal briquettes for household use. South African Bureau of Standards, Pretoria.

SABS Standard Method 925 (1978). Moisture content of coal samples intended for general analysis (air-oven method). South African Bureau of Standards, Pretoria.

SABS Standard Method 926 (1978). Ash content of coal. South African Bureau of Standards, Pretoria.

SABS Standard Method 927 (1978). Volatile matter content of coal. South African Bureau of Standards, Pretoria.

SABS Standard Method 928 (1978). Calculation of fixes carbon content of coal. South African Bureau of Standards, Pretoria.

SADCC Energy (1984). "95% of households in Zambia depend on woodfuel". SADCC Energy, No.5, June-Aug.

SADCC Energy (1987). "Malawi project aims to make small business energy conscious". SADCC Energy, Vol.5, No.15.

Shaw, G D H (1989). The use of alien woody biomass for low cost small-scale charcoal production. Energy Research Institute, University of Cape Town.

Williams, A T and Eberhard, A A (1987). Potential for the production of energy from biomass in South Africa. South African Journal of Science, Vol.11, No.1.

Yatim, B and Hoi, W K (1987). Quality of charcoal from various types of wood. Fuel, Vol.66, No.9.