THE DESIGN OF A
WAX-BURNING STOVE

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DECLARATION

I declare that this dissertation, which I herewith submit to the University of Johannesburg for the research qualification MTech Industrial Design, is, apart from recognised assistance, my own work and has not been submitted for any other qualifications.

Ryan Fowler

Date

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ABSTRACT

This project aims to design a stove that is fuelled by wax, rather than paraffin, in order to reduce the problems created by the use of paraffin and paraffin stoves among the urban poor living in South African townships and informal settlements. The project, in suggesting that conventional approaches to industrial design are inadequate to this task, seeks to explore more appropriate avenues for resolving the design-related problems that arise from the socio-cultural and economic conditions of poor urban communities. In order to more accurately address the needs of these communities with whom the designer may have little in common, indigenous knowledge traditions, and the needs associated with these traditions, are valued in defining the design problem. Fieldwork was conducted from this intellectual standpoint with the purpose of gaining a fuller understanding of the conditions under which paraffin stoves are used in South African townships and informal settlements, and to determine how these conditions should impact on the design of the stove. A set of recommendations, that are informed by the principles governing fuelled stove efficiency, and by which further wax-stove developments should proceed, is presented with reference to the findings of the fieldwork programme. The practical outcome of this research is the design for a wax-stove fuel system that accounts for the specific requirements of potential stove users and supports the most successful solutions to the problems of wax-stove ignition, control and shutdown that have been developed through the course of this project.

CHAPTER 1 – THE DESIGN OF A WAX-BURNING STOVE

INTRODUCTION

Despite the robust and growing economy that the South African government has achieved in its drive towards transformation over the past ten years, the country is still marked by a large divide between rich and poor.[1] About 28% of South Africa's urban population live below the poverty line (May 1998:online) and are forced by their circumstances to live in informal settlements situated in and around urban centres. Members of these communities can often only afford to buy the cheapest products and services available, irrespective of any negative ramifications that using these products and services may have. Most notable in this regard is the use of paraffin for cooking. Paraffin is a highly volatile fuel and is poisonous if ingested (PASASA 2004a:4) but the fuel continues to be used by a large sector of the urban poor who cannot afford to use safer energy sources. In response to this situation, the South African-based petrochemical giant Sasol has proposed the use of one of their non-toxic and less volatile wax-fuels as a cheap and safer alternative to paraffin (Sasol Oil R&D 2002:1).

A change in fuel use will, however, only address this one aspect of the problem. A number of other problems result from the flawed designs and poor quality of manufacture of paraffin stoves that are currently in use. Most of these stoves have been shown to reach dangerously high temperatures as well as being unstable and prone to fuel leaks.[2] These design flaws are partly to blame for fires that destroy as many as 100 000 dwellings in South Africa each year (Lloyd 2002:56), costing the state an estimated R1,3 billion per annum (van Niekerk 2003:1). Paraffin stove related fires cause 75% of all burn deaths in South Africa (ibid).

This project proposes that an appropriately designed stove, fuelled by wax, could begin to address these problems by providing the urban poor with a viable alternative to paraffin stove use. The wax-stoves that have been designed through the course of this project aim to emulate those advantages of paraffin stove use that make paraffin stoves so accessible to the urban poor, while eliminating as many of their dangers and disadvantages as possible.

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[1] The Gini coefficient is used as an indicator of the levels of economic disparity between the rich and poor of a country, with 0 representing absolute equality and 1 representing absolute inequality. South Africa has a Gini coefficient of 0.58, the second highest in the world (May 1998:online).

In attempting to provide a comprehensive solution to the problems of paraffin stove use, this project also calls into question conventional approaches to solving industrial design problems. These approaches have tended to focus on satisfying the manufacturing and functional requirements of product design without considering how the economic and socio-cultural contexts in which the product will be used should affect its form and function. As a means of overcoming this short-sightedness, fieldwork was conducted in Langa (a small township near Cape Town) and the neighbouring Joe Slovo informal settlement to establish how paraffin stoves are used (and misused) and which aspects of their use have been either adequately or poorly provided for. The demands of the user cannot, however, always be accommodated in a design that is also constrained by manufacturing, economic and functional requirements. This necessitates that the designer make compromises to effect an optimum solution. Sensitisation to the full range of problems is thus essential in solving as many of the problems as possible.

As yet, no design for a wax-stove has managed to achieve immediate and sustained fuel flow to the source of combustion from the time of ignition, while also being safe and convenient to use and having the potential to be manufactured at a price that would make it affordable to the urban poor. This project seeks to resolve this central functional constraint without disproportionately compromising the safety, usability or cost of the stove, while also considering the other major and interdependent functional constraints of stove ignition, flame control and shutdown.

PROBLEM STATEMENT

For the purposes of this research, the problems to be tackled in the design of a wax-stove are as follows:

- Consideration of user preferences
- Achieving optimal fuel flow
- Achieving maximum combustion efficiency

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2. Test House, a company affiliated to the South African Bureau of Standards (SABS) has conducted tests on nine of the most commonly used paraffin stoves in South Africa. All failed the SABS (2002) specifications for the safety of paraffin stoves on six or more counts, some of which included key safety tests (Truran 2004b:4; PASASA 2004b:online).

- Addressing safety issues related to the use of a wax-stove
- Addressing safety concerns related to the nature of wax-fuels
- Ensuring effective ignition and shutdown
- Ensuring ease of operation

AIMS AND OBJECTIVES

The aims and objectives of this research can be summarised as follows:

- To develop an understanding of the range of problems involved in designing products for non-western product users, particularly those from lower economic groups.
- To conduct grounded research into the true problems and usage patterns of paraffin stove users so as to develop an appropriately informed brief for the design of a new wax-stove.
- To design a wax-stove to solve both the operational and functional problems uncovered through the course of the research.
- To prototype a wax-stove as a means of testing the design ideas developed through the course of the research.

Scope of the Research

This project aims primarily to provide a comprehensive evaluation of the range of problems related to the design of wax-stoves. The project then attempts to address as many of these problems as possible in the conceptual and computer-aided design process, but the wax-stove prototypes are intended only to provide a basic means of testing the main functional design developments. The findings of this research with regards to the design approach used may have applications for design for non-western product users from lower economic groups in general. However, these findings pertain mainly to a South African context, since the research focuses on fuelled stove users in a Western Cape township and informal settlement. [3] Similarly, the findings of the fieldwork programme are not intended to be

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[3] The term *fuelled stove* is used in this dissertation to refer to any stove that is fuelled by paraffin, gas or any biomass material (this includes wood, dung and crop waste).

exhaustive and cannot be said to be a comprehensive assessment of the needs of fuelled stove users, despite the important contribution of these findings to the wax-stove designs described in this dissertation. These designs cannot claim to be sufficiently developed for manufacture. They are intended only to show a possible way forward for the development of wax-stoves.

STRUCTURE OF THE DISSERTATION

Chapter 1 has outlined the purpose of this research project.

Chapter 2 describes the dangers of paraffin stove use, how these dangers are compounded by the adverse conditions of those living in townships and informal settlements, and why a wax-fuel may provide a viable alternative to paraffin when other alternatives have failed to do so. The chapter briefly reviews wax-stove design work that has been done to date, concluding that, partly on account of the design approaches that have been used, none of these designs provides a comprehensive solution to the problems of paraffin stove use.

Chapter 3 investigates the problems arising from approaches to industrial design, where the preferences of potential product users are not accurately addressed in the design of the product. The current global re-evaluation of indigenous knowledge is proposed as a starting point from which the needs prioritisations of potential product users can be assessed apart from the values and expectations of the designer.

The fourth chapter provides an introduction to the fieldwork programme, which sought to begin a design process that would more accurately address the needs of potential wax-stove users. The findings of the fieldwork programme are then reviewed. This chapter presents a set of user-defined criteria for the design of a wax-stove and shows how these criteria have impacted on the form and functioning of the wax-stoves that have been designed for the purposes of this project.

Chapter 5 provides a brief overview of the factors that determine the functional performance of fuelled stoves.

The sixth chapter negotiates solutions to the major functional difficulties involved in using wax as a stove fuel to present a potentially viable wax-stove fuel system and a number of possible solutions to the problems of wax-stove ignition, flame control and shutdown.

Chapter 7 concludes this research project in noting the progress that has been made and suggesting a way forward for future wax-stove design initiatives.

CHAPTER 2 – WAX-FUEL: AN ALTERNATIVE TO PARAFFIN

> Residents… fled for their lives as flames tore through the [Joe Slovo] informal settlement, injuring 13 people and leaving an estimated 8 000 homeless. (Mbambato 2005:8)
>
> One of the residents claimed the fire was started by a man who had left a paraffin stove unattended while he took a nap. (Mtyala & SAPA 2005:5)

WAX-FUEL: AN ALTERNATIVE TO PARAFFIN

Nearly 2.4 million of South Africa's poorest urban households use paraffin for cooking (STATSSA 2001:1) because it is one of the cheapest sources of domestic energy in the country (Truran 2004a). A litre of paraffin currently retails for about R3,65 and paraffin stoves can be bought for as little as R20,00. Paraffin is also readily available to the urban poor (STATSSA 1997:4), and in small quantities. In the Joe Slovo informal settlement, for example, most dwellings are situated within two or three hundred metres of a supplier of paraffin fuel and stoves, and most suppliers will sell as little as 500ml of paraffin at a time – this is important for those who live a hand-to-mouth existence.

Paraffin is, however, dangerous to use because it is highly flammable, having a low ***flashpoint*** of 43°C (Lloyd 2002:57).[4] The flashpoint of a combustible or flammable material is defined as the lowest temperature at which the material evolves sufficient vapour to form a flammable vapour-air mixture that will burn instantaneously when ignited (Corbett & Urban 1996:172) – an occurrence that is referred to as *flashing*. Paraffin is also poisonous and, if ingested, can cause chemical pneumonia, an often fatal condition that is contracted by over 55 000 children each year in South Africa (van Niekerk 2003:1). Accidental ingestion occurs regularly because paraffin is a clear liquid that is easily mistaken for water.

The dangers presented by the use of paraffin are compounded by three major problems attributable to the poor quality and design of many of the paraffin stoves that are being used by the urban poor. Firstly, once lit, the paraffin in the fuel tanks of these stoves easily reaches temperatures in excess of 43°C [5], causing the formation of paraffin vapour, which, if exposed to a flame, will flash (as was witnessed several times in the Joe Slovo informal settlement). These flashes sometimes result in sustained and uncontrolled paraffin fires (Truran 2004b:5). The risk of the fuel flashing is further increased when paraffin has been stored in containers that have previously been used to store other fuels such as diesel and petrol (Truran 2004b:2). Such contamination occurs easily because paraffin is

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4. Other sources cite 40.6 °C as the flashpoint of paraffin (see, for example, Floor & van der Plaas 1991:16).

5. Test House (PASASA 2004b:online) has published the following figures regarding fuel temperatures in paraffin stove fuel tanks after two hours of operation: Giant-brand wick stove, single burner, round – 80°C; Giant-brand wick stove, single burner, square – 67°C; Giant-brand wick stove, double burner – 84°C; Panda-brand wick stove, single burner – 68°C.

not sold in any standardised or distinctive containers in South Africa’s informal settlements.[6] Rather, those buying paraffin are expected to provide their own containers into which the fuel can be decanted (ibid). This arrangement also increases the likelihood that paraffin may be mistaken for a harmless drink because the containers used for this purpose are typically used milk or cool drink bottles (ibid). Secondly, paraffin stoves are often unstable and are easily knocked over during use, causing fuel to spill from their tanks and catch alight (ibid), and thirdly, once lit, paraffin stoves release harmful carbon monoxide gas and fine particulate emissions. High levels of exposure to carbon monoxide can cause hypoxia, leading to unconsciousness and in some cases death, while particulate emissions, some of which are recognised carcinogens, can cause acute respiratory infections (Kammen & Dove 1997:3).[7]

The adverse living conditions of South Africa’s urban poor further exacerbate the problems related to the use of paraffin and paraffin stoves. In informal settlements, dwellings are often built less than a metre apart and may even share two or three walls with adjacent homes. This promotes the rapid spread of fires and limits the access that fire engines have to the blaze (Gedye & James 2004:41). Fires also grow rapidly out of control because flammable materials, including plastic sheeting, wood and cardboard, are often employed in the construction of informal dwellings. In March 2004, these factors contributed to the destruction of about a thousand homes when a fire, started by a paraffin stove, swept through the Joe Slovo informal settlement (Cape Argus 2004:1).

The use of paraffin stoves in close proximity to flammable household contents presents another danger (PASASA 2004a:8). In one of the typically small single-room dwellings visited during the fieldwork programme conducted in the Joe Slovo informal settlement, a paraffin stove was used on a high shelf no more than half a metre away from the family’s double bed. Were the stove to have been knocked over, it would have almost certainly landed on the bed and started a fire. Due to the small size of such dwellings, critical concentrations of carbon monoxide are more easily reached, especially when paraffin stoves are used as heaters and left burning for long periods (Nielsen 1996:6). Many informal dwellings also have only one door and no windows. This improves the warmth and security of the

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[6] The Cape Argus (2004:2) has reported that highly flammable fuels such as diesel and petrol are at times intentionally mixed with paraffin so as to improve the combustibility of the fuel.

[7] In the Vaal Triangle, annual medical costs related to stove emissions are estimated to be R1200 per family (Swanepoel 2004).

dwelling but limits ventilation and can result in the only escape route (the doorway) being blocked when a fire starts (Daweti 2004).

Informal settlements, by nature of their informality, tend to lack the facilities (including hospitals, clinics and ambulance services) needed to deal with emergency situations (Economist Intelligence Unit 2004:online). Thus, residents of informal settlements who sustain burn injuries or those who have ingested paraffin have to be transported to often-distant hospitals or clinics to receive medical attention; a trip that can be delayed by several hours when victims are reliant on public transport. Often, informal settlers also have no effective means of preventing a fire from growing out of control because, as in the Joe Slovo informal settlement, the water necessary to extinguish fires is only available from a few communal tap points (Annecke 1992:88). The evening before I began conducting this project's fieldwork, eleven houses in the Joe Slovo informal settlement were destroyed in a blaze that claimed the life of an elderly woman. Residents had begun tearing the burning walls off dwellings as their only means of limiting the spread of the fire, however, only with the arrival of a fire brigade from Cape Town (there is no fire station in either Langa or the Joe Slovo informal settlement) was the fire eventually brought under control.

PASASA (the Paraffin Safety Association of South Africa) contributes to this discussion in concluding that "the use of paraffin for household energy has an unacceptably high harmful incident rate in South Africa" (2004a:4). Safer alternatives, such as LP gas (liquid petroleum gas) and electricity, are widely available to the urban poor throughout South Africa (Breach 2004:10) but the use of paraffin stoves persists in many informal settlements, largely because of the higher costs involved in buying and using LP gas or electrical stoves.[8] The cheapest electrical stoves cost at least R100,00, while an LP gas stove and a small refillable gas bottle will retail for a combined price of about R350,00.

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8. Energy researchers have noted that, at times, paraffin stove use continues even after electrification (Qase, Blom & Mehlwana 1996:15; Mehlwana & Qase 1998:58; Bank 1999:132; Annecke 2003:247). This observation is supported by statistics showing that the number of South African homes connected to grid electricity increased by 31% between 1995 and 1999, yet the use of electrical stoves during this period increased by only 14% in urban areas and as little as 6% in rural areas (King, Pemberton-Pigott & Pemberton-Pigott 2003:2).

According to South African energy researchers, there is also a general aversion to the use of LP gas in South Africa's informal settlements because it is widely perceived to be more dangerous than paraffin, and because carrying the heavy and cumbersome gas bottles to and from gas suppliers is an arduous task (Mehlwana & Qase 1998:35; Annecke 1993:111). The limited use of electrical stoves among the urban poor has been partially ascribed to unreliable power supply (Mehlwana & Qase 1998:67; Annecke 2001:81). When there is a power failure, those using only electrical stoves are left without any means of cooking. Both electricity and LP gas are also disliked because consumption of these energy sources cannot be gauged visually and is therefore difficult to manage (Truran 2004b:2).

Energy researchers agree that neither LP gas nor electricity provide a comprehensive solution to the problems of paraffin stove use (Qase, Blom & Mehlwana 1996:15; Bank 1999:132). Glenn Truran, the General Manager of PASASA, states that "no alternative [to paraffin] seems to match the needs of significant numbers of the lowest income households in South Africa" (Truran 2004b:6). However, a wax-fuel used in a suitably designed wax-stove may be able to meet these needs, and could also be significantly safer than paraffin for two reasons: firstly, the waxes being considered for use in a wax-stove have higher flashpoints than that of paraffin, and are therefore less susceptible to flashing,[9] and secondly, though these wax-fuels should not be ingested, they are considered toxicologically safe (Wildgruber 1996:157).[10] In addition, and very importantly, a wax-fuel will, according to André Swarts (2003), the Senior Engineer of the Sasol Oil R&D Department, be competitive with paraffin in terms of cost.[11]

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[9] Notably, increasing the flashpoint of paraffin has been recommended as a primary means of improving the safety of paraffin stoves. This has, however, not been done because of the 'wide ramifications' that it would have for the petrochemical industry, and because it would push up the price of paraffin (Lloyd 2002:59).

[10] The properties of the waxes being considered for use in a wax-stove are discussed further in Chapter 6 – Waxes.

[11] Dr. Andy Yates (2003, January 31) of Sasol is in agreement with this contention for the following reason: The South African government regulates the price of paraffin (through production quotas, subsidies and by means of a 33% restriction on the maximum permitted retail mark-up) because of the essential role of paraffin as a domestic fuel for the poor (Borchers & Eberhard 1991:6; Buchanan 2002:4). Both paraffin and Jet A1 (jet fuel) are kerosene derivatives. The production of the more profitable Jet A1 is thus indirectly limited by regulations governing paraffin production. Yates (2003, January 31) has therefore suggested that, should a viable wax-stove be developed, wax-fuel might even be sold below cost so as to liberate kerosene for Jet A1 production, in which case a wax-fuel would be significantly cheaper than paraffin. However, because the Sasol group is comprised of a number of different subsidiary companies, each existing as separate financial entities, there is currently no direct financial motivation for Sasol Wax (Pty) Ltd to reduce the price of its wax-fuels, as this would only be of benefit to Sasol Synfuels (Pty) Ltd, the subsidiary responsible for the production of paraffin and Jet A1. Efforts to establish a group-wide profit drive may change this situation (Sasol 2003; Swarts 2003).

Wax-fuels will also emulate three advantages of paraffin use: they will not require specialised storage or dispensation equipment (as is the case with LP gas) but rather, the fuel could simply be sold off the shelf in solid blocks, helping to ensure availability and limit distribution expenses; a wax-fuel could be bought in small quantities; and, as with paraffin stoves, fuel consumption could be gauged visually.

The R&D department of Sasol Oil, in realising the benefits of a wax-fuel over paraffin, and wanting to harness the economic potential of Sasol's waste wax streams,[12] opened a wax-stove design competition to all South African universities and technikons. The intended outcome of the competition was a wax-stove that addressed the health and safety issues surrounding paraffin stove use. Designs submitted for the competition were assessed according to a range of predominantly functional criteria including the power output and fuel efficiency of the stove, ease of ignition and operation and shutdown, emission levels during operation and after shutdown, and material and manufacturing costs (Sasol Oil R&D 2002:5). Notably, less than 30% of the assessment was allocated to criteria that related directly to user interaction with the stove.

In 2002 (during my fourth year of study towards obtaining a degree in Industrial Design at the Technikon Witwatersrand) I designed and prototyped a wax-stove that was named the *Mosquito* (see Figure 1). Four weeks were assigned to the project by the Department of Industrial Design, after which time the Mosquito was submitted for the Sasol competition and chosen as the winning design. Though neither this stove nor any of the other competition entries provided a comprehensive solution to the functional problems presented by the use of a wax-fuel, they did, according to Dr. Andy Yates (2003, January 31) of Sasol Oil R&D, demonstrate that wax combustion releases sufficient energy to be used for cooking, and that wax has the potential to be used as a safe, cheap and clean-burning stove fuel.

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[12] The term *waste wax* is misleading. Though these waxes are unwanted by-products of profitable lines, they are of some commercial value. Mostly they are reintroduced into the various refinement processes from which they originate or at very least they are sold as furnace fuel (Swarts 2003).

Safety, cost effectiveness and cleanliness of combustion are important functional criteria, but it is equally important that designers consider other needs that potential users would want to have addressed in the design of a wax-stove. However, potential wax-stove users were not consulted by Technikon Witwatersrand students involved in the Sasol competition and neither do the reports of the more successful entrants to the Sasol competition (Buchanan 2002; Gantvoort 2002; van Rooyen 2002) show any evidence of interaction with these users or a sufficient understanding of the conditions under which fuelled stoves are used in South Africa. The following chapter considers the failings of these design approaches and proposes ways in which industrial design can more accurately address the needs of potential product users.

Figure 1: Promotional poster showing the Mosquito wax-stove.

CHAPTER 3 – PREJUDICIAL ASSUMPTIONS IN DESIGN

> Finally, a science for design cannot but respect the cultural differences of users, specifically in support of cultural diversities. Rather than standardising people under the guise of universalistic ideologies, it has to respect different rationalities… (Krippendorff 1995:155)

> Design… is a cultural activity in which meaning and identity relative to a group, society or country are essential considerations. (Whiteley 1993:112)

PREJUDICIAL ASSUMPTIONS IN DESIGN

Tooling for mass-production generally requires extensive capital investment that is amortised and made profitable through the sale of large volumes of the article being produced. The task of maximising sales is partly the responsibility of the industrial designer, who, in the design of the article, must satisfy as many of the preferences of potential users as possible, so as to ensure widespread product acceptance. However, the number of differing preferences concerning, for example, the form and function or cost of the article, will be as multitudinous as the number of potential product users, each having his or her own opinion of what constitutes the ideal. Conflicting opinions will invariably arise. One user may insist on the product being cheap, while another will rather pay a little extra for a product that is more durable, but the nature of mass-manufacture is such that individual preferences can only be catered for to a limited degree. Industrial designers therefore have the unavoidable responsibility of prioritising user preferences in the design of products such that some preferences are better catered for than others. When there is major conflict between the priorities of the designer and those of potential product users, the product is unlikely to be widely accepted by the latter, as has been the case with some South African products that have been lauded as excellent examples of industrial design. Consider the *Freeplay* range of wind-up radios:

Freeplay radios are powered by wind-up mechanisms, rather than electricity or batteries, and therefore do not incur any operating expenses. According to Freeplay (2004:online), the intention of this design innovation was to provide poor households (particularly those who do not have access to electricity) an alternative to battery-powered radios, which are costly to operate because the batteries have to be replaced regularly. However, purchasing a Freeplay radio can cost several times more than purchasing a battery-powered radio.[13] Thus, though Freeplay radios can provide long-term savings, battery-powered radios are still more accessible to low-income households who cannot afford the initial capital outlay involved in buying a Freeplay radio.[14] Consequently Freeplay radios are reportedly more often found on the desks of affluent designers than in the homes of those without access to electricity (Maykuth 2002:1).

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13. Freeplay (Till 2004, September 06) recommends that the Ranger wind-up radio retail for R399-00 (Cape Union Mart stores sell these radios for R499-00), whereas cheap battery-powered radios can be bought for as little as R50-00 or less.

A similar problem has beset the acclaimed Vesto biomass-fuelled stove, which recently won the Design Institute of South Africa's Chairperson's Award for design excellence. The stove is said to be very safe and up to three times more fuel-efficient than an open fire (DISA 2004:online) but the R299-00 price tag of the stove is, in the words of Isaac Senakgomo, a township shop owner, "a huge problem for many potential customers." (quoted in Gedye & James 2004:41).

Biomass-fuelled stoves (most of which have been shown to be more fuel-efficient than traditional cooking methods) have been promoted in a number of developing countries with the aim of reducing wood-fuel consumption so as to decrease rates of deforestation.[15] However, few, if any, of these stove programmes have achieved this goal.[16] In India, for example, the wood-fuel saving from the 23 million biomass-fuelled stoves distributed since 1984 is estimated at less than 1% of the total national wood-fuel consumption (Hulscher 2000:17). This programme, like many others, has since been suspended for failure to achieve its objectives (Karve, 2003, September 12). A stove designer has explained this paradox of functionally successful stoves but unsuccessful stove programmes as a consequence of a "lack of adequate attention to social… issues" (Sharma 1993:i). For example, some stoves feature fire boxes (where the fuel is burned) that have to be closed once the wood has been ignited (see Bussmann S.a.:98). This design feature can improve fuel efficiency but necessitates that longer branches be cut into smaller lengths if they are to fit into the stove – a task that can take more time than that of collecting the greater quantity wood of needed for cooking over an open fire. The user is thus left with little incentive to persevere in using the biomass-fuelled stove. Some stove designers have also made the following observations regarding other often-unacknowledged ancillary benefits of cooking on an open fire:

- Little expertise is required to control an open fire (Kammen 1995:online).
- The visibility of the flame serves to warn children that the fire is dangerous (Nielsen 1996:3).

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14. The importance of low capital outlay over operational costs is widely emphasised by the following authors in literature concerned with developments for the poor: Burne (1989), Sharma (1993), Graham & Dutkiewicz (1999), Mushamba, Still & Gitonga (2003) and REPP (S.a).

[15] In Kenya, for example, over 600 000 biomass-fuelled stoves have been distributed since the mid-1980s (Karekezi 1993:37; Karekezi & Murimi 1995:21), while in China, this figure is nearing 120 million (Kammen 1995:online).

[16] The following authors all report that no biomass-fuelled stove programme has had any noticeable effect on rates of deforestation: Tucker (1984:online), Sharma (1993:2) and Bussmann (S.a.:118).

- In addition to being used for cooking, open fires provide light and heat (Lillywhite 1984:27) and a social focal point around which a household can gather at meal times (Clancy 2002:7). The inability of electrical stoves to fulfil this latter function has been suggested as a reason why coal braziers continue to be used on the South African Highveld, even by those with access to electricity (Viljoen 1995:83).

With reference to these points, J.B. Tucker, a stove researcher, contends that “If these extended or latent functions are not met by the new stove or provided by some alternative means, the technology is not likely to be accepted permanently.” (1984:online). This contention is also applicable to the design of wax-stoves, yet none of the wax-stoves designed to date shows evidence of any attempts to address or even find out what extended or latent functions are provided for by the paraffin stoves used in South African townships and informal settlements. Rather, wax-stove designs tend to exhibit misconceptions regarding the needs of paraffin stove users.

A good example is found in Pierre van Niekerk’s design for a wax-stove. In 2003, van Niekerk began researching wax combustion and wax-stove design following the success of the Sasol competition, and as a requirement to obtain a degree in Mechanical Engineering from the University of Cape Town. Van Niekerk limited the size of his stove’s fuel tank so that if the stove is not refuelled within 25 minutes of the time of ignition the fuel will run out. He viewed this as “an excellent safety feature because an unattended stove is a potential fire hazard, whereas this unattended stove extinguishes itself.” (van Niekerk 2003:65). However, this short refuelling interval would inconvenience stove users who need to buy additional fuel or cooking ingredients while a meal is being cooked, as was seen to be the case twice during this project’s fieldwork.

In describing a design methodology intended to more accurately address the needs of potential product users, L. Bank, a South African energy researcher, states that needs should not be evaluated “independently of the specific social and cultural contexts within which these needs are understood and experienced” (1999:129). Designers should be aware of socio-cultural conditions that may contribute to differing needs prioritisations, and should then address these needs according to the prioritisations of potential users rather than those of the designer. Designers ought to concentrate on how to best satisfy the needs of potential product users rather than pronouncing judgement on what may appear to be illogical needs prioritisations. The difficulties involved in achieving this end have been described by a developmental practitioner:

> Our way of thinking (and consequently, of seeing) takes place within the contextual landscape of our time. We walk within this landscape; its parameters provide guidance, meaning and form. All this takes place largely unconsciously, as part of the 'given' within which we function. It demands tremendous effort of will to step outside these given parameters, to free ourselves sufficiently to see the terrain within which we walk from the outside, to become conscious of the underlying assumptions which we take for granted, and to think (and see) afresh. (Kaplan 2002:1)

The current global re-evaluation of indigenous knowledge and the methodology employed by the various participatory research approaches provides a platform from which one can begin to see beyond the parameters of one's own landscape and gain an appreciation of potentially differing needs prioritisations apart from one's own values and expectations.[17]

Indigenous knowledge has been defined by researchers working in this field as knowledge that has been developed in a particular locality to address the specific agro-ecological and socio-cultural needs of those residing in that locality (Raza & du Plessis 2002:70). Raza & du Plessis are of the opinion that "a deeper insight into the cultural complexities of thought that prevail in a society is imperative for suggesting workable solutions to socio-technical problems" (2002:57). Appreciating the values and needs associated with other knowledge systems has been for myself predominantly about understanding that Western knowledge is simply one of many knowledge systems, all of which, according to L. Le Grange, a South African educationalist, have "equal claims and respectability" (Le Grange 2000:116). Several prominent academics now agree that the global dominance of Western knowledge over indigenous knowledge traditions is a consequence of the manner in which Western knowledge is portrayed, rather than as a result of any ineluctably superior mode of thought or of methodological excellence.[18] For example, E. C. Eze, the editor of ***Postcolonial African Philosophy***,

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17. Several participatory research approaches have been developed, including RRA (Rapid Rural Appraisal), PRA (Participatory Rural Appraisal), PLA (Participatory Learning and Action) and most recently PAR (Participatory Action Research). All stress the need for community participation as a means of validating research findings; the importance of acting upon research findings; and the value of empowering research participants by disseminating any knowledge generated through the research (see Chambers 1985; Joseph, Shanahan & Stewart 1985; Uphoff 1985; Mahlako 1996; Narayan 1996; Swanepoel 1997a, 1997b; Bless & Higson-Smith 2000; Buhler et al. 2002; Creekmore 2004; Hart 2004).

18. See Fanon (1993), Said (1994, 1995), Chabal (1996), Eze (1997), Harding (1997), Hountondji (1997, 2002), Oguibe (1999), Smith (1999) and Sardar (2002).

describes Western knowledge as having been able to ‘posit and represent itself’ as the embodiment of reason (Eze 1997:13), but Le Grange notes that despite this “appearance of universal truth and rationality”, Western knowledge also has the “cultural fingerprints that appear to be much more conspicuous in other knowledge systems.” (2000:115). With this view of Western knowledge, other knowledge traditions can be seen as being of equal value and importance to Western knowledge. Designers can then begin to appreciate the values and needs associated with other knowledge traditions, and design products that address needs in a manner that is consistent with the values of potential product users. This sort of appreciation of differing values is also encouraged by the participatory research approaches which suggest that researchers should gain insight into people’s “attitudes, behaviours and beliefs” (Scott 2002:60) because the “priorities [of the researcher] often differ from people’s own views” (Pretty quoted in Buhler et al. 2002:115). An industrial design methodology that does not acknowledge the values of potential product users is unlikely to be able to address accurately the needs of these users, and widespread product acceptance is then unlikely to be achieved.

In investigating the participatory research approaches and the approaches used by indigenous knowledge researchers (both of which have only been touched on very briefly here), I have been awakened to the value of understanding the viewpoints of non-western product users, and of the cultural bias to be found in conventional approaches to industrial design. The participatory and indigenous knowledge research approaches have provided me with the intellectual and attitudinal tools by which I can better do research across cultures and across socio-economic groups. They have challenged and helped to alter my attitudes towards the values and priorities of potential wax-stove users. This attitudinal shift has allowed me to have a more open-minded outlook on the needs of potential wax-stove users and has provided me with a more objective starting point from which to conduct a fieldwork programme relevant to the needs of these users. The findings of this fieldwork programme are discussed in the following chapter.

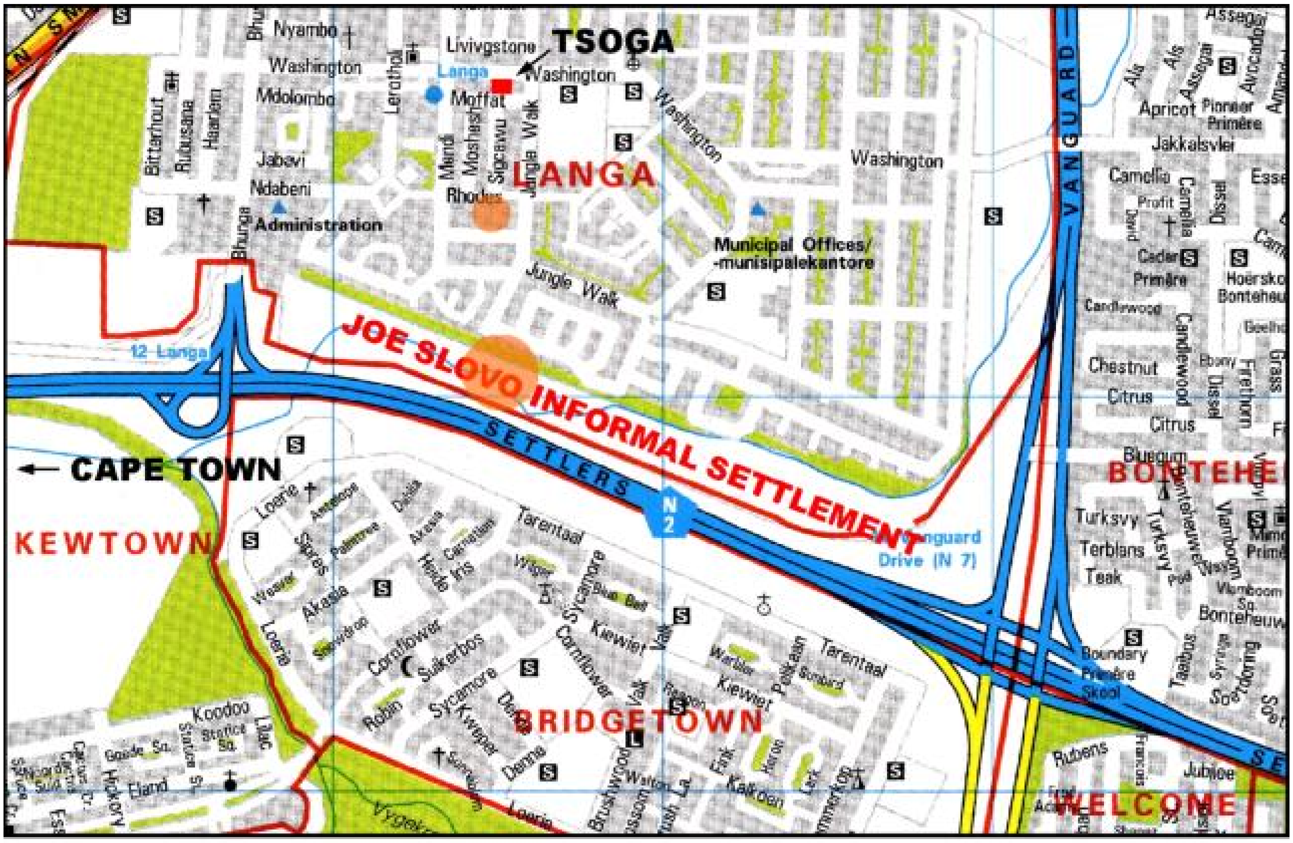
CHAPTER 4 – DEFINING WAX-STOVE DESIGN CRITERIA

The presumption is that culture, conceptualised simply as traditional beliefs and values, inhibits freedom, calculating rationality, individualism and progress. Culture is seen to constrain individual fuel users from making the most efficient and effective choices. (Bank 1999:129)

[It] is not culture which impedes but discrimination…
(Leatt, Kneifel & Nurnberger 1986:39)

FIELDWORK

As part of a design process that has sought to understand and address the needs of potential wax-stove users more accurately, fieldwork was conducted from 17 – 21 May 2004 in the Langa township (on the outskirts of Cape Town) and in the adjacent Joe Slovo informal settlement (see Figure 2). The circumstances of those living in these areas approximate the conditions under which a wax-stove might be used on two accounts. Firstly, paraffin stoves are widely used in both areas, almost exclusively in the Joe Slovo informal settlement (despite the availability of electricity) where they are reportedly a common cause of fires (Mehlwana & Qase 1997:10; 1998:51). Secondly, poverty is rife in these areas, but particularly in the Joe Slovo informal settlement where few residents have formal employment and extended families are sometimes supported by a single breadwinner.



🟧 AREAS WHERE FIELDWORK WAS CONDUCTED

Figure 2: Map of Langa and the Joe Slovo informal settlement (adapted from Map Studio 1995:47).

The fieldwork was facilitated by Tsoga, a community development organisation based in Langa, and conducted with the assistance of Lindiwe Daweti, an employee of Tsoga. Daweti located five households that were willing to participate in the fieldwork programme and whose demographic makeup was not uncharacteristic of households in the area. Daweti also provided an introduction to each of these households on the day that they were visited. She helped to explain the purpose of the fieldwork and assisted with any translation that was needed. All five of the households used paraffin wick stoves, and were selected for their use of these stoves (rather than paraffin pressure-stoves) because, for the purpose of this project, wicks (rather than a pressurised fuel system) are employed in the design of the wax-stove.

Of the five participating households, four were situated in the Joe Slovo informal settlement, and in three of these households, women were responsible for cooking for their families. They were Nowandile (52), wife of the household head, and Sibongile (22) and Nobathebu (20), sisters to the breadwinners of their respective households. The fourth respondent from the Joe Slovo informal settlement was a single man named Litha (30). He was supported financially by his brother who also participated in the fieldwork. All these participants had electricity supplied to their dwellings, but water was only available from a handful of communal tap points situated on the periphery of the settlement. Ablution facilities were limited to a line of toilets on the edge of a watercourse that forms the boundary between the settlement and the N2 (one of the major roadways in and out of Cape Town). Nongenile was the fifth participant. She shared a single room in a Langa hostel with her husband and their children and grandchildren. This room opened onto two communal areas, the smaller of which had been designated as the kitchen and was shared by the residents of seven other private rooms.

An informal interview (guided by an interview schedule that also functioned as a questionnaire) was conducted with each of these households, after which I observed a member of each household preparing a typical midday or evening meal on a paraffin stove – from the initial purchase of fuel and food, through to the refuelling, use and extinguishing of the stove. The purpose of this process was to paint a more complete picture of the conditions under which paraffin stoves are used; to identify any problems related to these conditions of use; and most importantly, to explore the causes of these problems and identify any specific needs in which they may result.

The questionnaire (see Appendix 1) was drafted under the guidance of Sonwabo Ndandani (Acting Executive Director of Tsoga), Nthabiseng Mohlakoana (sociologist at the Energy and Development Research Centre, University of Cape Town) and Hester du Plessis (Senior Research Fellow at the University of Johannesburg). These individuals provided methodological pointers to ensure that the nature of the questions asked was conducive to yielding only information that would be instructive in designing a wax-stove. In obtaining relative qualitative data, the design of the questionnaire embodied two principles of the participatory research approaches: *optimal ignorance* and *proportionate accuracy*. Optimal ignorance refers to knowing what data to collect and what information is unnecessary. Proportionate accuracy is the recognition that only a limited degree of detail and level of accuracy is needed. Often only orders of magnitude and direction of change are necessary.[19] Some of the questions did require specific answers from the respondents but mostly they were intended to provide opportunities for open (but topical) discussion. The purpose of the questionnaire was not to generate quantitative data on fuelled stove use. This has been done by a number of South African energy researchers whose work focusing on energy and appliance use in South African townships and informal settlements has provided the broader context for the findings of this chapter.[20]

From these findings, a set of user-defined criteria for the design of a wax-stove has been developed. An attempt has then been made to meet these criteria in the design of the S2 – a wax-stove that I designed in response to the problems encountered in one of my earlier stove designs named the Shuttl. Conceptual design work that was done after the completion of the S2 is also considered. Other design outputs include a concept sketch portfolio, 3D CAD models, CAD renderings (see Appendix 2 – 3), video animations and basic prototypes used to test some of the design ideas. These outputs need to be consulted for a fuller understanding of the content of this and the remaining three chapters. The following description of the basic functioning of the S2 will also help the reader to understand the recommendations made in this chapter. This description should be read with reference to the drawings shown in Appendix 2.

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[19] See Chambers (1985:403), Joseph, Shanahan & Stewart (1985:34), Narayan (1996:33) and Buhler et al. (2002:104).

[20] Studies reviewed for this chapter include Dickson & Baldwin (1990), Annecke (1992, 1993, 2000, 2001, 2003), Viljoen (1995), Mehlwana & Qase (1996, 1998), Qase, Blom & Mehlwana (1996), Mehlwana (1997), Bank (1999), De Lange & Wentzel (2002), Clancy (2002), Mushamba, Still & Gitonga (2003), King, Pemberton-Pigott & Pemberton-Pigott (2003) and Ross (1993).

To begin using the S2, the user must first lift the fuel tank from the stove base assembly. This action will cause the diffuser assembly also to be lifted from the stove base. Six blocks of wax fuel stock can then be placed between the wax-retaining walls on the stove base. The user must then ignite each of the eight cotton wicks protruding from the wick support that rests on the centre of the stove base. The fuel tank must then be repositioned on the stove base, and the diffuser assembly lowered back into position. The user can then adjust the power of the S2 by rotating the diffuser assembly (by means of the control levers) between the blue and red markers on the side of the fuel tank.

The following description of the functioning of paraffin wick stoves (such as Panda-brand paraffin stoves)[21] will also be helpful in understanding the recommendations made in this chapter because both the Shuttl and the S2 function in a manner that is in some ways similar to that of paraffin wick stoves (see Figures 3 – 6).

Paraffin wick stoves are refuelled by pouring paraffin into a tank that forms the base of the stove. From here the fuel is drawn by wicks through the stove head. This component houses the mechanism used to adjust the temperature of the flame by increasing or decreasing the length of wick that protrudes from the stove head into the combustion chamber. The combustion chamber is the annular space formed between two concentric cylinders, called air diffusers, which stand upright on the stove head. Here combustion of paraffin vapour emanating from the wicks occurs. The body of the stove encloses all of the above-mentioned components and supports a trivet centrally located over the combustion chamber. Cooking vessels are placed on pot rests positioned on top of the trivet.

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[21] Panda-brand paraffin stoves will for the remainder of this document be referred to as Panda stoves.

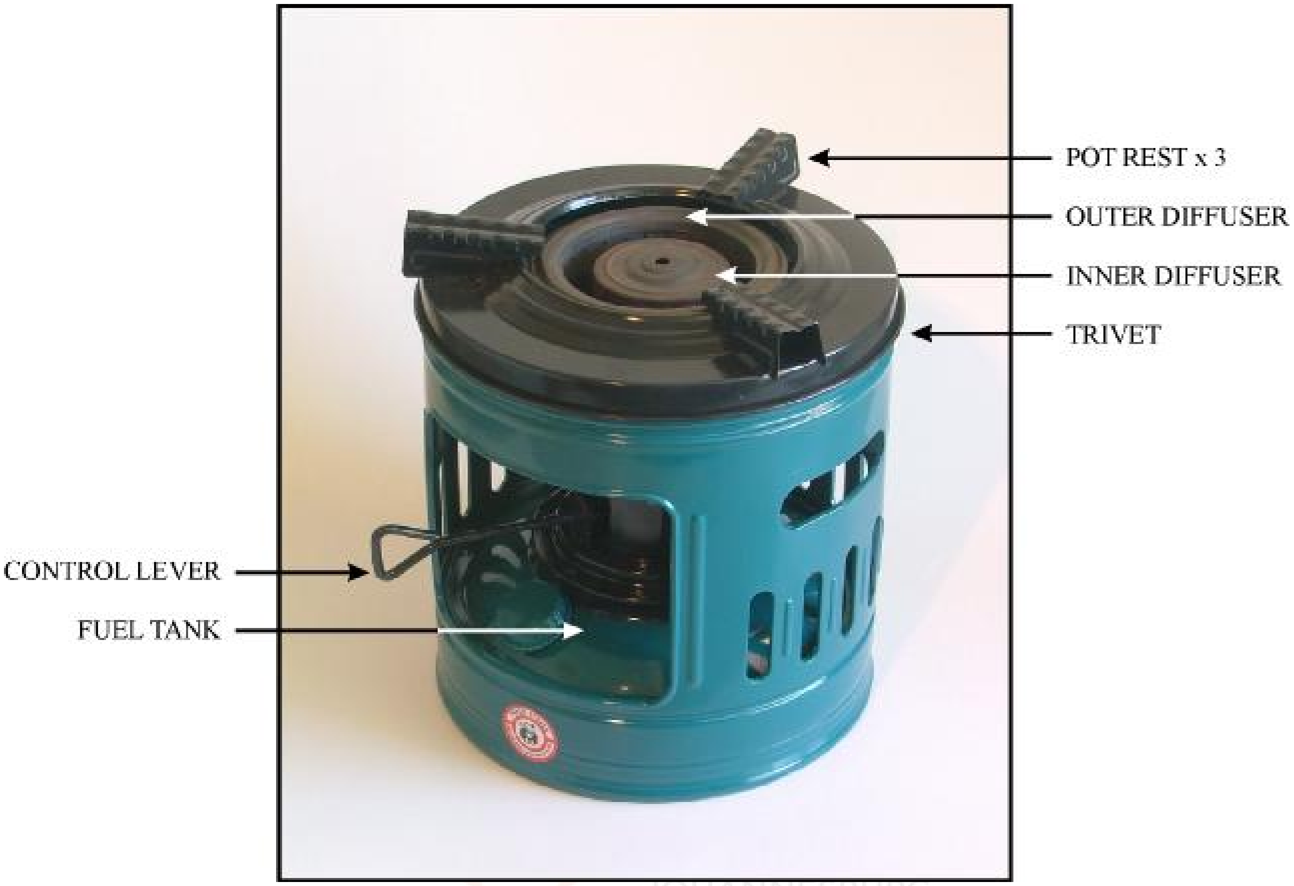


Figure 3: Panda paraffin stove.

TOP VIEW

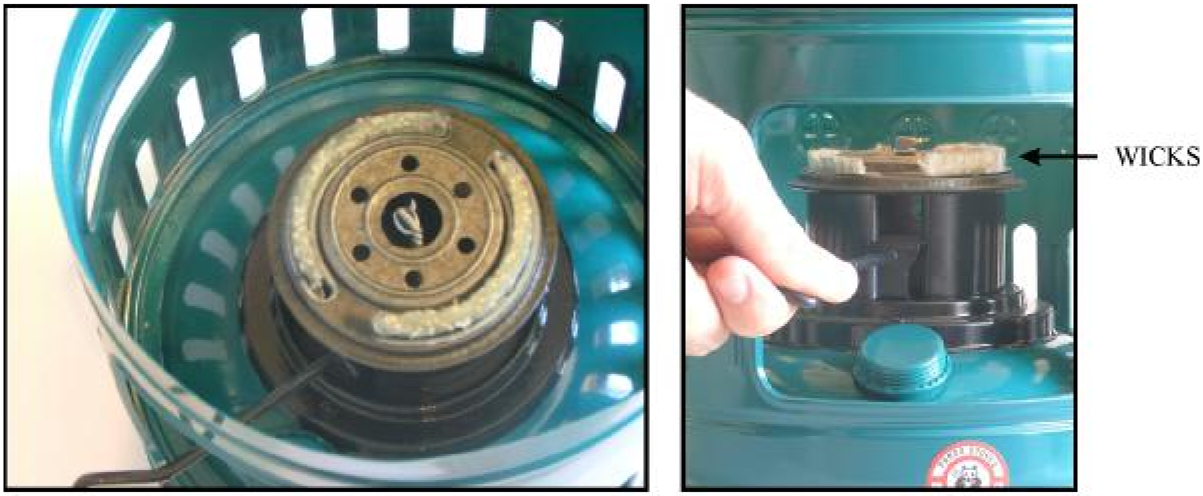
FRONT VIEW

Figure 4: Panda paraffin stove combustion chamber (trivet removed).

TOP VIEW

FRONT VIEW

Figure 5: Panda paraffin stove shown with wicks lowered into the stove head (trivet and diffusers removed).



TOP VIEW

FRONT VIEW

Figure 6: Panda paraffin stove shown with wicks protruding from the stove head (trivet and diffusers removed).

UNDERSTANDING FUELLED STOVE USE IN SOUTH AFRICA

Stove and fuel use practices in townships and informal settlements are not easily understood because of the many and varied factors that influence the choices of stove users – hence Mehlwana's (1997:13) assertion that "What may appear to be an irrational behaviour vis-à-vis fuel in economic terms may be entirely rational in social terms." An example is provided by the South African energy and gender researcher, Wendy Annecke (1992:93), who noticed that the women living in an informal settlement near Durban would often bake their own bread even though it cost nearly twice that of a regular loaf of bread. These women felt that, in social terms, this practice was justifiable because it required their expertise (as mothers, wives and housekeepers) to know how to prepare and serve the bread, and so fulfilled their roles as providers and nurturers. Energy researchers emphasise that decisions pertaining to stove and fuel use are influenced by three household characteristics: composition, gender structure and headship. These provide a basis for understanding the needs and preferences of fuelled stove users.

Household Composition

In poor black South African communities, the abstract boundaries that define the household often include extended family members and even tenants (Kuzwayo 2000:11; Clancy 2002:4). These boundaries also change to incorporate new members and lose others.[22] During this project's fieldwork, members of neighbouring households often ate with the family that had prepared the meal but were mostly not included in the response to question 4.1 of the questionnaire: How many people do you usually cook for?

Gender

The significance of gender roles is illustrated by Annecke (1992:96) in her explanation as to why hot boxes have not been widely accepted by women living in informal settlements. Hot boxes are insulated containers into which partially cooked meals are placed and then cooked to completion by the heat retained within the box, thereby reducing fuel expenditure. However, cooking with a hot box requires little attention and thus the role of the cook becomes less visible. Annecke suggests that, though cooking is often burdensome, it is "a form of empowerment and control for women" (2000:11), diminished by the use of hot boxes. Women are generally responsible for cooking, and control the use of stoves and the purchase and use of stove fuels, but men tend to make decisions related to the purchase of domestic appliances, including paraffin stoves (Posel 2001:662; Clancy, Skutsch & Batchelor 2003:10). A wax-stove design must thus attempt to meet the potentially conflicting needs of both groupings: stove buyers (men) and stove users (women).

Headship

A comprehensive analysis of headship in South Africa (Posel 2001) has found that in poor black households, headship tends to be vested in the oldest male resident, who is then usually the key decision maker, particular if he is the primary breadwinner. However, the household head seldom has authority over all areas of decision-making (Posel 2001:661), and in about one-third of black South African households, decision-making is shared between the male and female head (Posel 2001:663). Interestingly, children are said to have the final say in most matters in nearly 12% of female-headed households in Kwa-Zulu Natal (ibid). Mehlwana & Qase (1998:89) report that in poor urban households in the Western Cape, children as young as six make decisions regarding the purchase and use of cooking fuel and victuals, often without any adult supervision.[23]

USER-DEFINED CRITERIA FOR THE DESIGN OF A WAX-STOVE

The remainder of this chapter is a discussion about the findings of the fieldwork programme. Where relevant, the findings of various researchers contribute to the discussion. Design problems related to the use of the stove are addressed as they arise to illustrate the impact that the fieldwork programme had on the design of the S2.

Stove Appearance

Designers acknowledge that "[products] are not… bought just to fulfil primary functions or use-value. They are also bought to confirm status, confer prestige…" (Whiteley 1993:137). Even in the poorest South African communities the appearance of fuelled stoves is reportedly a high priority (Viljoen

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22. This is a widely reported occurrence in informal settlements in the Western Cape. See Annecke (1993:110), Mehlwana & Qase (1997:5) and Ross (1993:153).

23. The two teenage girls living in the homes of Nowandile and Nongenile confirmed this report, saying that they had been using paraffin stoves for several years. This highlighted how important it is for a wax-stove to be exceptionally safe but also easy to use.

1995:28). Yet after only a month or two of use, paraffin stoves become somewhat of an eyesore as they are blackened by soot and begin to corrode. In this state they do not confirm status or confer prestige. There is thus a predilection among the urban poor for electrical appliances (rather than paraffin appliances) because “the ‘sign-value’ of electrical appliances often far [outstrips] their ‘use-value’.” (Bank 1999:132). Unsightly paraffin stoves are of little sign value. Bank’s point is well illustrated by the following comment made by a woman living in the Khayelitsha township with reference to her defective electrical stove:

> Even if it doesn’t work [visitors] do not know that and it makes my house to look dignified and nice (sic).
> (quoted in Mehlwana & Qase 1998:45)

However, none of the fieldwork respondents from either Langa or the Joe Slovo informal settlement expressed concern over the appearance of their stoves or the damage that the stoves did to the surfaces on which they were used. These surfaces had all been scratched and charred by the stoves, and fuel had been spilled from the stoves while they were being refuelled. In many cases, the work surfaces were also stained by fuel leaking from the stoves’ bases. This apparent lack of concern was contrasted by the respondents’ efforts made to improve and maintain the appearance of their dwellings. Nongenile of Langa, for example, took great care to ensure that her Formica kitchen unit was not damaged by her occasionally-used electrical stove. The stove was placed on two newspaper-covered bricks to prevent it from charring the surface of the kitchen unit, and the newspaper stopped the bricks from scratching the Formica.

It has been reported that paraffin fires are regarded by the urban poor “as a fact of life; a terrible, but unavoidable consequence of poverty” (Ahmed 2004:10) and it is similarly possible that unsightly stoves and damaged work surfaces are tolerated in the absence of any viable alternatives. The design of the S2 has thus sought to be more visually appealing than Panda stoves by using appropriate materials and colours to evoke a contemporary electrical stove aesthetic. The two most exposed components of the S2 are a matt black, mild steel base and a stainless steel fuel tank that rests on this base. Should the use of stainless steel prove to be prohibitively expensive, the fuel tank could also be manufactured from mild steel and enamelled white or any other colour that reflects a contemporary electrical stove aesthetic (certainly not the red or deep turquoise of Panda stoves). The soft and rounded forms of the

S2 represent a further shift away from the utilitarian aesthetic of the Panda stoves and these forms will not incur additional manufacturing costs because of their compatibility with the pressing process that would be used to manufacture the stove base and fuel tank. Care has been taken to conceal the thin edges of the stove base and fuel tank (as is done with many pressed components for electrical stoves). This gives the S2 a more solid appearance than the Panda stove despite the use of equally thin sheet metal. The design also features rubber feet intended to prevent work surfaces from being scratched or charred (in the interests of minimising costs, these feet could be substituted by four similarly placed bowl-shaped depressions in the base of the stove).

Durability

Cheap paraffin stoves are said to last for about a year (Pemberton-Pigott 2003, September 15)[24] but most of the stoves seen in the Joe Slovo informal settlement had reportedly been in use for much longer periods. Paraffin stoves may only operate safely and at optimal efficiency for a year but this appeared to have little impact on whether a stove continued to be used or not. Sibongile, who moved to the Joe Slovo informal settlement “to cook for her brother”, used a five-year old paraffin stove (see Figure 7). Much of the trivet had corroded away. The fuel cap was missing. Paraffin was seeping slowly through the corroded base of the fuel tank. The stove head was detached from the fuel tank and could no longer be used to adjust the height of the wicks because the components involved in this operation were bent out of alignment and badly corroded. Yet, despite the poor condition of her stove, Sibongile said that she would continue to use the appliance for at least another year. Many of the stoves seen in the Joe Slovo informal settlement were in a similar state of disrepair and all of the respondents expected a similar period of use from their stoves even when important components had ceased to function properly. Respondents had devised rudimentary solutions to address problems arising from the use of defective components rather than replacing them with new components (Nongenile was the only exception in this regard. She said that the best way to fix a paraffin stove was to throw it away!).

Small stones and even fuel caps were used to replace corroded or missing pot rests.[25] In one instance, an assortment of iron rods was arranged on the stove body to form a crude trivet. Several stoves were

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[24] Truran (2004b:2) estimates that these stoves have a life span of only three months.

[25] The use of stones as pot rests was also seen in Sweetwaters (a township near Pietermaritzburg) and the Cape Argus has reported that this practice is widespread (Bailey 2004:10).

seen in use even though the flame control mechanisms were broken. Nowandile addressed this problem by manually pulling the wicks to the desired height before they were lit. However, once the stove had been ignited, the temperature could no longer be adjusted. The high temperature at which the stove was set was initially effective in bringing food to the boil but soon caused the food to burn. Nowandile then placed a metal sheet between the stove and pot to reduce the amount of heat transferred to the food. Though this achieved the intended result, fuel efficiency was probably compromised as energy was lost to the surrounding environment, and the possibility of the fuel flashing would have been increased by the greater amount of heat being radiated back to the fuel tank. When the respondents could no longer extinguish their stoves by lowering the wicks into the stove head as intended, they either removed the diffusers and snuffed out the flame with an overturned metal cup or tin can, or water was flicked onto the flame. This caused the flame to flare up and then die out. Though effective, these techniques were cited by the respondents as a cause of fires. Wicks that have not been lowered into the stove head can apparently re-ignite.

John Jones, a design theorist and one of the founders of the design methods movement, suggests that "It is always worth paying a lot of attention to crude adaptations that users make to their equipment and important to discover the reasons for them." (1990:216). These adaptations that have been made to paraffin stoves clearly point to the need for more robust trivets (particularly pot rests) and adjusting mechanisms.

Pots placed on the S2 are to be supported by four rests that protrude from the upper surface of the fuel tank. This area is most susceptible to corrosion because it is exposed to high temperature flames. The stainless steel of the fuel tank will resist corrosion, as will the shape of the pot rests because they do not cause edges of the sheet metal (which is where corrosion usually sets in first) to be exposed to the flame. The intersecting curved surfaces of the pot rests impart to them an inherent strength not found in the design of Panda stove pot rests, which can collapse under the weight of heavy pots. The proposed flame control mechanism of the S2 is simple and robust, and it is not dependant on the precise alignment of small components as is the case with Panda stoves. The functioning of this mechanism is discussed in Chapter 6 – Flame Control and Stove Shutdown.

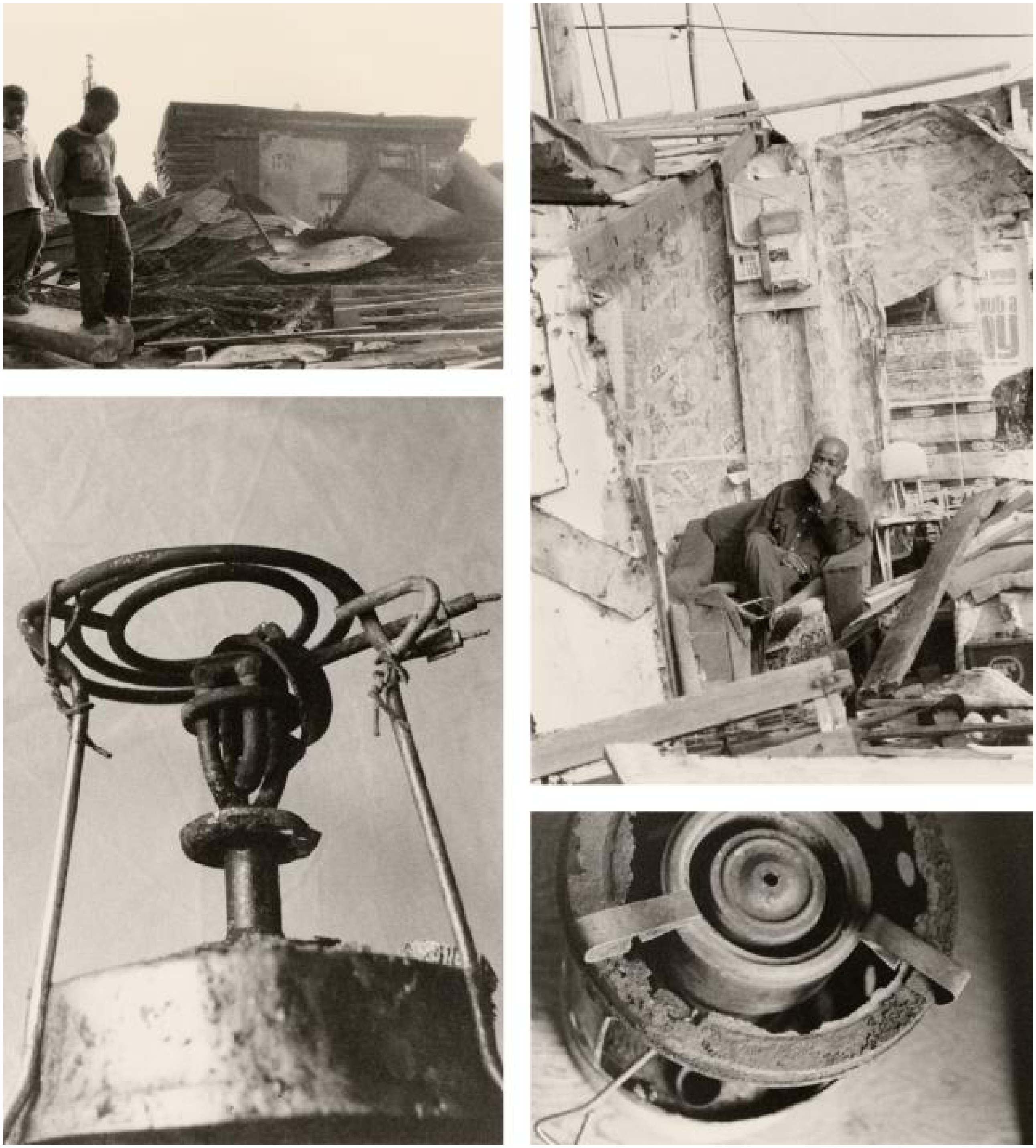

Figure 7: Photos taken in Langa and the Joe Slovo informal settlement.

Clockwise from top left:1) Children from the Joe Slovo informal settlement survey the damage resulting from a fire that destroyed eleven homes and claimed the life of an elderly woman. 2) A resident of the Joe Slovo informal settlement sitting ‘inside’ the remains of his electrified home the morning after the fire. 3) Still in use: a severely corroded five-year-old paraffin stove with few functional components. 4) Make-shift trivet: an electrical stove coil wired onto a paraffin stove.

Stove Ignition

During this project’s fieldwork, paraffin stoves were consistently lit by temporarily removing the inner diffuser and lowering a match or a burning strip of newspaper onto the wicks. Stove users were adept at this and performed the task rapidly without getting burned. This technique would, however, be problematic in lighting a wax-stove because of the greater time needed for the wicks to ignite (see Chapter 6 – Wicks and Stove Ignition). Care has thus been taken in the design of the S2 to allow the wicks to be accessed from the sides of the stove where the user’s hand is not exposed to heat rising from the match (or burning newspaper) or wicks that have already been ignited. When the fuel tank is lifted from the stove, the diffuser assembly is simultaneously lifted from the wicks by the guide plate (the uppermost component of the diffuser assembly), which rests on a step protruding from the inner wall of the fuel tank. The wicks can then be freely accessed from all sides. After having ignited the wicks of a paraffin stove, the users must reposition each air diffuser over the flaming wicks. This can take some time and may result in burn injuries. In the design of the S2, the cone shape that protrudes from the stove base automatically guides the diffuser assembly into position over the wicks when the tank and the diffuser assembly are simultaneously lowered over the stove base. This is done by holding the sides of the fuel tank, away from the flames.

Stove Shutdown

In all of the households visited in the Joe Slovo informal settlement, paraffin stoves were carried outside before or shortly after the stove had been extinguished because much smoke was emitted from the stoves after shutdown. Only in the Langa hostel, where there was a separate and ventilated kitchen area, was the stove not taken outside to be extinguished. However, here the once turquoise walls were blackened from years of paraffin stove use.

All respondents from the Joe Slovo informal settlement said that they also needed to be able to move their stoves outside if they burst into flame, as this was the only way to prevent their dwellings and its contents from catching on fire. This need was not initially catered for in the design of the S2. The CAD model does not have any handles by which to pick the stove up, and during use, the body of the S2 may reach temperatures in excess of 55°C – considered by the South African Bureau of Standards (SABS 2002:5) as the highest acceptable temperature that the outer walls of a paraffin stove should be allowed to reach. This oversight in the design of the S2 has been addressed on pages 46 and 47 of the concept sketch portfolio (see Appendix 4) which arrive at the design for inexpensive bent rod handles that are to be spot welded on either side of the base of the stove where they are likely to heat up least.

Refuelling

Respondents in Langa and the Joe Slovo informal settlement reported that most meals take between five minutes and one hour to cook but that *umqusho* (samp), which is a staple food in many poor South African households (IMCSA 2004:online), takes up to six hours to cook. This requires that paraffin stove tanks have a six-hour fuel reserve as recommended by the SABS (2002:4). Paraffin stoves can be refuelled during use but this is not a safe practice because of the increased risk of exposing the fuel to an open flame or spark. This could cause the fuel to flash. To sustain wax combustion for six hours, the fuel tank of a wax-stove needs to contain about 0.760 litres of wax,[26] nearly 70% less than the 2.5 litre fuel tanks of Panda stoves that can sustain combustion for up to 12 hours (Advantage Marketing 2003:online). The fuel tank of the S2 can contain up to 1.056 litres of wax-fuel, supplied in solid blocks, of which up to six can be placed between the wax-retaining walls on the base of the stove to form a ring of fuel stock. The shape of these fuel blocks is dissimilar to the candle-shaped fuel stock used by van Niekerk (2003:64). This is intended to avoid the wax-fuel of the S2 being associated with candle wax, which is perceived to be dangerous because the careless use of candles is a common cause of fires in informal settlements (Annecke 1992:88), so much so that their use has been banned altogether in the Joe Slovo informal settlement (Ndandani 2004).

Mehlwana (1997:14) suggests that paraffin provides some form of economic stability within poor communities because, when a household cannot afford to buy paraffin, a little can be borrowed from a neighbour – a favour that will be reciprocated when the neighbour is in need. Paraffin is well suited to being traded between households in this way because it is available in small quantities and because the value of paraffin is easily quantifiable in terms of its volume (LP gas, which is contained in pressurised metal canisters, cannot be shared in the same way). The small fuel blocks of the S2 imitate this

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[26] This figure is based on the fuel consumption figures presented by van Niekerk (2003:58) who calculated that his wax-stove burned 2.2 grams of fuel per minute when fuelled with candle wax having a density of 995kg/m^3.

advantage of paraffin use and are suited to being sold individually to stove users who do not need or cannot afford more than one block of wax-fuel.

Stability

The number of people eating the meal that had been prepared in the various households visited in Langa and the Joe Slovo informal settlement ranged from two to nine with the ubiquitous Hart aluminium pots being used by most households and for most purposes. These pots ranged in diameter from 175mm to 260mm. The latter can contain up to seven litres of food. The smallest vessel to be used on a paraffin stove was a kettle with a base diameter of 110mm. Any vessel with a diameter of less than 98mm is too small to be supported by the trivet of a Panda stove but this did not seem to be a problem for any of the fieldwork participants as the above-mentioned kettle was the only cooking vessel seen with a diameter of less than 150mm. The pot rests of the S2 can accommodate pots with diameters of 145mm or more.

Pots with larger diameters are more problematic. As their bases extend further beyond the reach of the pot rests they becoming increasingly unstable. The rests of the S2 reach 125mm from the centre of the stove – 20mm further than Panda stove pot rests. This design improvement takes advantage of the square format of the S2 by extending the rests right to the corners of the fuel tank. The amount of stability afforded to the cooking vessel has also been increased by the addition of a fourth pot rest.[27]

Cooking vessels resting on Panda stoves can also be easily toppled from the stove because they have high centres of gravity. Yet none of the fieldwork participants saw this as being dangerous, even when preparing meals – such as *mvubo* (maize meal) – which required vigorous stirring while being cooked. The pot was simply removed from the stove and placed on a stable work surface when the food needed

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[27] A vessel resting on the pot rests of a stove can be caused to topple by applying sufficient pressure from above to any point on the base of the vessel that falls outside of a polygon delineated between the points where each pot rest meets the circumference of the vessel's base (see Figure 8). When a greater percentage of the area of a vessel's base is covered by this polygon, the pot will rest more firmly on the stove. This percentage can be calculated according to the following expression: $175n \sin(360/n) / 11$ where n is the number of pot rests (the equation assumes a cylindrical vessel positioned centrally upon a radial support system where the supports are of negligible thickness and extend beyond the edge of the base of the vessel – stability is compromised greatly when the base of the cooking vessel overhangs the pot rests). The triangle delineated by three pot rests represents a maximum of 41.33% of the area of a vessel's base; the square delineated by four pot rests represents 63.64% this area; with the addition of a fifth rest, this figure is increased to 75.65%, and so on. However, the addition of more pot rests to the fuel tank of the S2 would not result in improved stability because additional rests would be constrained by the square format of the stove and thus could not extend the size of the polygon beyond that already delineated by the current four pot rests.

to be stirred. Efforts have, however, been made to maximise the stability of the S2. The height of the stove has been kept to a minimum and its feet have been positioned at the extremities of the base. Having the feet further apart would not necessarily be beneficial since many of the respondents used their stoves on benches or other narrow work surfaces. Unless all of a stove's feet fit on the work surface, the stove will be particularly unstable.

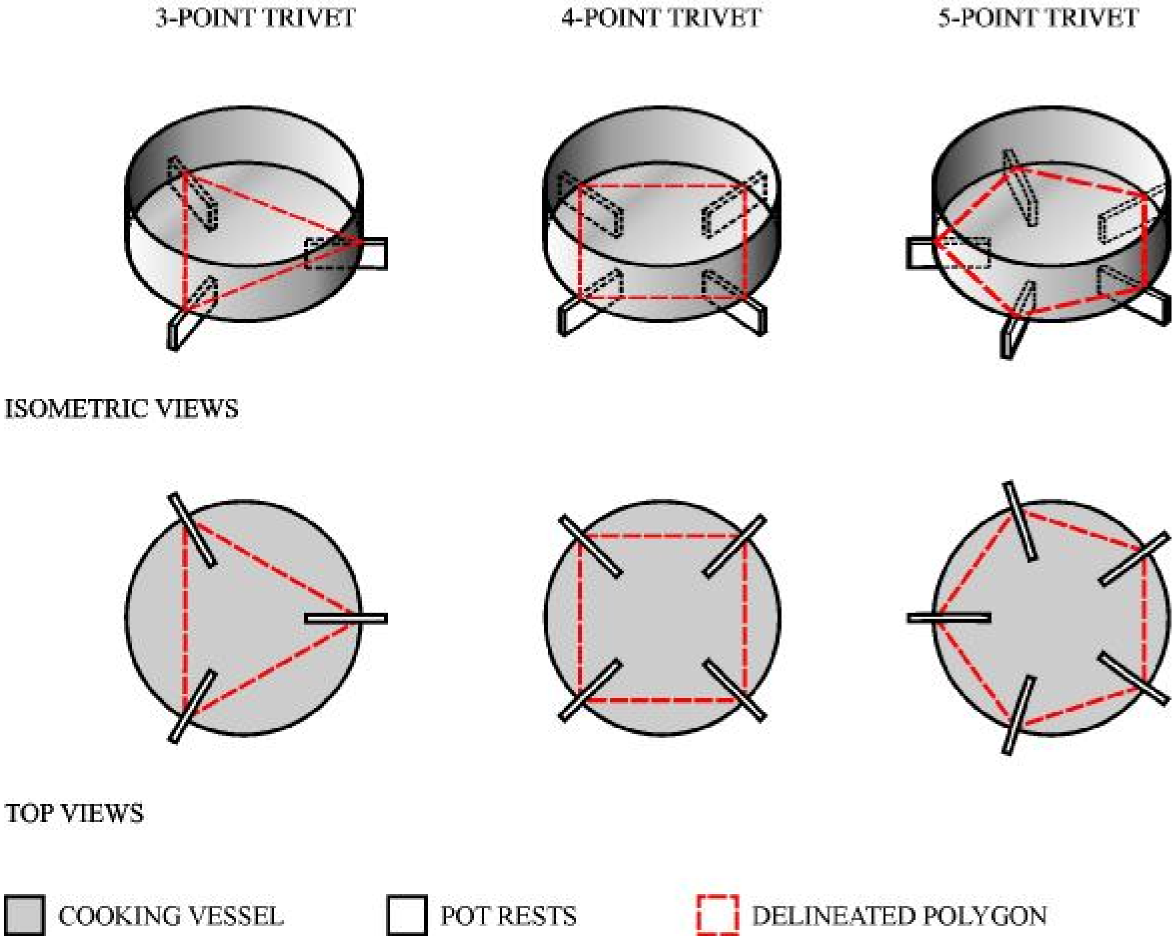

Figure 8: Stability afforded by stove pot rests.

Ease of Use and Safety

Annecke (1992:102) notes that even in the poorest South African households, the convenience of using a particular type of stove is often prioritised above the cost of using that stove or its energy source, and practices that minimise fuel expenditure or increase safety are employed until they become burdensome. This accounts for the limited acceptance of solar cookers in South Africa (Clancy 2002:7). Solar cookers do not incur energy costs but they are only effective at midday when the sun is at its hottest (so to speak) and therefore do not provide a practical solution for those who want to eat their main meal in the evenings. Solar cookers are also cumbersome and difficult to move around, and if left unattended, they may be stolen (Truran 2004b:6). This requires that the user remain in the vicinity of the solar cooker until the slow process of cooking is complete.

Some energy researchers report that women living in Cape Town’s informal settlements find this need for constant monitoring one of the main inconveniences of using paraffin stoves (Qase, Blom & Mehlwana 1996:15). This was confirmed during the course of this project’s fieldwork by Nowandile and Nobathebu who allowed their children to play near paraffin stoves. They felt that the children were unlikely to come to harm because they always kept an eye on the stove whether the children were there or not. Only in the brick kitchen of the Langa hostel was a stove ever left unattended. Here the consequences of a stove bursting into flame were less severe than if it were to happen in any of the highly flammable dwellings in the Joe Slovo informal settlement.

Ease of use has been a foremost consideration in the design of the S2. Simpler solutions that demand less attention from the user have constantly been sought. A good example is provided in the conceptual design for a mechanism that is intended to prevent the user from lifting the fuel tank from the stove base before the wax-fuel in the stove has solidified. The initial concept (pages 48 & 49 LHS of the concept sketch portfolio – see Appendix 4) features two small blister-shaped pressings that protrude towards the centre of the stove from opposite sides of the inner wax-retaining wall. When the fuel tank is lowered onto the base of the stove, these blisters snap into corresponding holes cut into the inner wall of the fuel tank, locking the stove base and the fuel tank together. The user can then only open the stove when it has cooled sufficiently to be able to press the blisters away from the two holes in the fuel tank. This would discourage users from opening the stove before the wax-fuel had cooled and solidified. The system has a high risk of burn injury and would require the use of both hands to open the stove. The second concept (page 49 RHS) has been adapted to allow users to unclip the fuel tank from the stove base using only one hand. This concept has, however, been rejected in favour of a third concept (page 50) where the fuel tank is locked to the stove base when the diffuser assembly is lowered into the stove.

This action forces three or four sprung tabs (positioned at the base of the inner wall of the fuel tank) into corresponding slots cut into the inner wax-retaining wall. When the diffuser assembly is lifted from the stove, these tabs will spring free from the slots, allowing the fuel tank to be removed from the stove base. Although this third solution does not prevent users from intentionally opening the stove before the wax-fuel has solidified, it would prevent it from being opened accidentally if, for example, the stove were to be picked up by its fuel tank. The system also reduces the risk of burn injury and requires no additional effort on the part of the user to separate the fuel tank from the stove base.

Appliance Cost

When cooking on a single-burner Panda stove for a two-week period in April 2004, I was greatly inconvenienced by being able to heat only one pot at a time. This was not a concern expressed by any of the respondents from the Joe Slovo informal settlement, none of whom owned more than one single-burner paraffin stove. If food got cold while other food was being cooked, it was simply reheated or mixed with the hot food shortly before the meal was served. The expense involved in buying a second stove or stove with a double-burner outweighed the inconvenience of having only one single-burner stove. Though convenience is often a priority, the economic concerns of stove users are by no means unimportant. Numerous sources agree that for any stove project to be successful, the cost of a new stove design must be competitive with the cost of the stoves that are already in use.[28] In informal settlements in the Western Cape this means competing with the likes of Panda stoves which sell for as little as R20,00. Efforts have been made to keep the probable manufacturing and material costs of the S2 to a minimum, but it is unlikely that the stove could be sold for as little as R20,00 – at least not initially because of the extensive capital investment involved in tooling for mass-production.

IN CONCLUSION

Although I shared little in common with any of the research participants, and despite the brevity of the fieldwork programme, which by no means allowed sufficient time to be able to experience any form of true acculturation, the fieldwork programme did provide valuable insight into the socio-cultural

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[28] See Burne (1989:130), Gusain & Khosla (1989:130), Annecke (1992:84), Sharma (1993:2), Mehlwana & Qase (1998:60), Graham & Dutkiewicz (1999:18), Rouse (1999:13), Ergeneman (2003:online) and Mushamba, Still & Gitonga (2003:online).

conditions of paraffin stove users, and raised my awareness of the conditions under which paraffin stoves are used. Without this insight and awareness, the wax-stove design solutions that may have been proposed would probably not have been in serious conflict with the needs of the potential stove users, but there certainly would have been design oversights on my part. The fieldwork programme thus succeeded in generating information pertinent to the design of a wax-stove, which may not have been gained otherwise.

The value of this chapter is accurately summarised by Mehlwana & Qase (1998:72) who, with reference to appliance and fuel choices made by the urban poor, argue that it is important to “probe the notion of ‘efficacy’ within an emic perspective so that it is presented from householders’ own perspectives.” (Mehlwana & Qase 1998:72). Close attention to the needs of potential product users has also been cited by design theorist J. Heskett (2002:199) as necessary in ensuring the profitability of any design.

Although the functional aspects of stove design are by no means secondary concerns, they should not be seen as the only critical issue of fuelled stove design, but rather as an integral facet of the design process that shares a space with the demands placed on the product by potential stove users. André van Niekerk, a South African energy researcher, notes that the challenge in this regard is to design “within the total context of household and community.” (1998:5). Within the design parameters set in this chapter, the following two chapters now turn to consider the functional constraints involved in designing a wax-stove.

CHAPTER 5 – OPTIMISING FUELLED STOVE EFFICIENCY

FUELLED STOVE EFFICIENCY

Fuel-efficient stoves use less fuel. They therefore cost less to operate. This is important for poor South African households whose energy expenditure can account for as much as 20% of their income (Annecke 1992:89). Three factors determine the fuel efficiency of a stove: its thermal efficiency, combustion efficiency and the level of control over the rate of combustion. This chapter briefly considers the aspects of these factors that are relevant to the design of a wax-stove and draws on an understanding of the functioning of paraffin wick stoves as applicable to wax-stove design. The experience that I gained through my participation in the Sasol competition has also proved valuable in understanding the functional constraints involved in designing a wax-stove.[29]

THERMAL EFFICIENCY

Thermal energy is released from stove fuels when they combust. The thermal efficiency of a stove is a measure of the amount of this thermal energy that is transferred to the food. Fuelled stoves transfer heat to the food by a combination of radiation, convection and conduction.

Radiant Heat Transfer

Stove flames and heated stove components emit radiant energy that is absorbed by the cooking vessel and transferred to the food. The percentage of radiant energy transferred from one surface to another is determined by two factors collectively known as *view factors*:

1. **The orientation of the emitting and absorbing surfaces relative to one another**. A high percentage of radiant energy is transferred between surfaces that face one another. Energy transfer is reduced as the angle between these surfaces increases.

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[29] Numerous sources have been referred to in compiling this chapter. For the sake of readability they will not be referred to in the text but are noted here under the following headings: Thermal Efficiency: Krishna Prasad et al. (1983:13), Baldwin (1984:online; 1987:41, 50, 51), Sharma (1993:75, 85), Kammen (1995:online), Sasol Oil R&D (2002:3), Bussmann (S.a.:46). Combustion Efficiency: Baldwin (1987:28, 31, 61), Bussmann, Visser & Sangen (1987:27, 41), Floor & van der Plaas (1991:28), Sharma (1993:40, 75, 85), Kammen (1995:online), George (2002:25), Sasol Oil R&D (2002:3, 4), van Niekerk (2003:9, 20), Bussmann (S.a.:46). Control: Baldwin (1987:31), Bussmann, Visser & Sangen (1987:16), Kammen (1995:online).

2. **The distance between the emitting and absorbing surfaces**. Radiant heat transfer increases exponentially as the distance between the emitting and absorbing surfaces is decreased. The base of the cooking vessel should thus be in close proximity to the flame and any heated stove components without restricting the flow of convective gases as they exit the stove between the top of the combustion chamber and the base of the cooking vessel.

Convective Heat Transfer

The fuel efficiency of a stove can best be improved by increasing the convective heat transfer that happens when hot gases move away from the point of combustion and come into contact with the cooking vessel. Contact between heated gas particles and the cooking vessel should thus be maximised, particularly by preventing drafts from driving convective gases away from the cooking vessel.

Conductive Heat Transfer

Conductive heat transfer occurs through a material or between two materials that are in direct contact with one another, for example, from the base of a pot to any food with which it is in contact.

COMBUSTION EFFICIENCY

The combustion process releases energy that is stored in fuels. Combustion efficiency is a measure of the amount of this stored energy that is converted to thermal energy. Higher conversion rates translate into improved fuel efficiency.[30] Complete combustion occurs when all the energy stored in a fuel is converted to thermal energy. This is seldom, if ever, achieved in any fuelled stove. The level of completion is determined by two factors:

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30. Higher conversion rates also result in a reduction in carbon dioxide (CO_2) emissions, which are considered by some to be the principle cause of global warming (Grover S.a.:online). Should the level of CO_2 production by wax-stoves prove to be significantly lower than that of any paraffin stoves they may replace, there is potential for financial gain through the sale of *carbon credits*. Industrialised nations that cannot meet emissions targets recommended under the Kyoto Protocol (which aims to reduce global CO_2 emission levels) can buy carbon credits from 'greener' countries (Pinnock 2003:154). European industries are paying 40 Euros per tonne of CO_2 traded and by 2007 this rate is expected to have increased by 150% (Miles 2004, February 17). The Cape Town City Municipality has been investigating the possibility of earning (and selling) carbon credits through an energy efficiency initiative being implemented in Khayelitsha (Cousins 2003). The initiative involves the instillation of solar water-heating systems and ceilings as a means of reducing household energy consumption. An energy efficient wax-stove may have the potential to reap similar benefits.

1. **The percentage of stored energy released from the fuel**. Paraffin does not burn in its liquid state. Rather, radiant heat from the flame vaporises the fuel, releasing combustible gases (volatiles), which then burn. Wax-fuels combust in much the same way except that solid wax must first melt to form a liquid.

2. **The percentage of released volatiles that are burned**. Volatile carbon particles that are released from the fuel burn with a yellow flame. When these particles are not burned, they agglomerate to form soot. Soot emissions are harmful and cause cooking pots to blacken. Cleaner combustion is indicated by a blue flame. However, radiant heat emissions increase as the flame tends towards yellow. Optimal conditions are therefore found at an intermediate point where radiant heat emissions peak without the formation of soot. This point is described as *blue flame maximum power* (Bussmann, Visser & Sangen 1987:17). The following factors determine the level of volatiles combustion:

    a. **Temperature within the combustion chamber**. Higher temperatures promote cleaner combustion. The temperature within the combustion chamber can be increased by preheating incoming air through forced contact with hot stove components, and by insulating the combustion chamber. Pages 52 – 53 of the concept sketch portfolio (see Appendix 4) show a design development intended to provide incoming air with a dedicated passage to the outer diffuser (rather than having to compete with outgoing convective airflow as in the current CAD model – which may contribute to the poor power output of the S2 prototype). This design development forces incoming air to pass under the air intake plate where it will be preheated by the flames above the plate before entering the combustion chamber.

    b. **Ratio of volatiles to air**. Complete combustion can only occur in the presence of sufficient oxygen, but excessive air supply will cause a lowering of temperature within a combustion chamber. The optimal balance between volatiles and air supply is referred to as a *stoichiometric ratio* (van Niekerk 2003:8). This ratio remains constant for each fuel type. Greater air supply is thus required when the stove is used at a higher power because volatiles are released more rapidly. Biomass-fuelled stoves featuring mechanisms designed to regulate air supply have generally been unsuccessful because these mechanisms are both difficult and inconvenient to use (Rouse 1999:19). It is thus preferable that the rate of air supply be fixed at a level that is sufficient to sustain stoichiometric combustion at maximum power.

c. **Mixing of volatiles and air**. Thorough mixing of volatiles and air is essential for clean combustion.

d. **Residence time in the combustion chamber**. A stove's combustion chamber should be designed with enough height to allow volatiles sufficient time to combust before exiting the chamber, so promoting cleaner combustion.

CONTROL OVER THE RATE OF COMBUSTION

High power settings are useful for bringing food to the boil rapidly but much energy is wasted if the rate of combustion cannot be reduced when rapid heating is no longer required. In terms of fuel consumption, a stove with a wide range of power settings can be used more efficiently.

CHAPTER 6 – WAX-STOVE DESIGN

> Sometimes a product functions properly, is economical and can solve a certain problem. Such a product could, nevertheless, be poorly received by the end-user. In the case of a technology-driven solution, the reaction of the service or product provider is then to try and change the context in which the product must function (rather than the product itself). …This is a very common approach but is seldom effective. (Van Niekerk & Van Niekerk 2000:174)

WAX-STOVE DESIGN

Significant research regarding the use of wax as a cooking fuel is limited to the BSc Mech. Eng dissertation of van Niekerk (2003) and the reports of three entrants to the aforementioned Sasol competition, Natalie Buchanan (2002), Henk Gantvoort (2002) and I.E. van Rooyen (2002). The findings of these studies and the design ideas of fellow Technikon Witwatersrand students who were involved in the Sasol competition inform this chapter as it negotiates a suitable design for a wax-stove fuel system and develops solutions to the problems surrounding wax-stove ignition, flame control and shutdown.

An understanding of how paraffin stoves function has been instructive in designing several components of the S2, some of which (including the wicks and the air diffusers) function in the same manner as that of their equivalent paraffin stove components, because once a wax-fuel has melted it combusts in the same way that paraffin combusts (Sasol Oil R&D 2002:3; van Niekerk 2003:9). This chapter thus also elaborates on the functioning of certain paraffin stove components so as to provide the reader with a fuller understanding of all the constraints that have been taken into consideration in the design of the S2.

WAXES

John Beigley (2003, April 25) of Sasol Wax has recommended three waxes for use in a wax-stove: Techniwax TW601, Waste Wax and Waksol A. This recommendation is based primarily on the low cost of these waxes. They are the cheapest waxes available from Sasol Wax.

Table 1: Properties of waxes recommended by Sasol Wax for use in a wax-stove.

Trade name	**TECHNIWAX TW601**	**WASTE WAX**	**WAKSOL A**
Origin	Crude-oil distillation	Fischer Tropsch synthesis	Fischer Tropsch synthesis
Chemical classification	‘Fossil’ wax	Synthetic wax	Synthetic waxy-oil
Bulk price (R/tonne)	~ 2800 (variable)	~ 2000 (negotiable)	~ 2400
Annual production (tonnes)	100 000	500 (maximum)	20 000
Melting point (°C)	64	95	27
Flashpoint (°C)	~ 180	>180	>27
Viscosity at 120°C (cp)	4	9	3
Molecular mass (Da)	420	850	280
Chemical consistency	Stable	Variable	Stable
Toxicity	–	Mildly acidic at times	Mild skin irritant
Current applications	Petroleum jelly component	No specific use	Hand cleaner component
	Waterproofing of board	–	Polish

(adapted from Sasol Oil R&D 2002 and Beigley 2003, April 25)

TECHNIWAX TW601

WASTE WAX

WAKSOL A

Figure 9: Waxes recommended by Sasol Wax for use in a wax-stove.

From the properties of the three waxes listed in Table 1, Techniwax TW601 appears to be the most suitable for use in a wax-stove. It has a high flashpoint and is produced in larger quantities than both Waste Wax and Waksol A.[31] Although Waste Wax has a higher flashpoint than Techniwax TW601, only small quantities of the fuel are available because it is a by-product of several refinement processes that are intended to minimise its production. The variable chemical consistency of Waste Wax is undesirable and may result in a smoky flame at times. If spilled, the wax could cause severe burn injuries because it has a melting point of 95°C. In addition, water coming into contact with melted Waste Wax would boil almost instantaneously, resulting in what is known as a steam explosion (Beigley 2003, April 25). Waste Wax thus presents too many dangers to be considered for use in a wax-stove.

Techniwax TW601 is the more expensive of the waxes but storage and transportation of the fuel could be more cost effective than that of Waksol A because Techniwax TW601 has a melting point of 64°C and is therefore more likely than the other waxes to remain in a solid state under normal storage and transportation conditions. Inexpensive, dry packaging of the wax will thus be possible. The same cannot be said for Waksol A. The melting point of Techniwax TW601 is also advantageous in that the fuel will solidify if spilled, preventing it from being drawn towards the source of combustion by any wicking material. Solid wax can be recovered and reused after a spill.

Experimentation with Waksol A or various wax combinations may be worthwhile, but Techniwax TW601 does appear to be the most suitable fuel for use in a wax-stove. Accordingly, the various wax-stove design options that are presented in this chapter have been developed with the properties of this fuel in mind.

WICKS AND STOVE IGNITION

The power produced by a paraffin wick stove (or a wax-stove that uses wicks), as determined by the rate of combustion, is related to the rate at which the fuel is vaporised from the portion of wick protruding into the combustion chamber (van Niekerk 2003:9). According to paraffin stove experts

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[31] 769 million litres of illuminating paraffin were sold for domestic purposes in South Africa in 2003 (SAPIA 2004:online). Insufficient quantities of any of these waxes are produced to meet this demand. Wax-stoves could thus only service a small percentage of the current number of paraffin stove users.

Bussmann, Visser & Sangen (1987:17, 25, 29, 41) and Floor & van der Plaas (1991:11), there are three factors that determine this rate of vapour release:

1. **The fuel transport capacity of the wicks**. Paraffin stove wicks have been successfully used by van Niekerk (2003) and most entrants to the Sasol competition to transport liquid wax at a sufficient rate to sustain a high level of combustion. Paraffin stove wicks have been used in the design of the S2.

2. **The length of wick protruding from the stove head**. The rate of vapour release is proportional to the length of exposed wick in the combustion chambers. In Panda stoves the amount of wick exposed can be adjusted by turning the control lever that protrudes from the stove head. This action either extends the wicks further into the combustion chamber or draws them into the stove head. When fully raised, about 8mm of wick is exposed. The rate of combustion is then high. By turning the lever in the opposite direction, the wicks are drawn into the stove head, up to 20mm below the base of the combustion chamber. Here the wicks are starved of oxygen and combustion ceases. The distance that the wicks can travel needs to be sufficient to both extinguish the flame and to allow a high rate of combustion, but if the wicks are extended too far into the combustion chambers, the rate of vapour release will be too high to maintain a stoichiometric volatiles to air ratio. Too much exposure of a wick also reduces its lifespan.

3. **The temperature at the surface of the wicks**. Without enough heat, fuel will not be vaporised from the wicks at a rate that is sufficient to sustain combustion. The reason why combustion ceases when the wicks are lowered into the stove head is partly because of the lower temperatures therein. Conversely, if the temperature at the base of the combustion chamber is too high, lowering the wicks into the stove head may not terminate combustion. This was a flaw apparent in some of the wax-stoves designed by Technikon Witwatersrand students for the Sasol competition. The problem can be rectified by increasing the depth of the channel into which the wicks are drawn.

Igniting the wicks of wax-stoves has proved to be particularly difficult because the wax in the wicks must first melt to form a liquid fuel before combustible gases will be driven from the fuel. This ignition process requires higher temperatures than are necessary in a paraffin stove where the fuel is liquid at room temperature. Only when the wax in a section of the wick has melted can a flame spread to that section of the wick, but initially only areas close to the point of ignition are hot enough to cause the wax to melt. The spread of the flame along a strip of wick is thus slow.[32] Van Niekerk (2003:43) resolved this problem by running thin copper wires through the crescent-shaped wicks used in his wax-stove design. Being an excellent conductor of heat, these copper wires cause wax to melt in areas further away from the flame, allowing the flame to spread more rapidly into these areas.

A system based on this same principle has been proposed in the design of the Shuttl, which uses the same crescent-shaped wicks used in Panda stoves. However, van Niekerk's copper wire solution is of little value in the design of the S2, which employs a multiple wick set-up consisting of eight individual cords of wick. The flame of one wick cannot spread to other wicks because the distances between the wicks are too large, requiring that the exposed end of each wick be lit individually. This would still be necessary if a copper conductor were used. Although this ignition procedure is more time consuming than lighting two crescent-shaped wicks, it nevertheless guarantees an immediate full flame.

AIR DIFFUSERS

Air diffusers are manufactured from thin, perforated sheet metal. They control airflow into the combustion chamber in order to establish a stoichiometric volatiles to air ratio. The diffusers also promote the mixing of volatiles with air entering the combustion chamber. Air diffusers thus play an essential role in achieving clean and high-powered combustion. Their performance in this regard is, according to paraffin stove experts Krishna Prasad et al. (1983:13), Bussmann, Visser & Sangen (1987:26, 36) and Floor & van der Plaas (1991:28), determined by three factors:

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[32] A primer fuel (such as benzene or methylated spirits) could be used to hasten the ignition process but always needing to have such a fuel available would be an inconvenience to the stove user, and dangerous – primer fuels are highly volatile and often poisonous.

1. **The size and number of perforations in the air diffusers**. Air is rapidly removed from the combustion chamber by convection, and replaced by air entering through the perforations in the diffusers. Incoming airflow is restricted by the size and number of these perforations, ensuring that air is not in oversupply. The pressure gradient between the external environment and the combustion chamber, which is established as a consequence of this restriction, causes incoming air to be drawn rapidly into the combustion chamber through the perforations in the diffusers. The resulting jets of air that form at each perforation are able to penetrate all areas of the flame, ensuring good mixing of volatiles and air. The hole on top of the inner diffuser performs a similar function, feeding air into the centre of the flame plume.

   If air enters the combustion chambers between the base of the diffusers and the stove head, the pressure gradient between the external environment and the combustion chamber decreases and air ceases to be drawn into the combustion chamber through the perforations in the diffusers. This is prevented in the design of paraffin stoves by having the diffusers fit tightly onto the stove head, but because the diffusers are not accurately manufactured they often need to be forced by stove users into alignment over the flaming wicks. This can take some time and may result in burn injuries. In the design of the S2, the diffusers are permanently fitted to the snuffer plate, which forms the permanent base of the diffuser assembly. The snuffer plate couples with the stove head, forming an airtight seal under the weight of the diffuser assembly.

2. **The size of the annular space between the inner and outer air diffusers**. The diffusers contain the combustion process and therefore determine the ‘thickness’ of the flame. Air will not be able to penetrate all areas of a thick flame. The distance between the diffusers is thus set to provide just sufficient space to contain the exposed ends of the wicks.

3. **The height of the combustion chamber**. Taller combustion chambers allow volatiles more time to combust. Radiant heat transfer to the cooking vessel is, however, disproportionately compromised by an increase in the height of the combustion chamber. The height of the S2’s combustion chamber has thus been left unchanged from that of the Panda stoves on which the design is based.

WAX-STOVE FUEL SYSTEMS

Techniwax TW601 exists in a solid state at room temperature and so it must be melted before it can be drawn into a wax-stove's combustion chamber by the wicks. This is the primary functional challenge in designing a wax-stove. Paraffin stoves are designed to limit heat transfer to their fuel tanks, thereby minimising the possibility that the fuel therein may flash, but in a wax-stove a certain amount of heat must be directed towards the fuel so as to cause it to melt. However, excessive heating can also cause wax to flash. To date, I have developed and classified three fuel systems in response to this dilemma:

1. Wick-feed fuel systems

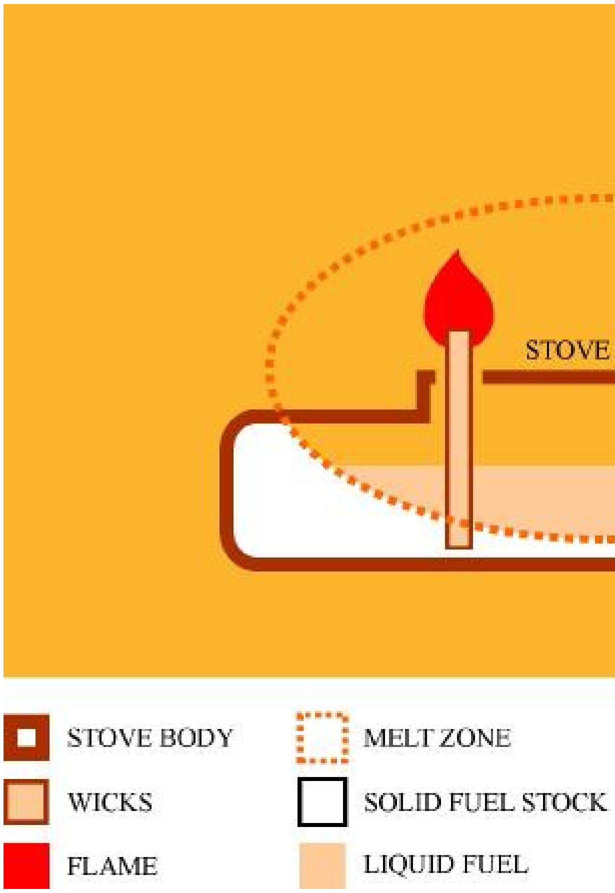

Figure 10: Panda-type fuel system.

Most of the wick stoves submitted for the Sasol competition featured fuel systems similar to those of Panda stoves where the fuel is stored in a tank below the stove head. In the wax-stove adaptation of this fuel system, heat is intentionally directed towards the tank to cause the wax to melt. Wax not located near enough to a heat source – be it radiant heat from the stove components or heat conducted from the combustion chamber – will not melt. All of the wax in the fuel tank therefore needs to be within the ***melt zone***: the area in which there is sufficient heat to cause the wax to melt.[33] However, having all of the fuel melting concurrently is undesirable for three reasons. Firstly, one of the primary benefits of using a wax-fuel like Techniwax TW601 is that it exists in a solid state at room temperature, and as a solid it is easier to contain than paraffin and therefore less likely to be spilled.[34] Secondly, if spilled, solid wax cannot be drawn by wicking materials towards the source of combustion.[35] Thirdly, once melted, a wax-fuel that is spilled may be hot enough to cause burn injuries. The volume of liquid fuel in the tank should thus be kept to a minimum.

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[33] The term *melt zone* is a theoretical construct used in this dissertation to help to explain how the S2 and the Shuttl function. For the sake of clarity, the size of the melt zone has (in most instances) been regarded as remaining unchanged, but in reality the boundaries of the melt zone will change constantly. A breeze or low ambient temperatures, for example, could decrease the size of the melt zone while radiation from the base of a large pot may cause an increase in its size. When the stove is shut down, the melt zone will (in time) cease to exist altogether. The size of the melt zone is also determined by the fuel being used: when fuelled with Techniwax TW601, a stove will have a smaller melt zone than when fuelled with Waksol A, which has the lower melting point.

[34] Truran (2004b:6) claims that ethanol-based gel fuels are safer than paraffin because the high viscosity of these fuels limits their spread when a stove is knocked over.

[35] Van Niekerk (2003:63) found that even when liquid wax was spilled it continued to burn only in the vicinity of wicking materials and then only for a limited time because of the absence of the high temperatures that are needed to sustain wax combustion. Spilt wax also tended to solidify before it could be wicked towards the source of combustion.

2. Gravity-feed fuel systems

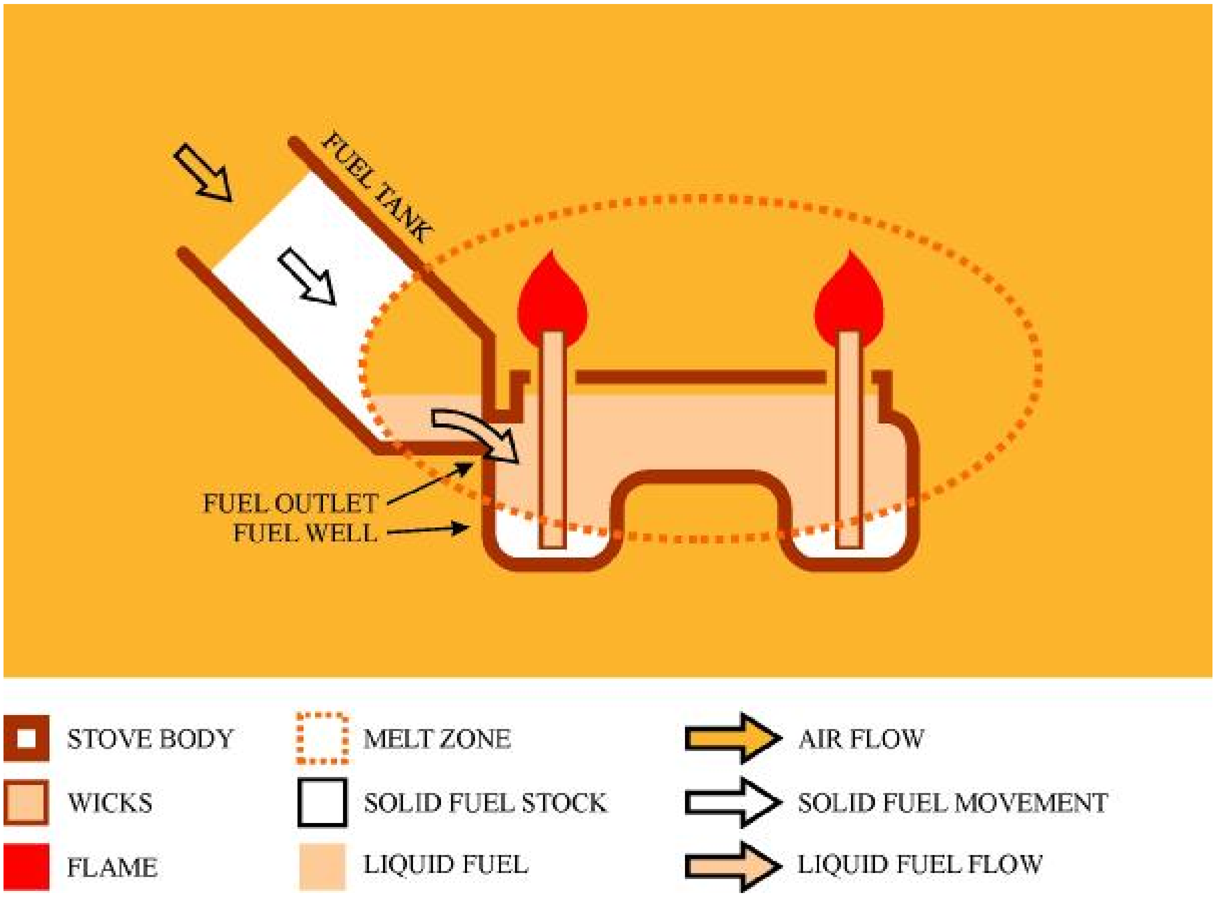

Figure 11: Gravity-feed fuel system.

Gravity-feed fuel systems are intended to minimise the volume of liquid wax contained in the wax-stove at any given time by melting wax only at the rate at which it is burned. In these systems, the fuel tank is raised above a fuel well from where the wicks draw liquid wax. As wax is drawn out of the well by the wicks, so it is replaced by wax flowing into the well from the fuel tank. However, only a small portion of the tank falls within the melt zone and thus the bulk of the wax in the fuel tank remains in a solid state until it moves into the melt zone under the force of gravity. This requires that the fuel tank be positioned in a way that ensures the movement of solid wax towards the melt zone and that only the area of the tank near the outlet into the well falls within the melt zone.

The size of the area falling within the melt zone is crucial. If too little wax is melted and supplied to the well combustion will cease, but if too much wax is melted the fuel well will overflow. Under laboratory conditions, van Niekerk (2003:56) and André Swarts of Sasol achieved optimal fuel flow in their respective wax-stove designs. However, it is unlikely that a consistent flow of fuel is achievable under this system because the size of the melt zone will vary. A gravity-feed fuel system has the advantage of not being able to be fuelled with paraffin (or any other liquid fuel) because the fuel will immediately flow out of the fuel tank. Paraffin would almost certainly flash in a wax-stove where heat is intentionally directed towards the fuel tank.

3. **Sealed gravity-feed fuel systems**

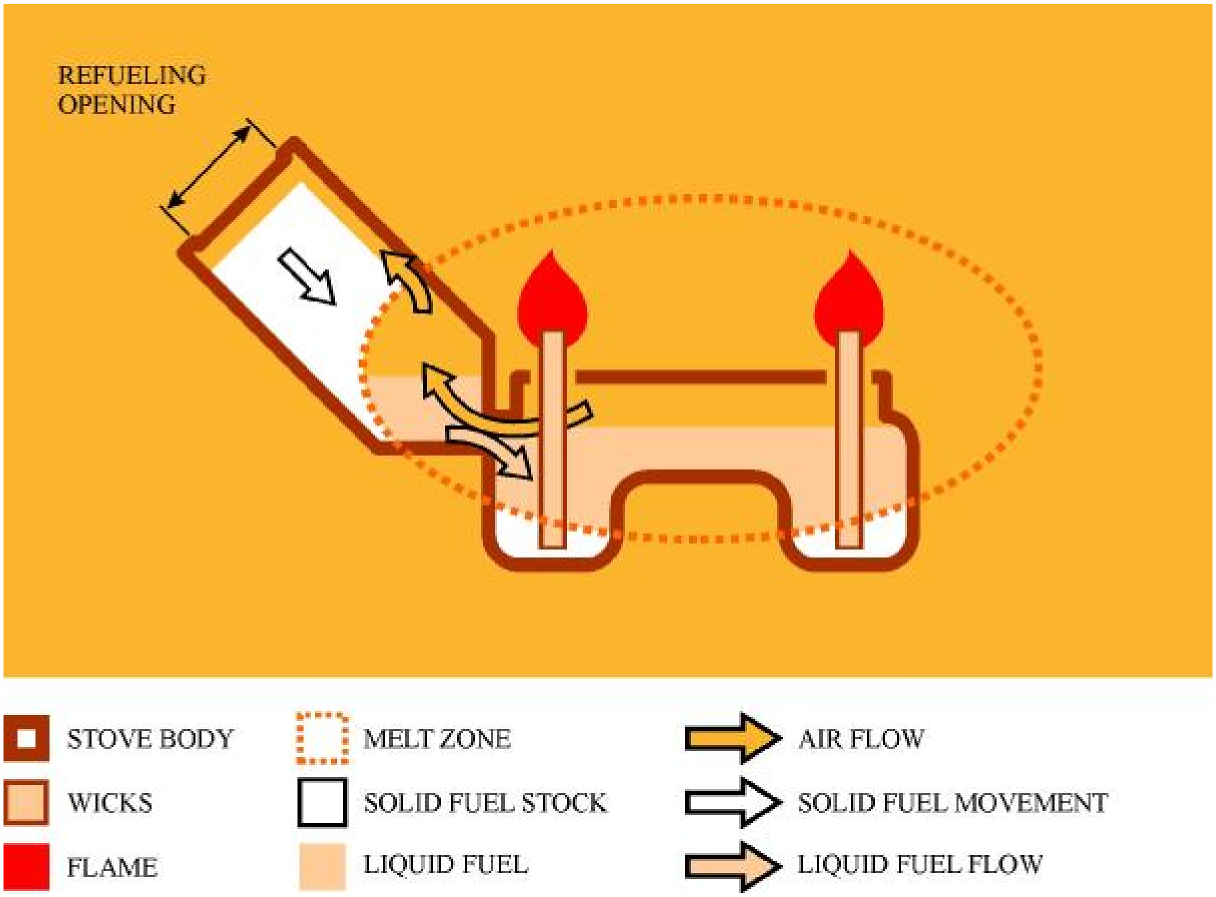

Figure 12: Sealed gravity-feed fuel system.

A sealed gravity-feed fuel system was employed in the design of the Mosquito wax-stove to circumvent the problem of variable fuel flow into the fuel well. In a standard gravity-feed fuel system, fuel flowing from the tank is replaced by air entering through the tank's refuelling opening. In a sealed gravity-feed fuel system this opening is sealed and air can thus only enter the fuel tank through the fuel outlet situated between the fuel tank and the well. When the well is full, this outlet is submerged below the surface of the liquid wax and air cannot enter the tank. Consequently wax cannot flow from the tank either. As wax is drawn from the well by the wicks, the level of the wax subsides until the point that the fuel outlet is exposed and air can then enter the fuel tank. Liquid wax then simultaneously flows from the tank, once again submerging the fuel outlet. In this way, the fuel level in the well is only ever able to rise marginally above the level of fuel outlet irrespective of the volume of liquid wax in the tank. Thus the problem of variable fuel flow can be avoided by ensuring that sufficient wax falls within the melt zone to sustain fuel supply to the fuel well even when, during operation, the melt zone is at its smallest. Melting unnecessarily large volumes of wax should, however, be avoided. It is essential that the refuelling opening remains airtight during use to ensure that wax does not flood dangerously from the fuel tank, overflowing the fuel well.

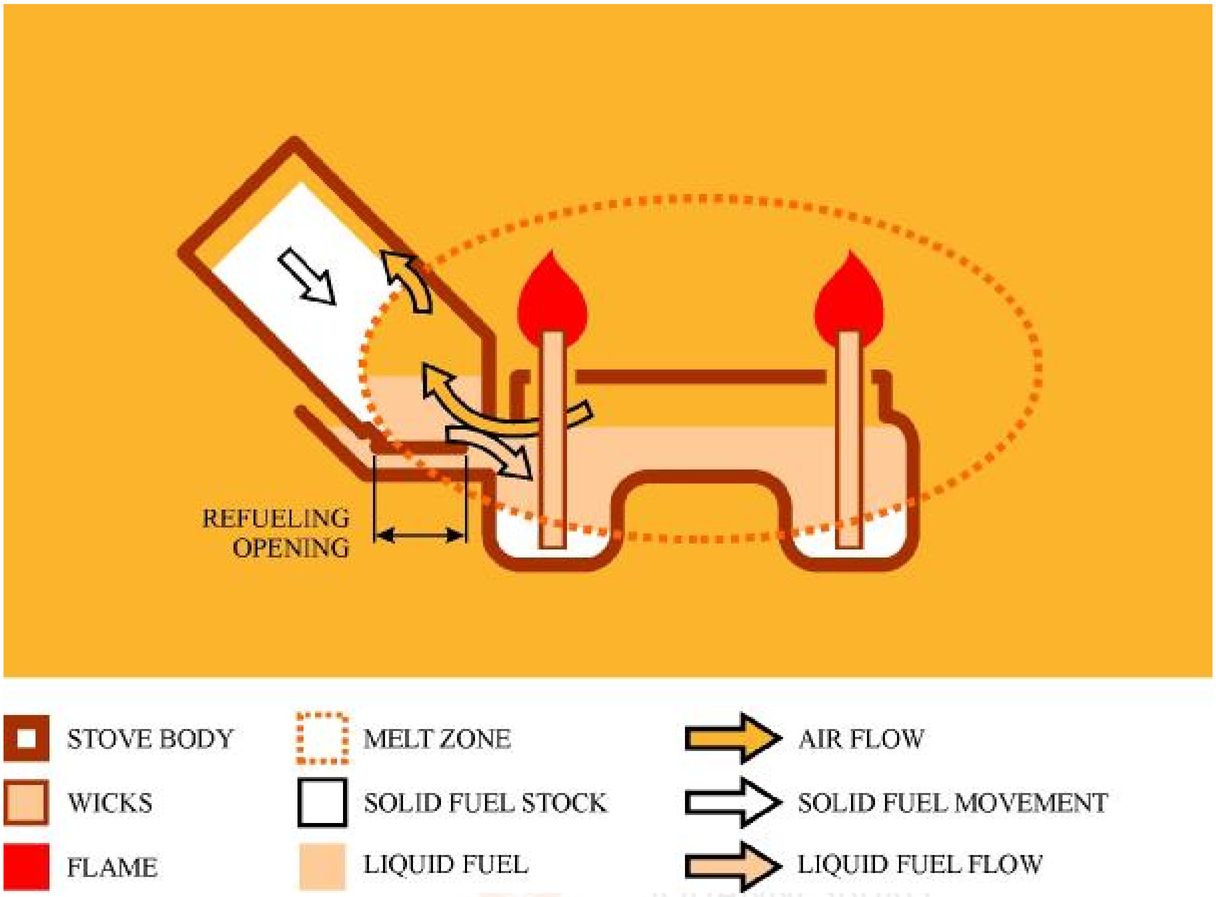

Figure 13: Sealed gravity-feed fuel system with inverted tank.

A significant improvement to the sealed gravity-feed fuel system of Figure 12 was made in the design of the Shuttl by moving the refuelling opening to the base of the fuel tank (see Figure 13). In having the fuel outlet at the same level as the refuelling opening, the need to ensure that the refuelling opening is airtight is eliminated because both the fuel outlet and the perimeter of the refuelling opening are submerged when the wax in the fuel well reaches its maximum level. Air is prevented from entering the fuel tank even if the refuelling opening is not properly closed, thereby limiting the consequences of human error. By not needing an airtight seal, manufacturing complexities are reduced. This fuel system was tested in the prototype of the Shuttl. When fuelled with Waksol A, combustion was sustained for over 30 minutes, after which time I extinguished the flame and removed the cover of the stove. All Waksol A in the fuel tank had melted and yet this wax had not flooded the stove. The fuel system succeeded in maintaining a constant fuel level in the fuel well despite the large volume of liquid fuel in the tank. Wax flow into the fuel well would also have been regulated even if the cover plate (the lid of the fuel tank) was not fitted at all – this is what has, in effect, been done in the design of the S2.

The fuel tank of the S2 has no cover plate. Thus, rather than having to overturn the fuel tank and remove a cover plate in order to put the fuel stock in the tank (as is the case with the Shuttl), the S2 is simply refuelled by placing wax-fuel stock between the wax-retaining walls on the stove base. The fuel tank is then lowered and locked into position. If the S2 could be used without the tank in place, wax-fuel would flood the stove, but this cannot be done because the pot rests of the S2 are a feature of the fuel tank. The fuel tank therefore has to be safely in place before a cooking vessel can be positioned over the combustion chamber.

The fuel tank of the S2 must remain airtight at all points above the level of the fuel in the well. Were the fuel tank to be manufactured from the low-grade steel used in the manufacture of Panda stoves, the steel would soon corrode and air would be able to penetrate the fuel tank. Shock-resistant borosilicate glass has been considered for this application but it is prohibitively expensive (Haltmann 2004). Other glass types would not be able to withstand any rapid temperature fluctuations that may occur. Stainless steel is thus proposed as the most suitable material for the fuel tank. It is less expensive than glass and very resistant to corrosion. An enamelled mild-steel would also be a suitable option.

In having the cooking vessel in direct contact with the fuel tank, heat transfer to the fuel stock is increased. This was a necessary design development because the amount of heat transferred to the fuel stock of the Shuttl proved to be inadequate to sustain the flow of Techniwax TW601 from the fuel tank. In the design of the S2, the fuel tank completely surrounds the combustion chamber so as to provide additional heat to melt the Techniwax TW601. When tested, the design of the S2 prototype promoted sufficient heat transfer to the fuel stock to maintain fuel flow to the centre of the stove. The S2, however, needed to be primed with a small amount of liquid wax shortly after ignition because initial fuel supply to the wicks was too slow, resulting in the wicks being burned (rather than the wax in the wicks). This is partly because the base of the prototype is not inclined towards the centre of the stove (unlike the stove base shown in the CAD model), causing some liquid wax, which should have been supplied to the wicks, to flow instead to the perimeter of the stove base. It may, however, be necessary for the stove to be supplied with a ring of wax that can be positioned under the wick support where it will melt rapidly when the stove is first ignited. This should not be necessary when the stove is next lit because unburned wax will have solidified around the base of the wicks after the stove was first used. An alternative option is for the stove to be supplied with wax-saturated wicks.

Importantly, the fuel tank of the S2 cannot be repositioned on the stove base if it has been overturned and filled with paraffin – not without spilling the paraffin – and any paraffin poured between the perforated wax-retaining walls would immediately flood the stove and overflow the base. Thus only the base of the stove, which has an intentionally small volume, could possibly be filled with paraffin. Lighting the S2 in this state would be less dangerous than lighting the Shuttl if its fuel tank were to be filled with paraffin and positioned in the stove.

FLAME CONTROL AND STOVE SHUTDOWN

In the design of Panda paraffin stoves, the large distance between the exposed ends of the wicks and the fuel tank helps to minimise heat transfer to the fuel. The rack and pinion mechanism used to adjust the height of the wicks (and to control the rate of combustion) is located here, occupying much of this space. However, in the design of the S2 there is not enough space to house a similar wick adjusting mechanism because the exposed ends of the wicks must be in close proximity to the fuel source in order to ensure sufficient heat transfer to the fuel. Thus a more compact solution was needed to effect flame control and shutdown.

Yates (2003), and the panel of adjudicators of the Sasol competition, felt that the most successful feature of the Mosquito was the way in which the wicks were immersed in the wax in the fuel well in order to extinguish the flame. This effectively curtailed visible emissions after shutdown. However, this solution is potentially dangerous because it requires that the flame come into contact with significantly large volumes of liquid fuel. Should sufficient heating of this fuel occur, volatiles will be released at a rate sufficient to sustain combustion even without the presence of a wicking material. Another problem is that the user would be unable to shut down the stove by submersion of the wicks if the level of wax in the fuel well were to subside below the top of the wicks when in their lowest position. Also, if one were to forget to raise the wicks after immersing them in the fuel well, wax would solidify around the wicks, making future ignition of the stove difficult.[36]

The S2 employs a flame control mechanism that functions in a manner comparable to that of the simmer rings used to reduce the power of methylated spirit stoves (see figures 14 – 15). When in position, these rings restrict the size of the flame by partially covering the source of combustion. Similarly, the S2's control levers rotate the diffuser assembly in an anticlockwise direction, moving the blades of the snuffer plate (which forms the base of the diffuser assembly) over the wicks, incrementally reducing the size of the flame and the power of the stove. When the diffuser assembly is rotated to its anticlockwise extremity, these blades enclose the wicks in the spaces between the protuberances on the wick support, thereby extinguishing the flame as it is starved of air.[37] The blades are also intended to contain any emissions resulting from the flame being extinguished.

As yet, this system has not been tested in the design of the S2 but a similar system with three blades, used in the wax-stove designed by Henk Gantvoort (2002:39) of the Pretoria Technikon, has been shown to provide an adequate form of control over the stove's rate of combustion and an effective means of shutting the stove down and containing emissions after shutdown.

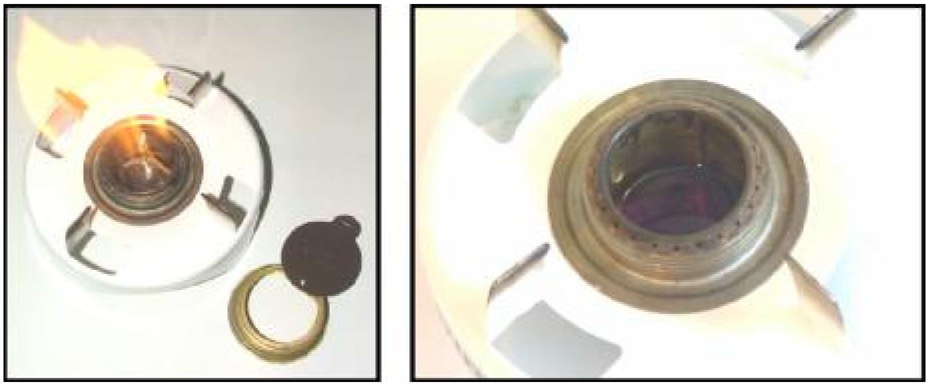

Figure 14: Trangia methylated spirit stove burning at full power with simmer ring set aside.

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[36] Van Niekerk (2003:65) resolved this latter problem by spring-loading the wick adjusting mechanism so that the wicks could only remain below the surface of the wax while being held in that position.

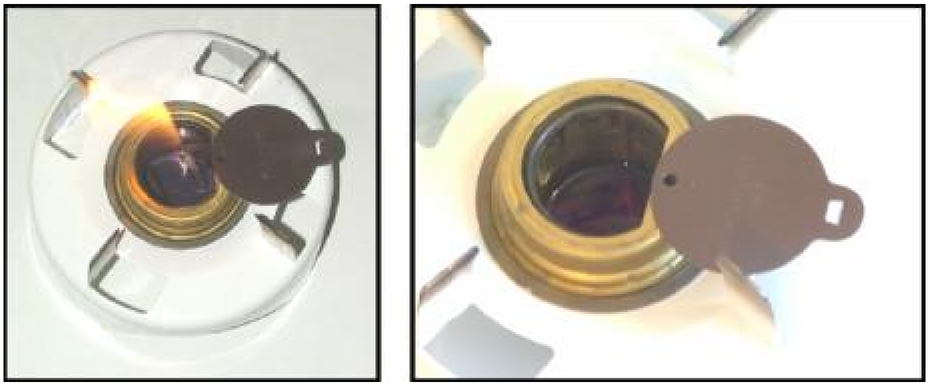

Figure 15: Trangia methylated spirit stove burning at reduced power with simmer ring in position.

MISCELLANEOUS DESIGN DEVELOPMENTS

Two design features of the Shuttl, which were not adopted into the design of the S2, may have valuable applications for other wax-stove designs. The first is a mechanism used to adjust the power of the stove, based on a design by Apostolos Sfetsios while he was a student at the Technikon Witwatersrand. Two copper sheaths that surround the wicks are moved either higher up around the wicks (to reduce the length of exposed wick and slow the rate of combustion) or downwards (to expose a greater length of wick and increase the rate of combustion) by rotating the adjuster plate from which they are suspended. The three blades protruding from this plate are constrained within angled cut-outs in the guide ring, causing the adjuster plate to move either up or down when rotated. This motion, in effect, achieves the same results as moving the wicks up or down (as in Panda stoves) but not having to move the wicks permits a more compact control mechanism. A snuffer would be needed to extinguish the flames because the control mechanism does not provide sufficient travel to effect shutdown. However, having a free snuffer is far from ideal. Loose components (like paraffin stove fuel caps) are often lost, which, in this case, would leave the user without an effective means of extinguishing the stove. In addition, the components of this system would need to be manufactured very precisely to prevent air from entering the combustion chamber from below.

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37. The rotation of the diffuser assembly in an anti-clockwise direction is contrary to conventions of other control mechanisms that operate from left (minimum) to right (maximum). This oversight should be addressed in future designs.

The second notable design feature of the Shuttl is the channel (that follows the perimeter of the cover plate) through which the fuel must first pass before exiting the tank. This could significantly improve the safety of the stove. In the event of the fuel tank being knocked from the stove and coming to rest on its side, a portion of this channel will always lie above the level of the wax in the tank, thereby stemming the flow of fuel from the tank. If the tank were to be inverted, the fuel would be contained in the bowl of the upturned tank. In an upright position, the rate of wax exiting the tank would be slowed by air passing through the channel in the opposite direction. This system has not yet been tested but it may prove to be a valuable safety feature in the design of a wax-stove and could also be adapted for use with paraffin stoves.

SUMMARY

This chapter has presented a number of potentially viable solutions to the problems of wax-stove ignition, control and shutdown, and a feasible fuel system is arrived at in the design of the S2. This system addresses the problem of variable fuel flow while also taking safety and the conditions of potential stove users into account, and in so doing has overcome the design impasse that wax-stoves entered into the Sasol competition appeared to present. The S2 has also advanced the proposed methods of ignition, control and shutdown employed in earlier wax-stove designs.

CHAPTER 7 – CONCLUSION

RESEARCH CONTRIBUTION

The potential safety benefits of using a wax-fuel rather than paraffin can only be realised in a suitably designed wax-stove. In seeking to achieve this end, a number of design solutions that address both the functional and the safety requirements related to wax-fuel combustion have been proposed and developed through the course of this project. However, the design challenge presented by the use of a wax-fuel is not limited to achieving regulated fuel flow or a high level of safety, both of which are achievable.[38] Solutions that satisfy only these or any other functional or safety requirements will not necessarily meet all the demands of potential stove users. The design problem must be viewed and defined from the wider perspective of potential stove users, in terms of their needs and requirements, and with their socio-cultural conditions in mind. This research project has sought to foreground the needs and requirements arising from the user's knowledge traditions, apart from the values and expectations of the uninformed designer.

Ultimately, this approach has been less about revising design methodology to suit the demands of the project at hand, and more about altering my own mindsets towards the needs of those with whom I do not share a common socio-cultural or economic background. This latter concern is, however, probably of equal importance – especially in South Africa where the effects of the negative discrimination that was perpetuated under the Apartheid system continue to be felt. Constantly acknowledging and addressing the needs of the user in the design of wax-stoves adds further constraints to the design process but is essential in presenting a clearer picture of the real problems. By creating awareness of these constraints, design solutions are more likely to meet the needs of potential wax-stove users. The fieldwork programme, though it did not result in any unexpected constraints or user requirements, did provide valuable insight into the conditions surrounding paraffin stove use and allowed for a clearer prioritisation of the needs of potential wax-stove users. The findings of the fieldwork programme have thus contributed to the design of the S2 in ways that may have otherwise been overlooked.

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38. Page 35 of the concept sketch portfolio (see Appendix 4) shows the beginnings of a concept for a sealed fuel system from which fuel will only be released when the fuel tanks are correctly positioned in the stove. If knocked over, the fuel outlet will automatically seal, preventing a wax spill. This would certainly improve safety but add to manufacturing costs and the user would be inconvenienced by having to take the fuel tanks to an authorised service provider for refuelling.

This research project has also sought to identify and classify criteria for the design of a wax-stove by considering the broader context of energy and appliance use in South Africa and by developing an understanding of the principles that govern the efficient combustion of wax in wax-stoves. This latter component of the research draws on information concerned with the functioning of biomass-fuelled stoves, knowledge generated through the testing and development of paraffin stoves, and new findings arising from the development of the wax-stove designs. This compilation of wax-stove design criteria provided a comprehensive foundation for the design of the wax-stoves developed for the purposes of this project and it will also provide a point of departure for any further wax-stove design initiatives.

WAX-STOVE DESIGN OPPORTUNITIES

Though wax-stove design progress has been made through the course of this project, there is still much work to be done before any wax-stove design is effective for cooking on and sufficiently safe to begin testing within a community of potential users. The S2 requires further design development, particularly with regards to ignition of the stove – a process that has proved to be somewhat slow and one that may present a stumbling block to user acceptance of the design. Achieving sufficient fuel flow to the wicks immediately after ignition of the S2 remains an unsolved problem. Some possible solutions to this problem have been discussed in this dissertation but accurate prototyping and testing is required to ascertain whether or not these solutions have any merit. More precise prototyping is also needed to test the fuel system of the S2 sufficiently and to adapt it to achieve optimal fuel flow. This will require that stove components be made as per mass-production standards and that they be manufactured from materials of the recommended specifications. One of the aims of this project was to prototype a wax-stove as a means of testing the design ideas developed through the course of the research. However, accurate testing has not been possible both because of time constraints and because of the low level of precision that was achieved in the S2 prototype. The prototype did however demonstrate the effectiveness of a sealed gravity-feed fuel system with an inverted tank. This system is possibly the most significant functional contribution of the project and it will hopefully provide a good point of departure for further wax-stove design initiatives.

Experimentation with other wax-fuels, particularly Waksol A, and possibly various wax-fuel combinations, may provide further design opportunities as it may be possible to blend two or more waxes to create a fuel of optimal consistency and melting temperature. Pressurised fuel systems should also be considered. Wax-stoves are not automatically safe simply because wax-fuels have the potential to be safer than paraffin. In fact, a poorly designed wax-stove could be as dangerous, if not more dangerous, than any paraffin stove because of the high melting temperatures of the waxes used. Wax-stove safety must therefore continue to be a high priority of any wax-stove design initiative.

Using wax as a cooking fuel has proved to be a difficult and multi-faceted design challenge that has not readily yielded comprehensive solutions. Yet wax-stove design and development deserves continued investigation because of the potential safety benefits that a wax-stove could have over paraffin stoves.

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APPENDIX 1 – PARAFFIN STOVE USE QUESTIONNAIRE

<u>All questions are underlined.</u> Instructions to the interviewer are not. A question should only be asked if it cannot be answered through observation. ***Answers to questions written in italics need not be recorded. The purpose of these questions is to introduce a topic.*** Should any of the topics covered by this questionnaire arise spontaneously during the course of the interview, they should be dealt with immediately under the relevant section of the questionnaire. The principle respondent should be the family member having the most experience with cooking on paraffin stoves but other family members should not be excluded from the discussion. The questionnaire is intended to provide answers relevant to stove **design** only. Discussions irrelevant to design should be avoided. Begin by explaining to the respondent the purpose of this research.

Date: __ __ / 05 / 2004

Name of principle respondent:

Relationship status:

Estimated age:

Gender: G Male G Female

1. STOVE LOCATION

1.1 <u>What type of paraffin stove/s do you use?</u>

G Crescent-shaped wick, single-burner. G Crescent-shaped wick, double-burner.

G Multi-wick, single-burner. G Multi-wick, double-burner.

G Other:

1.2 <u>Where do you use your stove/s?</u>

Area / room that the stove/s are used in:

Surface that the stove/s are used on:

Material: Height: Width: Condition of surface:

Reasons for location of stove:

1.3 Do you ever move your stove/s away from here for any reason?

☐ YES Location that stove/s are moved to:

Reasons for moving the stove/s:

☐ NO

2. STOVE MAINTENANCE

2.1 How long have you had your stove/s for?

2.2 When do you think your stove/s will be too old to carry on using?

2.3 How do you know when a stove is too old to carry on using?

2.4 Do you ever buy new parts for your stove/s?

☐ YES

a. Component purchased:

Reasons for component failure:

b. Component purchased:

Reasons for component failure:

c. Component purchased:

Reasons for component failure:

☐ NO

2.5 Do you ever have to fix your stove/s?

☐ YES

a. Component repaired:

Reasons for component failure:

Method of repair:

b. Component repaired:

Reasons for component failure:

Method of repair:

c. Component repaired:

Reasons for component failure:

Method of repair:

G NO

3. STOVE USE

<u>What other types of stoves do your neighbours use?</u>

<u>Have you ever used any of these other types of stoves?</u>

3.1 <u>Which type of stove do you think is better: an electrical stove, a gas stove or a paraffin stove?</u>

G Electrical stove.
G Gas stove.
G Paraffin stove.

Reasons for choice of stove:

3.2 <u>Would you ever use any other type of stove?</u>

G YES – electrical stove.
G YES – gas stove.
G YES – other:
G NO

Reasons for answer:

4. COOKING PROCESS

4.1 <u>How many people do you usually cook for?</u>

4.2 <u>What pot do you use most often to cook your food in?</u>

Pot description:

Material:
Height:
Diameter:

4.3 What is the biggest pot that you use to cook your food in?

Pot description:

Material: Height: Diameter:

4.4 What is the smallest pot that you use on your stove?

Pot description:

Material: Height: Diameter:

4.5 Are any of these pots difficult to use on your stove?

G YES G NO

Reasons for answer:

4.6 What meals do you cook most often in the evenings?

a.

b.

c.

4.6 a How long does meal (a) normally take to cook?

Brief description of cooking process (a):

Estimated amount of paraffin used:

4.6 b How long does meal (b) normally take to cook?

Brief description of cooking process (b):

Estimated amount of paraffin used:

4.6 c How long does meal (c) normally take to cook?

Brief description of cooking process (a):

Estimated amount of paraffin used:

4.7 <u>Would these meals be easier to cook on some other type of stove?</u>

G YES – electrical stove.   G YES – gas stove.

G YES – other: G NO

Reasons for answer:

5. SAFETY (GENERAL)

5.1 <u>What type of stove do you think is the safest to use?</u>

G Electrical stove.   G Gas stove.

G Paraffin stove.   G Other:

Reasons for choice of stove:

5.2 <u>Are there any stoves that are very dangerous?</u>

G Electrical stove.   G Gas stove.

G Paraffin stove.   G Other:

Reasons for choice of stove:

6. SAFETY (FIRES)

6.1 <u>Have paraffin stoves ever caused fires in this area?</u>

G YES   Descriptions of the event/s:

G NO

6.2 <u>Is a paraffin stove safe if it is left alone while it is on?</u>

G YES   G NO

Reasons for answer:

6.3 Have you ever had any problems with your stove/s while you were busy cooking?

G YES Causes of problems:

G NO

6.4 Do the children who live in this house help you with preparing meals in any way?

G YES – buying food.

G YES – preparing food.

G YES – cooking.

G YES – other:

G YES – buying paraffin.

G YES – preparing the stove.

G YES – cleaning up.

G NO

6.5 At what age should children be allowed to use paraffin stoves without adult supervision?

Age:

6.6 Is it dangerous for children who are younger than this age to use paraffin stoves?

G YES

G NO

Reasons for answer:

6.7 Are there any ways to prevent a paraffin stove from causing a fire?

G YES Ways in which to prevent fires:

G NO

7. SAFETY (BURNS)

7.1 Do you know of anyone who has been burned by a hot paraffin stove?

G YES Descriptions of the event/s:

G NO

7.2 Do people ever get burned from hot food being spilled from pots?

G YES Descriptions of the event/s:

G NO

7.3 Are there any ways to prevent people from being burned when they are using paraffin stoves?

G YES Ways in which to prevent burns:

G NO

8. FUEL USE

8.1 How many times a week do you use your stove/s?

8.2 Where do you buy paraffin from?

8.3 How often do you buy paraffin?

8.4 How much paraffin do you buy each time?

9. EMISSIONS

9.1 Do older paraffin stoves make more smoke than new ones?

G YES Reason for answer:

G NO

9.2 Are there any ways of stopping a paraffin stove from making smoke or unpleasant fumes?

G YES Method of reducing emissions:

G NO

9.3 Do your stove/s ever need cleaning?

G YES Causes of dirtiness:

Method of cleaning stove/s:

G NO

10. STOVE FUNCTIONS

10.1 Do you use your stove for anything other than cooking?

G Space heating.	Method by which this function is performed:
G Heating of a clothes iron.	Method by which this function is performed:
G Heating water for drinking.	Method by which this function is performed:
G Heating water for washing dishes.	Method by which this function is performed:
G Heating water for bathing.	Method by which this function is performed:
G Other:	Method by which this function is performed:

Thank the respondent for their time and their willingness to participate.

APPENDIX 2 – IMAGES OF THE S2 WAX-STOVE

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APPENDIX 3 – IMAGES OF THE SHUTTL WAX-STOVE

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APPENDIX 4 - CONCEPT SKETCH PORTFOLIO (SELECTED PAGES)