Kerosene Stoves: Their Performance, Use, and Constraints

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KEROSENE STOVES:
their performance, use and constraints

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EXECUTIVE SUMMARY ................................................................. i

1. BACKGROUND ........................................................................... 1
   Introduction ............................................................................. 1
   Inter-fuel Substitution ............................................................ 1

2. INTRODUCTION ......................................................................... 8
   Wood Stoves ........................................................................... 8
   Charcoal Stoves ...................................................................... 8
   LPG Stoves ............................................................................ 9
   Need for a Kerosene Stove for African Households ................. 9
   Development Work on Kerosene Stoves .................................... 11
     High power wick stoves ...................................................... 12
     Low power wick stoves ...................................................... 12
     Pressurized stoves ............................................................ 12

3. HIGH POWER KEROSENE STOVES ........................................ 15
   Water Boiling Tests ............................................................. 16
   Safety tests .......................................................................... 16
   Controlled Cooking Tests ...................................................... 17
   Environmental Considerations ............................................... 22

4. LOW POWER KEROSENE STOVES ......................................... 23
   Water Boiling Tests ............................................................. 23
   Safety tests .......................................................................... 24
   Controlled cooking tests ...................................................... 24
   Consumer Acceptability Tests ............................................... 26
   Theoretical Model of Time and Fuel Savings .......................... 26
   Stove modifications ............................................................ 27
   Flow restriction ...................................................................... 28
   Pan support ........................................................................... 28

5. CONCLUSIONS ......................................................................... 30

Annex I : Financial Comparison of Different Alternatives for Cooking .................. 32

Annex II Testing of Pressurized Stoves .................................................. 36
   Power Rating Tests .............................................................. 37

Annex III (Stove Models) ............................................................... 39
TABLES

Table 1  Average Growth Rate (‘84 - ‘87) ........................................ 2
Table 2  Comparison of Household Fuels ............................................. 4
Table 3  Stove Use in Niamey, Zinder, and Maradi ............................ 8
Table 4  Fuel Consumption Parameters ............................................ 10
Table 5  Specific Fuel Consumption for Different Stove Types ............. 18
Table 6  Controlled Cooking Tests with Kerosene Wick Stoves .......... 25
Table 7  Time and Fuel Saving Options ............................................ 27
Table A1.1 1990 Fuel Prices in West African Countries ..................... 32
Table A1.2 Fuel Characteristics .................................................. 32
Table A1.3 Stove Characteristics .................................................. 32
Table A1.4 Annual Costs for Cooking ........................................... 33
Table A2.1 Summary Characteristics of Pressurized Stoves ................. 36
Table A2.2 Power Output - Nozzle Diameter Combinations ............. 37
Table A2.3 Characteristics of a 4 kW Pressurized Burner ............... 38

FIGURES

Figure 1  Kerosene and LPG Consumption (‘70 - ‘87) ....................... 1
Figure 2  Kerosene and LPG Consumption ..................................... 3
Figure 3  Right and Wrong Position of Evaporator Shaft .................. 17
Figure 4  Relation Between Power Output and Efficiency of the Stove .. 24
Figure 5  SFC as Function of Stove Power ..................................... 25
Figure 6  Cooking Time as Function of Stove Power ......................... 26
Figure 7  Relation Between the Efficiency of the Stoves and the Ratio of Pan and Burner Diameter .................................. 26
Figure 8  Breakdown of Total Annual Cooking Costs (All Countries) ... 34
Figure 9  Breakdown of Total Annual Cooking Costs (Mauritania) .... 35
Figure 10 Breakdown of Total Annual Cooking Costs (Niger) .......... 35
Figure 11 Thomas Cup ................................................................. 39
Figure 12 PET ........................................................................... 40
Figure 13 Primus ........................................................................ 41
Figure 14 Superior ........................................................................ 41
Figure 15 Zeppelin ........................................................................ 42
Figure 16 Nopalé........................................................................ 43
Figure 17 Tlip Banekh ................................................................. 43
Figure 18 Malgache Charcoal ......................................................... 44
Figure 19 Sakkanal ........................................................................ 44
Figure 20 Rondereza ..................................................................... 45
Figure 21 Kengo Jiko ................................................................. 45
Figure 22 Malgache Wood ............................................................. 46
Figure 23 Mali Sauki ...................................................................... 46
**ACRONYMS, ABBREVIATIONS, MEASURES**

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>Carbon Monoxide</td>
</tr>
<tr>
<td>EDP</td>
<td>Energy Department Paper</td>
</tr>
<tr>
<td>IT</td>
<td>Index of Toxicity</td>
</tr>
<tr>
<td>LPG</td>
<td>Liquified Petroleum Gas</td>
</tr>
<tr>
<td>SFC</td>
<td>Specific Food Consumption</td>
</tr>
</tbody>
</table>

- 1 MJ: mega Joule = $10^3$ GJ = 10,000 kJ
- 1 TOE: tons of oil equivalent = 42.5 GJ = 10.2 million kcal = 40.5 million BTU
- 1 MT: metric ton = 1000 kg
- 1 kg of wood: 18 MJ (at 15% moisture content, moisture content wet base)
- 1 kg of charcoal: 31 MJ
- 1 liter of kerosene (0.8 kg): 35 MJ
- 1 kg of LPG: 45 MJ
EXECUTIVE SUMMARY

In this report we show that, although LPG and other fuels are gaining ground, kerosene is still a major household cooking fuel in many countries. A particular case is Indonesia where in 1983 some 135 PJ \(^1\) (3.8 million m\(^3\) valued at US$400 million) of kerosene was used in simple kerosene stoves. Few other energy technologies use such large quantities of fuel. Improving energy efficiency in kerosene stoves, therefore, could yield potentially large fuel savings and could be an economically attractive activity. The purpose of this report therefore is to show how it is possible to increase the potential for kerosene savings, improve household welfare and reduce the cost of supplying kerosene to the economy.

Prior to the field activities on which the findings of this report are based, research on kerosene stoves had identified the key determinants of stove performance. It also showed that the performance of existing stoves varied greatly. Based on these findings it was decided to:

(a) identify and test a high-power stove adapted to West African conditions and, if necessary, modify its design;

(b) test the laboratory results in the field and work with users and producers of kerosene stoves; and

(c) raise the quality of existing low power kerosene stoves rather than to develop or identify a "best" stove.

The activities undertaken consisted of stove testing and consumer acceptability surveys supported by applied research. The field surveys were preceded by water boiling tests to provide technical parameters such as the efficiency and power of the stoves to be field tested. Because these laboratory results do not show how much fuel is actually used for a certain cooking task, controlled cooking tests were conducted using a standard meal prepared on different stoves. These cooking tests demonstrated the potential fuel savings resulting from the use of a more efficient model, but also those resulting from a change in consumer behavior. In addition, safety tests were conducted to determine the temperature of the relevant parts of the kerosene stoves and to measure the quality of combustion. Finally, consumers were given the modified stoves for use at home and to test them under real life conditions. The debriefing of the housewives yielded much practical information about the pros and cons of the use of a particular kerosene stove. These consumer remarks led to further applied research to try and address the problems they had identified. As a result of these activities the following conclusions can be drawn:

As far as stoves with a power output higher than 3 kW are concerned, we have been able to identify and adapt an Indonesian wick-stove, the Thomas Cup 36 \((P_{\text{max}} = 5\text{Kw})\), for use in W. African households. The TC\(_{36}\) was demonstrated to be an adequate and marketable kerosene stove during

\(^{1}\) 1 PJ = 1,000,000 GJ = 1,000,000,000 MJ
numerous field tests in the Cape Verde, Senegal, Mauritania, Burkina Faso, Mali, and Niger. Housewives have indicated that they consider this stove to be a product that they like and are willing to buy. The stove is efficient and reliable, and therefore acceptable to consumers. Currently, the TC36 is being marketed in Niger as a commercial product.

Another potentially promising kerosene stove (of the pressurized type) is the Columbian Superior ($P_{\text{max}} = 5$ Kw). However, despite its very appealing design there are still technical problems with this stove, which has been designed for use with cocinol (an intermediate product between kerosene and gasoline) which is not available in all countries. Some of these problems have been resolved during field tests, others however still remain. Further, applied research is necessary, in particular to address the issue of kerosene tolerance.

Additional work on stoves with a lower power output than $3$ kW in Indonesia showed that the technical changes required to save kerosene and/or change the power of most existing kerosene stoves are simple and inexpensive. For example, simply turning around the pan support (at zero cost), and placing a flow restrictor at the bottom of the flame holder increases the stove's efficiency. Further research may yield additional simple and inexpensive, energy saving technical changes.

The economics of kerosene cooking in Indonesia suggests that a $5\%$ change in a stove's kerosene consumption would be worth over Rp 5000 (present value) to a typical consumer, assuming a discount rate of $10\%$. The additional cost of producing such a change would be much less. For example, the cost of an airflow-restrictor ($<30$ Rp), omitted in most artisanal stoves could lead to an average kerosene savings of $3-6\%$.

The work in Indonesia also showed that, consumers purchasing a stove cannot ascertain its fuel-economy, either through physical inspection or reputation. Also, stove producers are also ignorant of their stoves' fuel economy. Given the diversity in quality of output, even for the same model by the same producer, implies what is needed is not so much a better stove design, but rather a change in the quality of production and to create consumer awareness about these issues.

In both the W. African and Indonesian cases it was demonstrated that simple behavioral changes can save considerable amounts of kerosene. Turning down the power during the simmering process (which is not done by many households) can save up to $10\%$ of kerosene used. Also, the effects of the technical and behavioral changes are interdependent. If a $10\%$ more efficient stove is used at the same high power setting (for a typical Indonesian meal) as with the non-efficient stove, $3\%$ of the kerosene will be saved. This higher efficient stove will thus deliver more energy to the pan, which, could result in time savings. If, in addition, the power output is reduced by $10\%$, so that the heat delivered to the pan remains as it was with the non-efficient stove, this will save $6\%$ of the kerosene.

Further applied research programs to improve kerosene stoves can be expected to uncover additional kerosene saving possibilities. The two simple technical changes identified for low power

---

2. $\$1 = \$1000 (1990)$
stoves were uncovered in a relatively short time. It is likely that further savings could be obtained from other design changes by, for example, changing the quality of the wicks used, and improvements in the flame adjustment mechanism.

Finally, this report confirms the Bank's earlier finding that wick stoves appear to be a generally better technical option than most pressure stoves. Good wick stoves have efficiencies of 40% or more as compared to 55% efficiency for pressurized stoves, but are cheaper, and have fewer operational problems. The Columbian Super-stove could be an exception to the rule, if certain technical fuel problems can be resolved.
1. BACKGROUND

Introduction

1.1 The household energy sector is the largest of all energy consuming subsectors in most developing countries. Households account for 40%-80% of total energy use, mainly depending on the level of development of a particular country. The household energy sector is often also the fastest growing one with regards to consumption of modern fuels such as kerosene, LPG, and electricity. This growth is manifested by a sometimes rapid switch from traditional to modern fuels in the urban areas.

1.2 Traditional fuels such as wood and charcoal provide the least cost solution to households in many low-income LDC's. However, this is so only because wood fuels are normally not priced at their economic costs: the price structure of both wood and charcoal normally includes a large component for transport and wholesale/retail, but very little is accounted for the costs to grow the wood or replace it; costs related to environmental damages resulting from overcutting of wood are usually not incorporated. In addition, woodfuels can be purchased in quantities which suit consumer needs most closely (in small monetary quantities), while cooking equipment costs are zero or very low. Households therefore continue to use woodfuels unless: (i) scarcities start occurring frequently; (ii) woodfuel retail prices increase substantially relative to modern fuels; (iii) disposable incomes increase; or (iv) subsidies are provided on modern fuels and equipment.

1.3 Wood and charcoal stoves are generally inexpensive - if not free of costs (e.g. three stone open fire) - and users discard and buy new stoves when needed, which in the case of charcoal stoves may be two times a year. Because of the low purchase price, the decision to buy a new stove is normally not an issue for discussion with the head of the household, unless a switch to another fuel is proposed.

Inter-fuel Substitution

1.4 The use of modern fuels (kerosene, LPG, electricity) is on the rise within the urban areas in many countries, especially among households in the middle and higher income brackets. This energy switch is due to a combination of rising incomes, increased availability and accessibility of modern fuels, rapid urbanization, increased prices and declining supply of biomass fuels, in combination with low (often subsidized) modern fuel prices. It is likely that this inter-fuel substitution will continue in many of the developing countries in view of rising urbanization.

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* See Figure 1 which gives the total kerosene and LPG consumption for all developing countries combined, and for western countries.
often existing price differentials are in favor of this substitution in many countries and are
accentuated by the higher end-use efficiencies and comfort levels of modern fuels.

1.5 Table 1 shows average annual ('84 - '87) growth percentages of petroleum and LPG use in
Africa, Latin America, and Asia. Kerosene use increases seven times faster than LPG in Africa,
while LPG use increases 2.5 times faster than kerosene in Asia. In Latin America, kerosene use
actually declined, indicating that these countries are one step further ahead on the road to
substitution to LPG or electricity from kerosene than their counterparts in Africa and Asia.

1.6 Of the modern cooking fuels used by households in developing countries, kerosene
dominates (see Figure 1). Although its growth in consumption is, generally, not as
pronounced as that of other modern fuels, one should realize that a decline in the growth
of kerosene consumption generally occurred while there was a simultaneous increase in the
use of other, 'more convenient', fuels such as LPG, natural gas and electricity. However,
at the same time, such a 'decline' masks ongoing penetration of kerosene in other segments of the household sector that were using
woodfuels previously. Kerosene invariably is a household's first modern fuel when it climbs the
energy ladder while LPG in many cases is the second modern fuel which is used only after the
household used kerosene for quite some time. First, kerosene is used as a lighting fuel (in urban
as well as in rural areas) and to ignite the wood or charcoal for cooking, and finally it is used as a
principal cooking fuel.

1.7 In Asia kerosene dominates as the urban household cooking fuel. In Indonesia, kerosene
accounts for over one quarter of petroleum product sales, with about 7 million m3 sold in 1987.
Of this, about 3 million m3, or 40% of total sales, were sold to 93% of urban households. Other
major kerosene users in Asia are India (35% of all urban households), Pakistan (42% of urban
households), and Sri Lanka (30% of urban households).

1.8 In some countries of the Middle East, LPG is making inroads on the position previously
held by kerosene, but the latter still is an important household fuel in countries such as Egypt,
Jordan, Turkey, and Tunisia. In Jordan, for example, kerosene represents 34% of total final energy

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4 See for example the case of Indonesia, Urban Household Energy Strategy Study, vol. 1, Main Report [ESMAP no. 107A/90]
5 Ibid.
6 Leeds; Household Energy In Asia, 1987
end-use by households in 1988. As such it still outpaced LPG which ranked second with 29%.
In Egypt, kerosene was used by 13 million households in 1981, while in Tunisia, 27% of
households used kerosene in 1984.

1.9 In Latin America the use of kerosene for household cooking is by now less widespread than
it was a decade ago and LPG is currently a more important cooking fuel than kerosene. However,
there are quite a few countries where kerosene use is important, such as in Peru, while also in some
Central American countries kerosene still occupies a major position.

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8 VITA: Cooking with Kerosene, 1981.
10 RSMAP: PERU: estudio de lineamientos de Estrategia a Corto y Mediano Plano para el Sector Energético; 1990
Los Alamos National Laboratory, La Situación Energética en Países Centro Americana, 1988
<table>
<thead>
<tr>
<th>Household fuel</th>
<th>LPG</th>
<th>Kerosene</th>
<th>Wood</th>
<th>Charcoal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offline price</td>
<td>world/spot market</td>
<td>same price as LPG</td>
<td>normally to international levels</td>
<td>same as wood</td>
</tr>
<tr>
<td></td>
<td></td>
<td>in Benin, up to 10%</td>
<td>distance transport</td>
<td></td>
</tr>
<tr>
<td>Transport</td>
<td>special tanker</td>
<td>any oil product</td>
<td>anything from a</td>
<td>same as wood</td>
</tr>
<tr>
<td>in bulk</td>
<td>restricted availability</td>
<td>can be carried</td>
<td>barrel to a truck</td>
<td></td>
</tr>
<tr>
<td></td>
<td>higher freight</td>
<td>easily available</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexibility of</td>
<td>low (lack of infrastructure filling stations)</td>
<td>larger, plentiful infrastructure</td>
<td>extremely flexible</td>
<td>across as wood</td>
</tr>
<tr>
<td>supply</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooking and</td>
<td>special installations</td>
<td>anywhere (kitchen technology, existing filling stations)</td>
<td>anywhere, preferably</td>
<td>same as wood under roof</td>
</tr>
<tr>
<td>handling</td>
<td>specially trained personnel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transport by</td>
<td>pressure vessels, more expensive, less flexible</td>
<td>just as gasoline, diesel oil or kerosene fuel, (multi-use equipment)</td>
<td>headload to any vehicle</td>
<td>any vehicle</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Handling at retail</td>
<td>Pressure cylinder filled by the distribution center (all sizes, from 3.6 litres to 12 litres)</td>
<td>Any small tank in the customer's vessel; funnel needed</td>
<td>buy around the corner or on truck</td>
<td>same as wood; small quantities or large quantities</td>
</tr>
<tr>
<td>and in the family</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>size</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equipment needed by</td>
<td>cylinder, pressure regulator, special tubing (expensive, limited lifetime, professional maintenance)</td>
<td>Any bottle, funnel</td>
<td>not needed</td>
<td>none</td>
</tr>
<tr>
<td>the family</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quantity measurement</td>
<td>weighing, deduct empty weight, client cannot check</td>
<td>volume or weighing (can be checked)</td>
<td>negotiating</td>
<td>at best weight or negotiating</td>
</tr>
<tr>
<td>at retailing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retailing on the</td>
<td>difficult (investment, training, safety)</td>
<td>as for charcoal, wood</td>
<td>same as charcoal, wood</td>
<td>same as charcoal, wood</td>
</tr>
<tr>
<td>market</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Danger (business,</td>
<td>Leaks not visible and very dangerous (explosions)</td>
<td>less than gasoline leaks stable</td>
<td>smoke, CO emissions</td>
<td>CO emissions</td>
</tr>
<tr>
<td>family</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Training/information</td>
<td>salesmen and household</td>
<td>salesmen and households (less important)</td>
<td>none</td>
<td>none</td>
</tr>
<tr>
<td>essentials</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Burner/stove</td>
<td>burners on the cylinder, or can be attached with tube</td>
<td>complete unit, either with or pressure type</td>
<td>3 stoves, or low-cost charcoal stove</td>
<td>low-cost charcoal stove</td>
</tr>
<tr>
<td>Ease of use/comfort</td>
<td>very large</td>
<td>lower (sometimes odorous)</td>
<td>smoke, odor, blindness of peas</td>
<td>better control than wood, less than charcoal sometimes lipoed power</td>
</tr>
</tbody>
</table>

Table 2: Comparison of household fuels

1.10 In Africa kerosene is used relatively little by households for cooking purposes. In some countries, however, it plays a significant role. In South Africa, among the black urban population, about 70% of the households use kerosene as a cooking fuel. In Djibouti nearly 100% of the households in the capital city use kerosene as cooking fuel, while in other towns the number of

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11 J. Govea, NFER, The Implication of limited electricity supply to low-income residential areas, Johannesburg, 1989.
households using kerosene vary between 44% and 76%\textsuperscript{12}. Similarly, there is some penetration of kerosene as a household fuel in Nigeria (18% in 1981\textsuperscript{13}, Zaire, and Congo. In other urban areas in Africa (Nairobi, Dar es-Salam) a larger number than the current one (25%) of households would use kerosene as a cooking fuel, if it were accessible and regularly available\textsuperscript{14}. That the switch from biomass fuels to kerosene can happen very rapidly is demonstrated by the case of Ethiopia where within a three year period (1984-87) the households in Addis Ababa changed from having no kerosene stoves to 70% of the households having one. As a result of this switch it is expected that kerosene will be the most important household fuel in urban Ethiopia in the 1990s\textsuperscript{15}. Of course, the situation in Ethiopia is not typical for other African countries. The switch to kerosene as a household fuel was occasioned by the fact that there was an increasing scarcity of traditional household fuels concomitant with rising and wildly fluctuating prices and a switch to low quality fuels such as agricultural waste, twigs and leaves. Expenditure for household fuels increased to one-third of cash income for poor households. In view of this situation consumers adopted a strategy of diversification of fuels for security reasons. The success of the kerosene stoves can be ascribed to the continued accessibility of that fuel on the market, the availability of adequate appliances, and stability of prices for both the fuel and the stove.

1.11 A different inter-fuel switch was also observed in the case of Cape Verde where until 1984, some 60% of urban households used kerosene as their principal household fuel. In 1988 this percentage has dropped to 12% due to a major switch to LPG\textsuperscript{16}. This shows that - on the household level - kerosene and LPG are interchangeable, and that the main determining factor are income levels, availability, and convenience in use.

1.12 Why this attention for kerosene, given the fact that more comfortable and cleaner cooking fuels are available, which also have higher end-use efficiencies. In fact, several African governments make a conscious effort to introduce LPG rather than kerosene, as a preferred urban cooking fuel, even though it is not the most economic solution\textsuperscript{17}. The reason for focussing on kerosene stoves is that kerosene offers in many cases the least-cost solution for household cooking in many countries that start on the road to substitution. It provides the user with a more modern, clean, and efficient cooking fuel compared to charcoal or wood while at the same time, considerable energy savings and

\textsuperscript{12} ABF, \textit{Etude sur les combustibles domestiques dans les districts de Djibouti}, 1986

\textsuperscript{13} ESMAP, \textit{NIGERIA: Issues and Options in the Energy Sector}, 1983

\textsuperscript{14} ESMAP: \textit{Tanzania - Urban Woodfuels Supply Study, Vol 1}, 1987

\textsuperscript{15} ESMAP: \textit{Cooking Efficiency Programme Planning in Ethiopia (CEPPE): Phase I}, 1987. However, this earlier conclusion may no longer hold at present because the earlier, low-cost kerosene supplies from the Soviet Union are no longer available.


\textsuperscript{17} The CILSS countries (Cape Verde, Chad, Burkina Faso, Mali, Mauritania, Niger, Senegal, Guinea-Bissau) with financial assistance from the European Community intend, for example, to make subsidized LPG bottles available to those consumers interested in using LPG, despite the fact that the LPG option is not the least-cost cooking fuel option for these countries.
biomass fuel savings are obtained. After all, kerosene is extensively used as a major cooking fuel in very populous Asian and Latin American countries, where other modern fuels are readily available, and there is no reason to doubt that this cannot be the case for many African countries also.

1.13 In Africa, problems with kerosene as an urban cooking fuel are likely to be end-use oriented and not related to transport and distribution. Attention should therefore be focussed on the stove. Transport and distribution of petroleum products is a well established practice and appears to be relatively efficient: kerosene is used for lighting even in the remotest areas. Storage of kerosene is quite flexible and modern facilities exist parallel to casual facilities like barrels, re-used beer bottles, etc. It thus appears that if the demand for kerosene increases, the existing supply network will be able to meet this demand.

1.14 What do we know about kerosene stoves? The current wick stove technology only dates from 1916. Research on kerosene household devices basically came to a standstill after World War I, after which households in western countries increasingly switched to coalgas, LPG, natural gas and electricity. The state of the art of simple kerosene devices which was depicted in 1937 by a student of the use of oil products (see text box 1), is generally still valid today.

1.15 In view of the fact that more than 1/8 of the world population use kerosene for cooking and/or lighting and that no reliable and modern information on kerosene stoves was available, ESMAP in 1983 asked the Woodburning Stove Group of the Eindhoven University of Technology, which had done much work to put biomass stoves on the scientific map, to test a number of commonly used kerosene stoves to obtain a better understanding of their performance and characteristics. The results of this work were published in September 1985. This report, based on an extensive testing program of 18 kerosene stoves, revealed that most kerosene stoves in use have a rather low maximum power. This, in combination with the measured efficiencies, would result in unduly long cooking times when used for food preparation in, for example, many W. African countries.

Text box 1

"Nowadays people very often speak disparagingly of oil lamps [which are in principle identical to kerosene wick stoves], which are seen to be ridiculously primitive devices, but it is often forgotten that they are the result of painstaking research done half a century ago. Readers who are interested in this matter are recommended to read Stepanoff's book 'Grundlagen der Lampentheorie' (1894) [Principles of Lamp Theory], for which he was rewarded the Nobel prize".

18 This is an observation; nothing is stated here about actual price structures, transporter & retailer margins, etc.


20 Energy Department Paper No. 27. Henceforth cited as ELIP No. 27.
1.16 In Chapter II the comparative advantages of modern fuel stoves are correlated to biomass stoves. In addition, development work on kerosene stoves are highlighted. Finally, the stoves that were tested are discussed in some detail.

1.17 In Chapter III the results of the laboratory work and field tests with high power stoves are discussed and conclusions are drawn with regard to safety and environmental aspects as well as to consumer acceptability of these stoves.

1.18 In Chapter IV the low power stoves are discussed. It is shown that there are quality and safety problems with these stoves. Also, that inexpensive technical improvements can be easily applied in existing stoves. Further, the importance of consumer behavior is highlighted.

1.19 In Chapter V policy and technical conclusions are drawn for operational use.
2. INTRODUCTION

2.1 In the earlier EDP 27 report ESMAP concluded that most kerosene stoves, although relatively efficient, have a low power output. For certain countries - certainly in the Sahel - this is one of the main obstacles to their acceptance. The same report further concluded that stove performance could be enhanced by design and operational improvements. In view of these conclusions, as well as the importance of kerosene as a substitute household fuel, ESMAP continued its activities in the field of kerosene stoves with a view to:

(a) develop a kerosene stove suitable for W. African cooking practices; and

(b) attempt to further improve kerosene stove performance for Asian countries.

The following sections will report on this follow-up ESMAP work and on the results that were obtained, but first, the state of the art of wood and charcoal stoves will briefly be discussed as this is the actual situation before households switch to modern fuels. See Annex II for drawings of most of these stoves.

Wood Stoves

2.2 Wood stoves commonly used in Africa are the three stone open fire, clay or ceramic stoves, or metal stoves. In urban areas, when households use wood, mainly metal stoves are used while in rural areas mostly three stone stoves are used. Table 3 shows the distribution of stove use among 180 wood using households in 3 towns in Niger (1988). Typical retail prices of these stoves range from F.CFA 0 for the 3 stone stove to F.CFA 750 - 1000 for the Malagache and F.CFA 1000 - 2000 for the improved stoves. The median daily wood purchase is approximately F.CFA 150 per household with a traditional stove. Energy savings range from 20% to 30% compared to the traditional metal (Malgache) stove, and more when compared to the 3 stone stove.

Charcoal Stoves

2.3 Charcoal is not commonly utilized in all countries, but there where it is used, the metal Malagache is the most common stove. Improved charcoal stoves exist in many countries, and the


22 Although the traditional stoves for both charcoal and wood are normally referred to as Malagache stove, they are actually quite different. Charcoal stoves invariably employ a grate on which the fuel is burned.
model(s) used vary from country to country. The Sakkanal stove is disseminated in Senegal and Mauritania, or its variant Multi-V3; charcoal use in Burkina Faso and Niger is insignificant and improved charcoal stoves have not been introduced there; in Eastern Africa, there are the Kego Jiko in Kenya, the Rondesza in Rwanda, etc. 22. Improved stoves are typically 2 to 3 times more expensive than the Malgache stove 24. Average daily charcoal expenditures range from F.CFA 200 - 230 per household in Senegal, UM 100 - 130 in Mauritania, F.CFA 225 - 250 in Mali, and FRw 65 - 80 in Rwanda.

LPG Stoves

2.4 Several LPG stoves are found in W. Africa and they may appear under different names in different countries. The most frequently used models in Senegal, Mali, Niger, Cape Verde, and Mauritania are: Blip Banekh, with a 3 kg bottle (Camping Gaz, UM 2200); the Nopalé with a 6 kg bottle (Total, UM 3000); and a Carena with either a 3 or 6 kg bottle (Camping Gaz, UM 2800, bottle extra). In Niger, apart from the Camping Gaz models, the Doré can be found, having a conical, multi-marmite pan support adapted to local cooking practices, using the 6 kg Total gas bottle and a Primus burner.

Need for a Kerosene Stove for African Households

2.5 Several African countries have woodfuel resources which are in a precarious condition. Options to alleviate this pressure are being pursued, including dissemination of improved woodfuel stoves, planting of trees, forest management, and substitution of cooking fuels. When considered on a per meal basis, one can conclude that in general cooking with woodfuels is not the best option: despite improved stoves (which can reduce the cost of cooking up to 30%), cooking with kerosene requires the same or less money, and is more comfortable. This depends of course on the relative pricing levels of the different fuels, but in general it is valid - at least for many of the Sahelian countries. Although improved wood fuel stoves can save up to 30% of the energy used, kerosene and gas stoves could save up to 65% of the energy used for cooking. In terms of wood however, kerosene stoves save much more than the best wood fuel stove ever will save. With that in mind, field tests (as part of Household Energy Strategy development work) were done to identify households' opinion on these issues in several countries.

2.6 Table 4 shows, as an example, the average specific fuel consumption 25 for the preparation of three standard meals in Burkina Faso (white rice with sauce, fried rice with sauce, tô with sauce; a total of 16 kg rice/tô, and 8 kg sauce for each stove). It is demonstrated that the SFC for LPG is the lowest, followed by kerosene, and wood. This test did not include charcoal because it is not


24 The Malgache costs F.CFA 450 - 650 (in 1987) in Senegal; UM 150 - 600 in Mauritania (1988); F.CFA 1000 - 1500 in Mali (1988); and FRw 150 in Rwanda.

25 SFC is defined as the total amount of energy used to cook one kg of food.
used for cooking in Burkina Faso, but would it have been used, the specific fuel consumption would probably have been on the same level as the wood stoves.

2.7 The analysis can be taken one step further, and by calculating the substitution ratios: in this case, one kg of new fuel (LPG, kerosene, charcoal) would replace an amount of x kg of wood in the traditional 3 stone open fire. In this particular case, the improved 3 stone open fire would replace 1.5 kg of wood used in the traditional 3 stone open fire; similarly, 1.6 kg of wood would be replaced with metal woodstoves, and 4.9 and 4.8 kg respectively with kerosene and LPG stoves. Thus, the substitution ratio would be the largest for kerosene.

2.8 Field tests within the context of the Niger household energy strategy project (1986) demonstrated that, for use in a West African country, a wick kerosene stove which has a high power output might offer a suitable alternative for household cooking purposes. One of the kerosene stove models with a moderate to high power output and a high popularity in Indonesia, the Thomas Cup, was tested by households in Niamey and Zinder (Niger). The results of these tests showed that initial perception of the households was quite positive. However, it was found that improvements were necessary on the mechanical and technical aspects of this stove model, in particular its maximum power was too low in comparison to wood and gas stoves, resulting in longer cooking time. In addition, the Asian kerosene stoves tested were not sturdy enough for W. African cooking practices would result in unacceptably short lifetimes.

2.9 Based on households' reactions and the stove technicians' experience, criteria were identified for such a suitable kerosene stove for cooking in W. Africa:

(a) its maximal power output ($P_{\text{max}}$) under W. African climatological conditions should be of the order of 5 kW while the minimal power output ($P_{\text{min}}$) should be less than 1.5 kW; the combustion process should, at all power output levels, be such that the emission level of CO and soot are minimal;

(b) its average efficiency should exceed 40%.

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26 Two types of efficiency are distinguished: $E_{\text{max}}$ - the energy efficiency at maximum power output ($P_{\text{max}}$); and $E_{\text{min}}$ - at minimal power output ($P_{\text{min}}$).
(c) its lifetime should exceed 2 years, even under W. African cooking conditions;

(d) it should be clean, easy to operate and maintain, and it should be safe, esp. for children.

**Development Work on Kerosene Stoves**

2.10 Following the foregoing experience, it was decided to improve/re-design an existing kerosene stove model to overcome these problems. This led to the design of the PET stove, a prototype multi-wick stove, which was developed to obtain higher power levels and a better turn-down ratio than the existing kerosene stoves. The design work was carried out by the Woodburning Stove Group [WSG] of the Eindhoven University of Technology. The additional research and design activities also resulted in a better understanding of the physics of the performance of wicks. Some of the conclusions of this work are:

(a) the kerosene transport capacity of the wicks is not the limiting factor in getting a high maximum power;

(b) the maximum and minimum power levels are determined by the size of the free wick end, and the temperature;

(c) the life time of the wicks can be increased by preventing oxygen approaching the direct vicinity of the wicks; and

(d) the temperature and thus the power can be increased considerably by closing the gap between the outer flame holder and shield.

2.11 This prototype as well as several other models have been field tested, and the results of these tests are presented in the current report. One observes that two relatively distinct classes exist in practice: low-power stoves (which range in power ($P_{\text{max}}$) from approximately 1 kW to 2.2 kW) and high-power stoves (with a range of 2.6 kW to over 5 kW). For the purpose of this report, a $P_{\text{max}}$ of 2.5 kW will be used as cut-off point for the determination of low- and high-power stoves. Although it is realized that this distinction between low and high power stoves is rather arbitrary, the reason for doing so is the following. The majority of kerosene stove users, mainly in Asia, have a stove with a $P_{\text{max}}$ of 2 kW. For their cooking purposes they do not need a more powerful stove. Another group of consumers, mainly in Latin America and the Middle East, prefer stoves with a $P_{\text{max}}$ of more than 2.5 kW, often a pressurized stove.

2.12 Finally, there is a group of consumers which do not as yet use modern fuels, notably in Africa, which finds the 2 kW power range too low. Consequently, their interest in these stoves is

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limited, although these consumers have expressed an interest in the purchase of kerosene stoves which have a power rating higher than 3 kW. It is for this reason that we have made the distinction between low and high power stoves, which is arguably artificial. For one could argue that a good high power stove that has a good turn-down ratio can also be used as a low power stove.

2.13 Ultimately, only the consumer can and will decide what stoves she wants. Some women prefer low power stoves, because this allows them to work on other tasks while cooking. Others prefer high power stoves, because they allow faster cooking. No single stove design may satisfy all users, who will make their choice based on the trade-off between cost and comfort of the stoves available in the market.

A few of the stoves mentioned throughout the report are described in the following paragraphs; their design parameters are included in Annex II.

High power wick stoves

2.14 The PET stove is a prototype wick stove. It has a cylindrical burner with 21 wicks, and a very rigid frame with a conical pan support. The tank capacity is 3 liters or 2.4 kg, which gives 6 hours of full power with a $P_{\text{out}}$ of approximately 4.5 kW to 5 kW.

2.15 The $T^\text{omass Cup 36 (TC}_{36}$ is an Indonesian stove, which has a cylindrical burner with 36 wicks, placed in a frame that serves as a pan support. The wicks are arranged in two concentric circles. These burners can be operated independently from one another. The tank capacity is 4 kg and provides 10 hours of operation at full power of 5 kW. The original design has been adapted for the preparation of W. African food such as tô as well as for the use of spherical pots. Therefore, the supporting structure has been reinforced and the pan support modified. A smaller version also exists, the $T_{20}$ with 20 wicks, and a maximum power of 3 kW.

Low power wick stoves

2.16 It is quite likely that fifty or more different low-power stove models exist in Asian and Latin American countries, often closely resembling one another, either locally produced or imported from China, India, etc, and of a varying quality. It goes beyond the scope of this document to describe all (or even generic) brand names, it suffices to indicate that there are enough choices for the consumer to make a selection. For a description of several stoves, see EDP No. 27, or contact LEMIGAS.

Pressurized stoves

2.17 With regards to pressure stoves, EDP no. 27 [p. 43] concluded that these did not seem to hold much prospect as a big competitor to wick stoves, despite their higher efficiency. Although pressurized stoves perform satisfactorily their operation entails various inconveniences. This is not only clear from laboratory work, but is also confirmed by users such as in Tunisia, for example, who

28 Research and Development Centre for Oil and Gas Technology, Jakarta, Indonesia
complained about the functioning of their currently used pressurized stoves (Canoun) in the following terms:

(a) the difficulty of lighting and controlling the flame;
(b) the stability of the stove;
(c) the complicated maintenance; and
(d) the quality of the stove.

Lighting a pressurized stove is indeed more complicated than lighting a wick stove, and for inexperienced users dangerous moments may occur when the lighting procedure is not precisely followed.

Pressurized stoves also:

(a) require alcohol (or another fuel) for preheating of the burner;
(b) are easily blocked by small impurities in the kerosene (which often cannot be prevented with the prevailing practices to transport, store and handle kerosene); and
(c) seem to offer less prospective opportunities for local production.

2.18 Despite these negative aspects of pressurized stoves, to which should be added their often higher purchase price, many households in quite a few countries use these stoves. ESMAP therefore decided to include these stoves in its field test program, so as to allow the consumer rather than the technician decide which stove would be the desired one. Through the work of Wittkowsky we learnt about the existence of the Superior, a pressure stove manufactured and widely used in Colombia, with a power rating of approximately 5 kW. Based on the available information this stove seemed to meet W. African cooking requirements. The stove therefore was included in the ESMAP testing activities in the Cape Verdes, Mali, Tunisia and Niger.

2.19 The most common high pressure stove is the Primus, which exists in a variety of models with different dimensions, pan supports, power ranges, etc. The fuel reservoir capacity is typically 0.5 liter, while $P_{\text{max}}$ ranges from 1.5 kW to 2.5 kW. Derived models exist also, like the Zeppelin, which is a Primus type burner to which is added a large kerosene reservoir, mounted on a 50 cm high frame; it is used with an external bicycle footpump.

2.20 The Superior looks very much like a gas burning table cooker. The stove consists of a fuel tank with pump, a fuel duct, a gas duct, one or two burners, and a supporting structure. The

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Superior with one burner has a tank capacity of 0.8 liter or 0.6 kg, which gives 1.5 hours of operation at full power; a two-burner model exists as well.
3. HIGH POWER KEROSENE STOVES

3.1 The technical performance of a stove is characterized by: [a] the power output (P); [b] the fuel efficiency (E) at different power outputs; and [c] the ability to control the power output, which can be expressed by the so-called turn-down ratio. In addition to technical performance parameters, there are several other aspects which need to be tested, like safety, ease of use, cleaning and maintenance requirements. To determine these parameters four standardized tests

(a) water boiling tests, which serves to establish $P_{\text{max}}$, $E_{\text{max}}$, $P_{\text{min}}$ and $E_{\text{min}}$

(b) safety tests;

(c) controlled cooking tests to determine the fuel consumption for a standard meal, and

(d) consumer acceptability tests.

3.2 $P_{\text{max}}$ and $E_{\text{max}}$ determine the speed of cooking; the higher these figures, the faster food is heated up. A high $E_{\text{max}}$ results in a lower fuel consumption during the heating up period, but a high $P_{\text{max}}$ increases the fuel consumption; of these two, $E_{\text{max}}$ is the most important factor that determines the fuel consumption. However, for the entire cooking process, the influence of $P_{\text{min}}$ and $E_{\text{min}}$ are more important because normally the heating-up phase is shorter than the simmering phase. During the simmering phase, $P_{\text{min}}$ is the most important factor that determines the fuel consumption. (See EDP No. 27 for more information).

3.3 These tests were carried out within the context of ESMAP's household energy strategy studies in e.g. Burkina Faso, Cape Verde, Mali, Niger, Mauritania, Senegal, and Tunisia. The water boiling tests as carried out in these countries with assistance of local laboratories are similar to those described in EDP No. 27. A pan (filled with water to 2/3 of its capacity) and the stove are weighed and the stove is lit. Water is brought to the boil and kept boiling for 30 minutes, with the stove at $P_{\text{max}}$. The stove and pan are weighed at pre-determined times during this process. Now the power is reduced to the lowest level possible, while the water must remain boiling. This low power phase is continued during 60 minutes, during which the stove and the pan are weighed several times. From the data obtained, the power rating $P_{\text{max}}$ and $P_{\text{min}}$ can be calculated, as well as the efficiencies $E_{\text{max}}$ and $E_{\text{min}}$.

3.4 After completing the water boiling tests, controlled cooking tests and safety tests were carried out. For the controlled cooking tests, the local counterparts provided a recipe for what is considered to be a typical local meal. The cooking was carried out by local women, under close supervision of the stove technician. The purpose of this test is to arrive at an estimation of the fuel consumption, that would be achieved in practice, were any of these stoves actually be used by

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30 In accordance with international standards recorded by VITA.
households in the country. After these series of tests, stoves are finally given to a sample of households which give their feedback on prolonged use of the stoves. The objective of these consumer acceptability tests is to obtain an indication of the stove’s marketability.

**Water Boiling Tests**

3.5 Determination of the power ratings of the stoves mentioned above in paragraphs 2.11-2.14 and 2.17 was done without a pan. The stoves were lighted, and the wicks adjusted so that combustion took place with blue flames. Then the stove was operated during 30 minutes, after which the fuel consumption was established. The minimum power was also measured without a pan during 30 minutes. Initially the wick settings were as used in EDP No. 27 which means that the wicks in the minimum position were level with the top of the wick tubes.

3.6 The results of these tests show that the behavior of the wicks is as described in EDP No. 27 and the maximum power $P_{\text{max}}$ is in accordance with the number of wicks, viz. 150 W/wick. The efficiency is reasonably good at maximum power (45% - 60%). The low power is, in general, not easy to control because often the lever mechanism does not operate well, but also because the flame at low power is not always visible for the operator. As to this aspect it is clear that stoves with a rotating wick control mechanism are easier to control, for the operator tends to manage the fire in such a way that she can still see the flame. Here the advantage of the double wick of the TC becomes evident. In the experiments with the TC only the inner flameholder was used to do the simmering, which permitted easy maintenance of the minimum power level of 1.2 kW or even lower.

3.7 The Superior has been designed to use cocinol (an intermediate product between kerosene and gasoline) as a fuel. Tests in the laboratory as well as in Tunisia and the Cape Verde demonstrated that the Superior performed well with local kerosene, provided the burner was clean and the fuel duct was preheated carefully, although the power output was sometimes lower than maximum value. In Mali, however, it was impossible to light the Superior with kerosene of Malian quality and gasoline was used satisfactorily. The Superior has been tested only recently, and its performance with other fuels than cocinol was not well known. Wittkowsky, in the laboratory had determined its $P_{\text{max}}$ at 5 Kw, while in the Cape Verde [World Bank, Household Energy Strategy Paper, 1990] it was measured at 3.7 Kw, a difference which can likely be explained by the prevailing wind conditions. In Mali [World Bank, Household Energy Strategy Paper 1991], it would not work with kerosene, and it was given gasoline instead which resulted in a $P_{\text{max}}$ of 1.8 kW and an excellent performance. Measurements performed in Niger (May 1990) confirmed the results of earlier laboratory tests: its $P_{\text{max}}$ is on the order of 4.9 kW, while its efficiency ($E_{\text{max}}$) is approximately 48%.

**Safety tests**

3.8 Safety tests were performed to determine whether a stove was safe to use in households. Stability and material strength are two of the factors involved. However, the most important factor is the temperature of the several stove parts and of the kerosene. If the stove parts, such as the control mechanism becomes too hot, the stove cannot be turned down anymore in a convenient way. Kerosene has a flash point above which it can ignite (40.6°C) without flame. If the kerosene
temperature in the reservoir increases, the risk of the reservoir catching fire increases also. Kerosene will start evaporating when it becomes sufficiently warm, making it easy to be lighted at the filler cap or any other spot where kerosene vapor can escape.

3.9 Ignition of pressurized stoves is not always easy and if done incorrectly, it can result in fire hazard. The ignition of the Superior stove was tested in Niger (May 1990), and it was found that the evaporation shaft should be slightly inclined for the kerosene to evaporate correctly (see figure 3). When the shaft is in a declined position, kerosene cannot evaporate and the stove will show difficulties with igniting. Even in the horizontal position these problems may occur. It is therefore necessary that the shaft is positioned correctly, and consumers be made aware of this.

3.10 These safety tests have always been performed in collaboration with a local institution, preferably one with a standing experience on stove testing, such as Onerol in Niger, CERER in Senegal, the BTFA (Base Technique Foyers Améliorés) in Mauritania, the SGS Supertest laboratories in Tunisia, the forestry center (SNF) in Cape Verde, LEMIGAS in Indonesia, etc. An internationally recruited stove technician normally worked in close collaboration with personnel of the institution, establishing testing procedures and training personnel in performing tests and analyzing test data.

Controlled Cooking Tests

3.11 Controlled cooking tests do not give much more information than what could have been deduced from the water boiling tests, although differences between stoves in terms of cooking times, fuel consumption are more pronounced. In addition, it is possible to determine the fuel costs per meal for the different stoves. Table 5 shows an overview of the results of some of these tests in a number of countries.

3.12 The time to prepare a Mauritanian dish, Ceebu Jeen, amounted to between 102 and 104 minutes with the TCm two LPG stoves (Nopalé, Blipe Banekh), and an improved charcoal stove (Sakkalan Multimarmite), and 122 minutes with a traditional charcoal stove (Malgache square), and approximately 112 minutes with a pressurized kerosene stove (Zeppelin) and an LPG stove (Carena). The differences between the LPG stoves and the kerosene stove were most clear in terms of energy use: the kerosene stoves used on average 2.0 MJ/kg of food cooked, while the LPG stoves used 1.6 MJ; the charcoal stoves used 2.0 MJ (improved stoves) and 2.3 MJ (traditional)
respectively. However, in terms of fuel costs \(^\text{31}\), the kerosene stoves used 9.3 UM per meal ($0.12), while the LPG stoves used 14.0 UM ($0.19), and the charcoal stoves 12.5 UM (improved) and 16 UM (traditional).

3.13 In Cape Verde, different stoves were used in the controlled cooking tests and the specific fuel consumption (SFC, per kg of cooked food) was the following: 13.6 MJ for the 3 stone open fire, 7.6 MJ for an improved wood stove, an average of 6.2 MJ for the LPG stoves (Enacol Small, Camping Gaz Feu, Camping Gaz Carena), and on average 6.4 MJ for the kerosene stoves (Lux-1, TC\(_2\), Pet, Sunflower, Zeppelin). In terms of monetary savings, none of the LPG stoves could be cheaper to use than wood stoves, and some of the kerosene stoves could only be marginally cheaper to use than wood stoves.

3.14 The SFC in Cape Verde demonstrates that it depends on the type of meal prepared: in Cape Verde a long simmering period is required, which, in combination with prevailing wind conditions, result in an SFC which is substantially higher than in other countries.

3.15 In Senegal, Ceebu Jèn was prepared on wood, charcoal, LPG and kerosene stoves. The SFC for the different stoves in this case was: 3 stone open fire: 3.7 MJ per kg of food prepared; Sakkanel wood stove: 3.1 MJ; average for charcoal stoves 2.1 MJ; average for kerosene stoves: 2.4 MJ; average for LPG stoves 1.9 MJ.

3.16 In Indonesia, Chap Choi (chicken) was prepared on kerosene and LPG stoves. The SFC was shown to be a linear function of the stove's \(P_{\text{net}}\) with an average value for all kerosene stoves tested of 4.4 MJ, and 3.3 MJ for LPG stoves.

3.17 The following four conclusions regarding the specific fuel consumption can be drawn, even though different types of meals were prepared:

(a) the SFC for stoves using woodfuels is generally higher than for those using modern fuels;

\(^{31}\) Both fuels are not subsidized.
(b) the difference in SFC between improved stoves and traditional stoves is quite significant (both for charcoal and wood);

(c) the SFC for wood stoves is higher than for charcoal stoves; and

(d) the SFC for kerosene stoves is approximately 20% higher than for LPG stoves.

Two remarks need to be made, regarding (c): if calculating the SFC in terms of primary energy, the SFC figure for charcoal stoves needs to be multiplied by approximately 5; this means that the SFC for charcoal stoves is much higher than that for wood stoves, reflecting the inefficiency of charcoal production; and regarding (d): the SFC difference between LPG and kerosene stoves is in accordance with the theoretical expectation: LPG stoves are approximately 20% more efficient than kerosene stoves, and the difference of the calorific value of both fuels is almost the same.

Consumer Acceptability Tests

3.18 The stoves were also submitted to a consumer acceptability survey in a number of W. African countries such as Cape Verde, Mauritania, Mali, Burkina Faso and Niger. The standard method was to invite a number of households to cook their meals with the stove during one week. Prior to this, it was adapted to the shape of the spherical cooking pots, while the support system was reinforced to allow the preparation of local foods such as tô, that require heavy stirring. Also, the women were shown how to use the stoves safely and efficiently. In addition, the maintenance requirements were explained, and each participating household received a quantity of kerosene sufficient for 2 to 3 days. During the test period, the households were visited by a surveyor and a technician each day. Observations were noted and technical problems, if any, were solved. After the test week the women were debriefed as to their reactions and the differences in perception, if any, were noted with those prior to the test week.

3.19 In Burkina Faso the participating households unanimously accepted the TC₃₆ stove, and the following conclusions were drawn:

(a) the stove is stable and suitable for use with various sizes of pots;

(b) it is easy to ignite and smokeless;

(c) it is rather sensitive to wind; and

(d) the wicks wear out rather quickly.

3.20 The same result was obtained in other W. African countries such as Mauritania, where the introduction of low power kerosene stoves in 1973 had met with adverse consumer reaction. In 1988, thirteen households in Nouakchott were given an adapted Thomas Cup, a PET stove, or a pressurized stove to be used for one week. During that time the stoves were used for food
preparation at least twice daily. The women using the stoves had no complaints about safety, inconvenience, taste difference, smell, etc. In fact, they were quite pleased with the stoves and would have liked to keep them, irrespective of the type of kerosene stove they had used. The same conclusions could be drawn from cooking demonstrations, where a total of 120 women participated: kerosene stoves should be considered as alternatives to LPG stoves, for they perform comparable to LPG stoves, but at a lower cost. Unfortunately for them, high power kerosene stoves are not available on the market in Mauritania.

3.21 However, the PET stove which performed well in the laboratory, encountered several technical problems during tests in Burkina Faso and Niger (1988-89), particularly increasing temperatures in the kerosene reservoir and a power drop while operating in high ambient temperatures. In Niger (1989), 180 kerosene stoves (PET stove) were used by households in three cities (Niamey, Zinder, and Maradi) during the period of one week while these households were visited every day. The reactions have been very positive and some of the most interesting results are presented below:

(a) 85% found that kerosene stoves were easy to light, and that they started quickly;

(b) 89% of the sample appreciated its kerosene stove, 94% said that they could use it for all their cooking needs, and 65% indicated that they did not need to use it outdoors like they are used to do with their woodfuel stove;

(c) 41% indicated that the cooking times were reduced;

(d) 88% indicated that the stoves did not smoke;

(e) with the use of kerosene stoves, households indicated that they could reduce the need to clean the outside of their pots and pans (70% needed to clean once a week with their old stove and 9% twice a week, whereas this is 0% for once a week and 57% for twice a week with kerosene stoves); and

(f) 94% of the households indicated that the taste of the food was not affected by the kerosene stove.

3.22 After three months of usage, it appeared that only 66% of the stoves still remained in working condition, while the rest broke down for one reason or another. From the technical point of view, the stoves were not yet good enough for a wide-scale dissemination, even though households clearly liked them and were interested in using them. In other words, households showed their willingness to switch to kerosene for cooking, even though a suitable stove did not yet exist.
3.23 The PET stove, despite further improvements made during the field tests which overcame these obstacles, did not reach a sufficient stage of development to warrant dissemination. Nevertheless, some consumers indicated that they were willing to buy and use this stove in the absence of a better alternative. The PET stove as tested in Cape Verde had a higher power output (comparable to LPG stoves existing on the market in Cape Verde) and was better protected from the wind than any other kerosene stove tested, and households indicated that they preferred it over the other models, despite its shortcomings. Existing stoves on the market in Cape Verde include a variety of LPG stoves and kerosene stoves. However, these kerosene stoves have a very low power output, and they have lost their market share following the widespread introduction of LPG stoves.

3.24 The TC\textsubscript{26} fared better than the PET stove. After strengthening of the frame of the stove, the TC\textsubscript{26} proved to be not only better (from the operational and energy points of view) than the PET stove, but also that it could be considered for dissemination. Although the TC\textsubscript{26} still does not meet all of the criteria for a good stove for W. African households (see §2.9), its performance is sufficiently reliable to warrant large scale consumer acceptability tests. Its main drawback is that the TC\textsubscript{26} only reaches high power levels at the expense of the stove’s fuel economy.

3.25 Although the Superior arrived too late in Cape Verde to be field tested under ESMAP supervision, the Forestry Department agreed to distribute the stoves and monitor consumer satisfaction on a monthly basis. Although no technical feedback was obtained this way we nevertheless learnt that lighting the stove sometimes caused problems. We also learnt that the users were generally pleased with the stove’s performance. It proved to be much sturdier than the other kerosene stoves, while its power output was valued sufficiently high for existing cooking practices.

3.26 A similar reaction was obtained in Tunisia in 1989. During a stove acceptability demonstration in Ain Draham (N.W. Tunisia), in which 50 women participated, the Superior, as compared with the LPG stove, was considered to:

(a) have better stability;

(b) be safer;

(c) be portable, which the LPG stove is not;

(d) to have a higher maximum power, that allows for faster cooking.

In addition, they stated that kerosene was always available while LPG is not, making it a strong argument for its use under Tunisian conditions.

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\textsuperscript{23} P. Busmann and P. Visser, \textit{Improving the PET Kerosene Wick Stove}, Biomass Technology Group, Enschede, January 1988 (Internal report to ESMAP).
Environmental Considerations

3.27 Because most kerosene stoves are sensitive to the wind, they are usually used indoors. Therefore, it is important to determine their safety with respect to the combustion quality and especially concerning the production of carbon monoxide (CO). Tests were carried out on the Thomas Cup in Burkina Faso 33 and showed that the stove's CO emissions are low, as its Index of Toxicity (IT) 34 was only 0.31. European standards require an IT value of about 1.2 for kerosene stoves. Thus, it may be concluded that the Thomas Cup can be considered as safe with respect to the production of CO. Similar results were measured for the experimental so-called 'REDI' stove, where a value of 0.2 was reached 35.

3.28 Gas leakages (Methane, Butane) are detrimental to the environment in that they increase the greenhouse effect. Compared to CO emission, methane is a factor of more than 10 times more detrimental and it is therefore imperative to minimize possible leaks. Most of the LPG stoves leaked gas from time to time mainly as a result of operator errors (when connecting the reservoir to the burner, forgetting to ignite immediately the burner, etc), which cannot happen with kerosene stoves. The chance of such leakage occurring exist with pressurized stoves, but only if these are not sufficiently supervised. In both cases, the occurrence can be minimalized through operator education.

3.29 Additional environmental problems with kerosene stoves may occur when the reservoirs are not correctly filled and/or the stoves are not properly cleaned, and kerosene may spill on the ground. However, the user acceptance surveys did not indicate a problem but if occurring, it could be solved relatively easy through operator education.

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33 Evaluation of Wood Stoves, Gas and Kerosene Stoves in Burkina Faso; Feb. 88; Consultant's Report.

34 The Index of Toxicity is an indication for the toxicity of the combustion gases and is defined as the ratio of the measured percentages of carbon monoxide and carbon dioxide, multiplied by a factor of 100.

4. LOW POWER KEROSENE STOVES

4.1 As mentioned before, most low power kerosene stoves are found in Asia. Past work on testing kerosene stoves in Indonesia had already yielded information about the characteristics of the types available in the market. Most stoves are of the low power, multi wick type, and have a comparable basic design. But these apparently similar stoves with minor differences cause the performance to differ widely. Fires due to exploding stoves are not uncommon and can be prevented by better designs. Past tests also reveal the existence of a wide range both in power and efficiency, resulting in a wide variation in their fuel consumption. These results suggest that a large scope for improvements exist. In EDP No. 27 a first attempt was made to link design features to performance for 20 stoves from all over the world. In its work in Indonesia ESMAP aimed to extend the insights gained in the earlier report into the determinants of the performance of Indonesian stoves as a kind of pars pro toto for similar low power wick kerosene stoves.

4.2 Lemigas, the Indonesian Gas Research Institute, conducted extensive tests for ESMAP on the performance of 18 kerosene stoves found on the market in Jakarta. The work consisted of a detailed description of the stoves followed by a series of tests: power rating tests, efficiency tests, fuel consumption tests, and safety tests. However, as will be explained later, of the 18 kerosene stoves tested in detail, 11 did not pass the Indonesian standard SII 0135-76 which is based on the British Industrial Standard.

Water Boiling Tests

4.3 These tests (see Chapter 3.) showed that the maximum power of the stoves tested in Indonesia ranged from 1.0 kW - 2.0 kW and from 3.0 - 3.3 kW. Higher power stoves exist, but are rarely used in households; the majority of households use the low-power stoves. It turned out difficult to find a stove with a power between 2 and 3 kW. The minimum power levels of some stoves were high compared with the maximum power rating, and therefore an alternative wick setting was applied, viz. the wicks entered the wick tubes when the lever was placed in the lowest position. If the wicks would be turned lower combustion would not continue between the flame holder, but only near the wicks at the top of the wick tubes, while the flames would still be stable. The minimum power ranged from 0.2 kW to 1.9 kW, which resulted in turn down ratios ranging from 1.0 to over 4.0.

4.4 Efficiencies of the stoves varied from 33% up to 51% as measured repeatedly through water boiling tests. It was striking that no relation existed between the price or the brand name nor the type of producer (factory or artisan) and efficiency. This means that neither manufacturers nor consumers are able to identify high efficiency stoves.

4.5 To better understand the results from these efficiency measurements, the efficiency was plotted against the power output of the stove (Figure 4), and the ratio between pan and burner

See: Annex 3; Tests and Evaluation of Kerosene and LPG Stoves; Sept 1988; Lemigas (Indonesia).
diameter of the outer flameholder (Figure 7). As is shown in these figures, the efficiency of the stove is higher when the power output is lower, as well as when the burner is more compact compared with the pan diameter. The influence of using a larger pan on the efficiency of a stove was already shown in 37, but that in addition small burners should be preferred is a new finding. A compact burner means that the wick surface is small, resulting in low power levels of the stove. However, when combined with higher efficiencies this low power rating does not necessarily mean longer cooking times for the same amount of food.

Safety tests

4.6 The safety tests established the temperature of the several stove parts, during a testing period of five hours. To that end, each stove was lighted with an almost full reservoir; the tests were stopped after five hours or if only 10% of the initial kerosene was left. Every hour the temperatures and weight of the stove was registered. According to Indonesian standards (SII 0135-76) the temperature of the reservoir when 10% of the kerosene is left should be maximum 50°C. The temperature of most stove parts regularly touched by the operator should be maximum 80°C, and the remainder of the stove's surface (excluding the burner) should be maximum 94°C.

4.7 Temperatures of 18 wick stoves were measured and it was shown that a majority of the stoves did not comply with the quality standard: the temperature of 50% of these stoves in the reservoir was in excess of the flash point, and 10% of the stoves had often touched parts with temperatures in excess of 80°C. Consequently, it was recommended to construct a heat shield to reduce the temperature of the reservoir.

4.8 As far as other safety aspects are concerned, such as reservoir construction and thickness of metal or stability when slanted at 15%, the stoves showed better results. In all these aspects the stoves passed the test.

Controlled cooking tests

4.9 The results of the controlled cooking tests shown in Table 6 demonstrate that using a high power stove can lead to considerably higher levels of fuel use, even for stoves with the same efficiency. They also demonstrate the potential fuel savings which could be obtained from turning the stove power down during selected cooking operations, and from minimizing the water used for rice steaming.

Figure 4: Relation between power output and efficiency of stove

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4.10 In figure 5 the specific fuel consumption (SFC) is plotted as a function of the power of the stove. The SFC increases with an enlargement of the power output. In Figure 6 the time required for the cooking of a standard meal is presented. Less time is needed to cook when the power of the stove is increased. These relations can be explained as follows. The preparation of the rice consists for about 50% of the time of heating up and 50% of steaming. The duration of the heating up period is directly influenced by the efficiency \([P_{\text{max}}]\) and \([E_{\text{max}}]\) of the stove, i.e. the higher \([P_{\text{max}}]\) and \([E_{\text{max}}]\) are the shorter this period will last.

<table>
<thead>
<tr>
<th>Stoves</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFC (MJ/kg)</td>
<td>3.3</td>
<td>3.6</td>
<td>3.8</td>
<td>4.1</td>
<td>4.2</td>
<td>4.6</td>
</tr>
<tr>
<td>Energy Consumption (MJ)</td>
<td>11.0</td>
<td>7.8</td>
<td>9.6</td>
<td>11.3</td>
<td>13.6</td>
<td>9.7</td>
</tr>
<tr>
<td>Raw Food (g)</td>
<td>1670</td>
<td>1635</td>
<td>1536</td>
<td>1536</td>
<td>1568</td>
<td>1817</td>
</tr>
<tr>
<td>Cooked Food</td>
<td>2200</td>
<td>2065</td>
<td>2304</td>
<td>2114</td>
<td>2440</td>
<td>1975</td>
</tr>
<tr>
<td>SFC = Raw</td>
<td>0.7</td>
<td>0.9</td>
<td>0.5</td>
<td>0.7</td>
<td>0.6</td>
<td>0.0</td>
</tr>
<tr>
<td>SFC = Cooked</td>
<td>0.4</td>
<td>0.2</td>
<td>0.3</td>
<td>0.4</td>
<td>0.6</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Table 6:

4.11 The efficiencies obtained during the water boiling tests showed less variation than the power levels. Therefore, we may conclude that the most important factor that influences the duration of the heating up period is \([P_{\text{max}}]\) of the stove. The more power is used, the faster the heating up period is completed. The simmer period is constant for all meals. If this is done with a lower power than \([P_{\text{max}}]\) less fuel is used. These results were confirmed for both the entire standard meal and the cooking process as well as for rice only.

4.12 The use of stoves with high efficiency does not necessarily mean that less fuel is used. Stove VI, with an efficiency of 30%, does not significantly use more fuel for the entire cooking task than stove III, which has an efficiency of 51%. This is partly due to the variation in consumer behavior, specifically, to the amount of water used. The water left over with stove VI is much more than the water left over with stove III. Also, the amount of cooked rice is larger with stove VI than
with stove VI. The amount of uncooked rice was identical, however. This illustrates the difficulties encountered with comparing water boiling and controlled cooking tests.

**Consumer Acceptability Tests**

4.13 There were no specific studies done which tested the consumer acceptability of kerosene stoves in Indonesia because cooking with kerosene is a normally accepted practice. All of the kerosene stoves considered in this report are in actual use, even though for example, 60% of the stoves failed the laboratory safety tests.

**Theoretical Model of Time and Fuel Savings**

4.14 A model of household cooking and water heating was developed showing how different factors affect daily kerosene consumption for a typical household starting with a typical stove. The results of a sensitivity analysis using this model are shown in Table 7. Looking at the stove perforce alone, roughly 1/3 of kerosene consumption depends on efficiency and roughly 1/3 on power (the rest being unexplained: consumer behavior). This implies, for example, that if efficiency increases by 30%, kerosene consumption will decrease by 10%, and cooking time will decrease somewhat. However, if this efficiency increase is accompanied by a power decline of 30% (leaving the power delivered to the pan roughly constant), kerosene consumption will decrease by 20%, and cooking times will not have altered.

4.15 The two more user-dependent factors, stove power adjustment while cooking, and the quantity of water employed for steaming rice, were also modeled. If power is decreased by two-thirds during both water simmering and rice steaming after the water has already been brought to boil), the households daily kerosene use would fall by about 10%. Alternatively, if the amount of water used for steaming rice is decreased from 1.3 to 0.3 liters, a 4% of the daily kerosene use could be saved.

4.16 Savings of roughly 25% in kerosene consumption can be achieved by combining efficiency improvements and maximum power reduction with a better turn-down ratio and the use of less water for rice steaming. Specifically, this would involve a decline in maximum power from 2.0 to
1.5 kW, and an increase of efficiency from 41% to 45%, turning the stove to half-power during simmering and steaming, and decreasing the water amount used for steaming rice to 0.3 liters. These actions have no implications for the user other than knowing what to do, and when to do this.

**Stove modifications**

4.17 Given the amount of time available, the study concentrated on the two most important factors in stove performance, viz. safety and efficiency. The efficiency was relatively low for a number of stoves, which is something that can be improved. Of the safety aspects the temperature of the kerosene in the tank is the most important, particularly when the stove is used for a long time. From earlier tests on kerosene stoves, it was known that the distance between the pan and flameholder has a big influence on efficiency 30. Therefore this aspect is not further discussed here.

![Table 7: Time and fuel saving options](image)

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30 P. Visser, Stoves for fuelwood and charcoal substitution, June 1987 (Senegal, internal ESMA report).
4.18 The two aspects considered were an air flow restrictor and an adjustable pan support. It is shown that the air flow restrictor can improve the efficiency with 5% to 15%, while adjusting the pan support position can improve the efficiency with up to 25%.

Flow restriction

4.19 Air flow through a kerosene stove is required for the combustion of the kerosene vapor. Therefore air has to enter the combustion zone via the shield and the outer flame holder, and the inner flame holder. If too much air is drawn into the stove via the inner flame holder, relatively more air will escape via the hole in the top of this flame holder. This will result in a wider flame plume above the stove and consequently the efficiency will be lower.

4.20 The efficiency is also influenced by the temperature of the gases leaving the stove. The average temperature of the gases will be lower if more air is pumped through the stove. It is clear that the air which goes to the inner flame holder, which is closer to the pan, is more important in this respect than the air going through the outer flame holder. A way to reduce the flow through the inner flame holder is by placing a flow restriction at the bottom of the flame holder (or at the top of the wick holder). Two complete and elaborate test series on the influence on the efficiency of a stove with and without a flow restriction were carried out with the Dua Saudara stove. The original design, which did not have any flow resistance at all in the inner flame holder, was modified with a zinc plated metal sheet in which holes were drilled. The net result was an increase in efficiency as a result of the flow restriction. The PET stove also had such a restrictor in its design.

4.21 Another important result from these tests with and without flow restriction is the reduction of the temperature of the kerosene in the reservoir. The flow restriction acts as a radiation shield between the hot inner flame holder and the top of the tank and the wick pipes. Other modifications that were tested during the Lemigas work (adding wood insulation beneath the wickholder plate; adding a restrictor and holes in the shield) did not result in any significant influence on efficiency or safety 39.

Pan support

4.22 Six of the tested kerosene stoves had a pan support which was constructed of metal and was placed on top of the stove. Some pan supports are fixed (of stoves procured by artisans), whilst others are not. The movable pan support has two positions. One is the ‘pan’ position where the welded circles of the support are above the joiner iron. The other is the so-called ‘wok’ position, because its purpose is to provide extra supports for the use of a wok, where the welded circles are beneath the joiner iron. This means that in case of the ‘pan’ position the pan rests on the ring, while in case of the ‘wok’ position the pan does not and sinks deeper into the stove.

4.23 The efficiency tests showed that where pots had been standing on the ‘pan’ position that the measured efficiencies were significantly lower than those in ‘wok’ position. When on the same stove

39 Lemigas, pp. 61-64.
the pan support was reversed from 'pan' position to 'wok' position there was an increase in efficiency ranging from 10% to 25% 40. There are many more stoves than were tested, thus no real quantified dimensions of the changes in construction could be given. However, for each stove type these dimensions can be determined separately.

4.24 These two simple changes would have a significant effect on kerosene consumption if adopted. Furthermore, they were uncovered in a relatively short time: it is likely that similar savings could be obtained from other design changes or, for example, changing the quality of the wicks used 41. A program to improve the quality of kerosene stoves can be expected to produce a variety of kerosene saving possibilities during the course of its work, especially if sufficient attention is given to applied research (as opposed to simply enforcing standards, for example).

4.25 Both factory and artisanal stove production are amenable to the modifications identified during the course of this study. Factories, being both larger and having more ready access to capital, are a more obvious target. Even the smallest artisanal producer should, however, be able to add a flow restrictor and produce stoves with efficient movable pan supports, and some even do already.

4.26 Materials are the major cost item for both factories and artisans. For artisans, reliability of material supply is also crucial. This could provide an opportunity for government assistance, linked to a stove improvement program 42. In addition, factory production, being more standardized and easily accessible, could be affected through official stove standards. But the same could also hold for part of the artisanal producers, a major part of whom are often clustered in one area, sometimes making the same model of stove.

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40 All changes in efficiency are relative changes: a 10% efficiency increase means changing from, say, 40% to 44%, etc.

41 Bussmann & Visser 1988, p. 8-10 discuss how wicks can be better protected against rapid decay by applying extra rings around the bottom of the flame holder and the wickholder. Also, by giving the wick a protection of a glass fibre collar.

5. CONCLUSIONS

5.1 In the preceding chapters we have reported on the results of field and laboratory tests of kerosene stoves in Indonesia and W. Africa. The analysis shows that there are simple, but important, technical possibilities to improve the quality of existing stoves. Also, that, if adapted, there are kerosene stoves that can be marketed in those parts of W. Africa where until now kerosene stoves have been rejected by the market as an alternative to cooking with wood or charcoal. Furthermore, that there are still non-technical obstacles that need to be overcome to make use of these findings. The challenge for policy makers in the developing world is to translate these technical and economic opportunities into successful stove programs.

5.2 The tests focussed on low power stoves (<2.5 kW) and high power stoves (>2.5 kW). Power and efficiency varied considerably among the low power stoves. Both consumers and manufacturers are ignorant of the stoves' fuel economy, and neither group can ascertain this through physical inspection. The high power stoves were both wick and pressurized stoves. Here also there is a difference in power and efficiency, and especially in the turn-down ratio.

5.3 The report confirms earlier findings that the determinants of fuel economy are (a) maximum power \( P_{\text{max}} \), (b) the ratio between \( P_{\text{max}} \) and \( P_{\text{out}} \) the so-called turn down ratio, and (c) fuel efficiencies \( E_{\text{max}} \) and \( E_{\text{out}} \). In addition, the report illustrates the importance of (d) consumer behavior, as a determinant of fuel economy.

5.4 In case of low power stoves the report concludes that, above all, there is a need for a program of standards and endorsements with accompanying support for the improvement of the manufacturing of kerosene stoves. In addition, only minor and inexpensive technical changes would be called for. The case of high power stoves is less straightforward. The TC\(_{26}\) wick stove, with adaptations, has been shown to be a marketable product that meets with consumer satisfaction. The Superior, a pressurized stove, only performed satisfactorily and met with consumer satisfaction in Tunisia and Cape Verde. Additional, more elaborate, market studies are required to confirm this and provide consumer's feedback. However, elsewhere in W. Africa fuel problems bedeviled the smooth performance of the Superior. Therefore, more work is needed to identify whether the problem here is fuel related or a design flaw.

5.5 In operational terms the following policy-relevant conclusions can be drawn:

(a) It would be desirable to initiate a stove manufacturing quality control program. Such a program should have two components. One for factory produced stoves (both imported and local ones) which will emphasize standards and endorsements. The other for artisanally produced stoves which require direct support in improving their production process. Factories are more amenable to standards and endorsements, and produce on a larger scale. Artisans are not easily amenable to standards. The program, therefore, should be initially be limited to large groups of artisans, who may already be involved in government supported activities;
(b) Programs should be undertaken to increase consumer awareness and solicit consumer participation in the kerosene conservation program. Without pressure from consumers it will be very difficult to convince producers to improve stove quality. Standards and endorsements must be understood by the consumers as well as producers, so that consumers can assess the costs of purchasing a sub-standard stove. Simultaneously, the knowledge and preference of consumers (or their representatives) must be tapped to insure that the standard program is appropriate to their needs; and

(c) Finally, consumers should be made aware that a fuel efficient stove can only realize its potential if it is used properly. User dependent factors such as using the turn-down ratio and the quantity of water used for cooking can considerably effect fuel economy. Consumers, therefore, should have access to information about how to cook more economically.

6. In addition, the following technical conclusions are submitted:

(a) the TC26 is a good stove for those consumers who prefer a high power stove. The Superior, although it got good marks from women in two countries, still suffers from technical problems which adversely effected its performance. These problems are most likely fuel related, because in Columbia this stove performs well when used with cocinol;

(b) there is a need to create an after-sales service for the repair and maintenance of kerosene stoves in those countries where Governments or private sector organizations intend to launch large-scale kerosene stove promotion schemes. The creation of such a service need not be expensive if one makes use of existing repair facilities who will participate in the promotion schemes, attracted by the prospect of new customers;

(c) additional applied research is required as an integral part of a kerosene stove program. This research should be undertaken by a single research center with information dissemination to interested national or international private sector groups or NGOs. This research should be aimed at making incremental improvements such as improving the flame control mechanism of kerosene stoves, the effect of different quality of wicks on stove performance, and the fuel parameters for a better performance of the Superior stove; and

(d) finally, as the tests for specific fuel consumption have demonstrated, kerosene stoves can be quite competitive with LPG stoves. Further improvements in the quality of kerosene stoves (better quality wicks, better flame control mechanism) will supply the finishing touch.
Annex I: Financial Comparison of Different Alternatives for Cooking

In this Annex, different cooking options are compared from the end-user's point of view. It is assumed that the user's diet is not a function of the fuel used (which probably is an over-simplification), and that each option uses a similar amount of end-use energy (approximately 22 MJ/person/day).

In this analysis, actual 1990 retail prices are used from W. African countries as published in [1]. See a summary Table A1.1 below:

### Table A1.1: 1990 FUEL PRICES IN WEST AFRICAN COUNTRIES

<table>
<thead>
<tr>
<th></th>
<th>Burkina</th>
<th>Mali</th>
<th>Mauritania</th>
<th>Niger</th>
<th>Senegal</th>
<th>Chad average</th>
</tr>
</thead>
<tbody>
<tr>
<td>wood</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>charcoal</td>
<td>45</td>
<td>50</td>
<td>123</td>
<td>60</td>
<td>60</td>
<td>68</td>
</tr>
<tr>
<td>kerosene</td>
<td>200</td>
<td>300</td>
<td>96</td>
<td>131</td>
<td>231</td>
<td>250</td>
</tr>
<tr>
<td>LPG</td>
<td>250</td>
<td>314</td>
<td>172</td>
<td>308</td>
<td>220</td>
<td>509</td>
</tr>
</tbody>
</table>

It is clear that kerosene and LPG prices vary quite a lot between the different countries. LPG is on average 50% more expensive than kerosene which can partly be explained by the higher costs for LPG distribution than for kerosene, and partly by the fact that kerosene is generally less taxed than LPG. In any event, in the analysis we look at financial rather than economic costs since we are looking at the end-user level rather than at the national economy level. If an economic analysis were done, the difference would be that the costs of wood would be higher than is reflected by financial costs (reflecting resource value + replacement costs) and consequently, this also holds for charcoal.

The following Table A1.2 shows the fuel characteristics, taking average retail prices from the previous Table A1.1.

### Table A1.2: FUEL CHARACTERISTICS

<table>
<thead>
<tr>
<th></th>
<th>retail price F.CFA/kg</th>
<th>USS/kg</th>
<th>MJ/kg</th>
<th>US$/kg</th>
<th>US$/kJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>wood</td>
<td>20</td>
<td>61</td>
<td>19</td>
<td>0.06</td>
<td>3.19</td>
</tr>
<tr>
<td>charcoal</td>
<td>68</td>
<td>205</td>
<td>31.0</td>
<td>0.20</td>
<td>6.61</td>
</tr>
<tr>
<td>kerosene</td>
<td>201</td>
<td>610</td>
<td>43.5</td>
<td>0.61</td>
<td>14.03</td>
</tr>
<tr>
<td>LPG</td>
<td>296</td>
<td>895</td>
<td>45.7</td>
<td>0.90</td>
<td>19.59</td>
</tr>
</tbody>
</table>

1) conversion factor used: 0.8 kg = 1 liter

Table A1.3 shows investment costs for the different stoves, their energy efficiencies and expected average lifetime, and annualized equipment costs.
Table A1.3: STOVE CHARACTERISTICS

<table>
<thead>
<tr>
<th></th>
<th>costs US$</th>
<th>energy eff.</th>
<th>life annuity $/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>wood tr</td>
<td>3</td>
<td>15%</td>
<td>1</td>
</tr>
<tr>
<td>wood lmp</td>
<td>6</td>
<td>25%</td>
<td>1.5</td>
</tr>
<tr>
<td>charcoal tr</td>
<td>9</td>
<td>22%</td>
<td>1</td>
</tr>
<tr>
<td>charcoal lmp</td>
<td>12</td>
<td>35%</td>
<td>1.5</td>
</tr>
<tr>
<td>kerosene</td>
<td>18</td>
<td>45%</td>
<td>4</td>
</tr>
<tr>
<td>lpg</td>
<td>35</td>
<td>55%</td>
<td>5</td>
</tr>
</tbody>
</table>

Table A1.4 combines all data from the previous three tables, and shows the total annual cost of the different cooking options available to households. It also gives data for daily fuel use, primary energy use, and cash expenditures. The analysis shows that (i) annual stove costs are less than 5% of the total annual cooking fuel bill (excluding food); and (ii) (improved) biomass stoves provide the cheapest option, although kerosene is of the same order of magnitude as charcoal with a traditional stove (See Graph A1.1).

It must be said however, that the situation changes drastically with the relative fuel price structures in each country, see Graphs A1.2 (Mauritania) and A1.3 (Niger), which show that kerosene is the most cost effective option for Mauritania, and improved wood stoves is the best cost effective option for Niger.

Table A1.4: ANNUAL COSTS FOR COOKING

<table>
<thead>
<tr>
<th></th>
<th>kg/day</th>
<th>Nj/day</th>
<th>US$/day</th>
<th>costs per year ---</th>
<th>1/</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>stove</td>
<td>fuel</td>
</tr>
<tr>
<td>wood tr</td>
<td>7.9</td>
<td>150</td>
<td>0.68</td>
<td>3.3</td>
<td>175</td>
</tr>
<tr>
<td>wood lmp</td>
<td>4.2</td>
<td>80</td>
<td>0.26</td>
<td>4.3</td>
<td>94</td>
</tr>
<tr>
<td>charcoal tr</td>
<td>3.3</td>
<td>418</td>
<td>0.68</td>
<td>5.5</td>
<td>247</td>
</tr>
<tr>
<td>charcoal lmp</td>
<td>2.1</td>
<td>263</td>
<td>0.62</td>
<td>9.0</td>
<td>195</td>
</tr>
<tr>
<td>kerosene</td>
<td>1.1</td>
<td>50</td>
<td>0.70</td>
<td>5.7</td>
<td>256</td>
</tr>
<tr>
<td>lpg</td>
<td>0.9</td>
<td>41</td>
<td>0.80</td>
<td>9.2</td>
<td>293</td>
</tr>
</tbody>
</table>

1/ In primary energy terms; carbonization efficiency = 15%.
FIGURE 8
BREAKDOWN OF TOTAL ANNUAL COOKING COST
FUEL + EQUIPMENT

US$/year

wood tr  wood impr  charcoal tr  charcoal impr  kerosene  lpg

stove models

fuel  equipment
FIGURE 9
BREAKDOWN OF TOTAL ANNUAL COOKING COST
FUEL + EQUIPMENT (Mauritania)

FIGURE 10
BREAKDOWN OF TOTAL ANNUAL COOKING COST
FUEL + EQUIPMENT (Niger)
Annex II Testing of Pressurized Stoves

1. In vapor jet burners, kerosene is available at higher than atmospheric pressure which is achieved by a hermetically sealed fuel container which is brought to pressure with a small hand-pump. Because of the pressure difference, the kerosene rises and arrives in the hot vaporizer where it evaporates and leaves through a small nozzle in a high velocity jet. In the free space between the nozzle and the flame holder/stabilizer, the jet mixes with air which enables the gas mixture to burn with a blue flame.

2. Details depicting best performance of pressurized burners are given in Table A2.1.

The Pump

3. The power output of a vapor jet burner is a function of the nozzle diameter, the vapor temperature and the pressure difference. Therefore, it is important that the pressure can be easily build-up as well as easily be controlled. Most of the handpumps which came with the stoves showed a poor performance. Because bicycle pumps sometimes have a better performance than hand pumps, in Indonesia one can often see a bicycle pump connected to the stove.

The nozzles

4. The quality of the nozzles appeared to be extremely important both for the performance and for the safety of operating the stove. A burr in one of the nozzles caused the nozzle to form a cloud of kerosene vapor instead of a vapor jet. For safety reasons this nozzle had to be excluded from further testing. A second nozzle which came with the stoves was choked-up completely and could not be used. This implies also that the quality of the kerosene should be sufficiently high to warrant a satisfactory performance.

<table>
<thead>
<tr>
<th>Table A2.1: Summary characteristics of pressurized stoves</th>
</tr>
</thead>
<tbody>
<tr>
<td>name of stove</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Indonesia</td>
</tr>
<tr>
<td>Zeppellin</td>
</tr>
<tr>
<td>Pedale</td>
</tr>
<tr>
<td>Butterfly</td>
</tr>
<tr>
<td>Sea &amp; Butterfly</td>
</tr>
<tr>
<td>Champion</td>
</tr>
<tr>
<td>India</td>
</tr>
<tr>
<td>Meta de Lux</td>
</tr>
<tr>
<td>Super Jet</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
Power Rating Tests

5. Firstly, the power ranges of the two burners selected (Super JLH and the Bee & Butterfly) were determined for different nozzle sizes. Secondly, the efficiency was measured as a function of the power and the “pan bottom - burner head” distance. It was essential to have control over the power output of the stove, which was done with a pressure governor valve. When a stove is used without such device the pressure will drop as kerosene is consumed, the air volume of the tank increases and thus the pressure and power will drop. The fuel tank was placed on the electronic balance to record the fuel weight loss; the time was recorded with a stop watch. For the efficiency measurements, an aluminum round bottom pan (size 3; diameter: 300 mm) was filled with water and hung above the burner at a fixed distance.

The power output

6. The experiments with the burners (Super JLH; Bee & Butterfly) were performed for different nozzle diameters. The pressure was varied from 5 kPa to 200 kPa, which reflects the quality of the pumps. Each experiment lasted about 15 minutes in which the pressure was kept constant at selected values. The experiments with the Bee & Butterfly were performed twice. The results with the nozzle of 0.65 mm could be reproduced within the experimental accuracy. On theoretical grounds it was expected that the stove would give a higher power output with the 0.80 mm, but the experiments showed the contrary. However, during the series with the 0.80 mm nozzle, the flame was blown away from the burner, indicating that the nozzle was damaged. This shows that, in order to obtain a maximum performance, the nozzle has to be in excellent shape.

7. A series of experiments was performed to determine the influence of the power output on the efficiency. The distance between pan and burner was kept constant at 6 mm. The power-efficiency curve measured with the 0.6 mm nozzle lies a few percentage points higher. It indicates that there are other parameters besides the power and the “pan - burner” distance which are important. Consequently, all burner dimensions should be chosen according to the nozzle size.

Efficiency

8. On the basis of these tests, the SUPER JHL was selected with nozzles of 0.4 mm and 0.6 mm for the efficiency tests. Taking into account the quality of the pump, the power range of these stove/nozzle combinations are given in Table A2.2.

<table>
<thead>
<tr>
<th>Table A2.2: Power Output - Nozzle Diameter Combinations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nozzle</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>0.4 mm</td>
</tr>
<tr>
<td>0.6 mm</td>
</tr>
</tbody>
</table>

Pan - Burner Distance

9. In a second series of experiments, the power was held constant while the distance (d) between burner and the pan was varied. The results of the tests clearly show the reduction of the efficiency with increasing "pan - burner" distance. As was expected, the
experiments with the 0.6 mm nozzle showed higher efficiency numbers. However, direct comparison is not possible due to the different power levels used in the series.

Discussion

10. The vapor jet burners tested belong to the classic primus type stoves. For a given pressure in the kerosene tank, the power primarily depends on the diameter of the nozzle. The theoretical relation between pressure, nozzle diameter and power output which depends largely on the square root of the differential pressure and a temperature component, was confirmed by measurements. The objectives of the work were to design a stove with a maximum power larger than 4 kW. Taking into account the quality of the pumps which came with the stoves, this means that the nozzle diameter should be larger than 0.35 mm. On the other hand, the nozzle size is restricted by the minimum power requirements. The experiments revealed that a minimum power smaller than 1 kW is not feasible with a nozzle of 0.6 mm. Thus, the diameter of the nozzles to be considered range from 0.4 mm to 0.5 mm. The vapor jet burners are very sensitive to impurities (e.g. little sand particles) in the kerosene. They clog the nozzle easily. The larger the nozzle diameter, the less important this problem. This finally leads to a nozzle diameter choice of 0.5 mm.

11. Once the nozzle diameter is known, the other burner dimensions can be found using the empirical expressions. The dimensions are summarized in Table A2.3 below. The choice of the nozzle described above implies that it is not necessary to improve on the quality of the pumps. It suffices when the maximum pressure delivered is larger than 150 kPa (1.5 atmosphere). The efficiency measurements clearly showed the influence of the distance between pan and burner head. On the one hand, this distance should be kept as small as possible while on the other hand, the pans of different sizes should not be allowed to touch the burner.

Table A2.3: Characteristics of a 4 kW pressurized burner

<table>
<thead>
<tr>
<th></th>
<th>Pump: traditional</th>
<th>Tank: traditional</th>
<th>Burners</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nozzle diameter</td>
<td>Burner head</td>
<td>Distance nozzle</td>
</tr>
<tr>
<td></td>
<td>0.5 mm</td>
<td>40 mm</td>
<td>70 mm</td>
</tr>
<tr>
<td></td>
<td>Burner head</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Annex III (Stove Models)

Wick Stoves

FIGURE 11: Thomas Cup 20
FIGURE 12: PET
Pressurized Stoves

FIGURE 13: Primus

FIGURE 14: Superior
Charcoal Stoves

FIGURE 18: Malgache

FIGURE 19: Sakkanal
FIGURE 20: Rondereza

FIGURE 21: Kengo Jiko
Wood Stoves

FIGURE 22: Malgache

FIGURE 23: Mai Sauki