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Laboratory and Field Testing of Monolithic Mud
Stoves ITDG Interim Report No. 3.2

by: S. Joseph and Y.J. Shanahan

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Intermediate Technology Development Group

STOVE PROJECT

Interim Technical Report

LABORATORY AND FIELD TESTING
OF MONOLITHIC MUD STOVES

by: S. Joseph and
Y.J. Shanahan

Report No. 3.2

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1.

INTRODUCTION

Fuelwood is the primary source of energy for over 90% of the households in the developing countries. In many areas population pressures have consistently led to demand exceeding supplies which in turn has led to higher costs in terms of money and labour. Women bear the burden of this increased cost by spending a greater proportion of their time and energy collecting firewood. The ecological consequences are equally grave: reduced soil fertility (even desertification), severe flooding and soil erosion.

It is likely that wood and other biomass fuels will continue for some years as the most important fuels for the majority of people in developing countries. The problem needs to be attacked in several ways. In the long term re-forestation and silviculture programmes need to be extended and new programmes initiated. Present supplies of wood need to be used more efficiently. A widespread introduction of more efficient wood stoves could potentially reduce the demand on biomass fuels and extend the time available for the long term measures to take effect.

During the 1950's and early 60's a large amount of work was carried out into the design and testing of so-called improved mud stoves (generally referred to as Chulas). Authors such as Singer (1961) and Raju (1953) claimed that these stoves saved up to 50% of the wood normally used for cooking and heating. Attempts were made to introduce these stoves in India, Africa and Asia. However, except in a few isolated cases, they were generally not accepted. The reasons for the failure of these stove programmes are many and varied¹. For instance, recent tests have indicated that for some types of cooking, such as Indian, Fijian and Chinese, most of the improved chules were less efficient than the indigenous stoves, (S. Siwatibau, 1978). A similar problem has arisen with a new type of improved mud stove called the Lorena which was produced in 1974 by a group of people in Guatemala. The designers, (Evans 1979) claimed that

¹ Detailed analyses may be found in works by Morgen et al (1979), Joseph and Gould (1978), Joseph (1980)

it could save up to 50% of the firewood used in traditional stoves; it would also be easier to use than traditional stoves and would promote kitchen cleanliness and hygiene by eliminating smoke and by raising the cooking surface from the ground. The Guatemalan Lorena stove is now being widely promoted throughout the world and a number of organisations have built and introduced these stoves into communities in Asia, Latin America and Africa. However, initial reactions indicate that in different cultural settings with shorter cooking times the Lorena may give a poorer performance² than is claimed by the designers.

In this report we shall examine:

- 1) the design and construction of improved mud stoves;
- 2) the results of field and laboratory work carried out by ITDG and its collaborators³;
- 3) the problems of introducing improved stoves and ways of overcoming these problems.

In the first half of 1981, our collaborators in Sri Lanka and Indonesia will be building and testing a wide range of mud stoves. The results of the laboratory and field work will form the basis of our second report on mud stoves.

² Performance - this relates not only to fuel consumption but also the cooking time and the ease of operation

³ Dian Desa, an appropriate technology organisation in Central Java and Sarvodaya, a rural development organisation in Sri Lanka

2.

TYPES OF IMPROVED MUD STOVES

2.1 The Chula

There are two basic types of improved mud stoves, the Chula and the Lorena stove. The chula, which was developed in India is the first type. The Lorena stove will be discussed in the next section.

Chula is a Hindi word and literally means fireplace. More than thirty different improved chulas have been designed and built in India (National Building Organisation 1964). However, the basic design does not vary significantly from those shown in Figures 1 and 2.

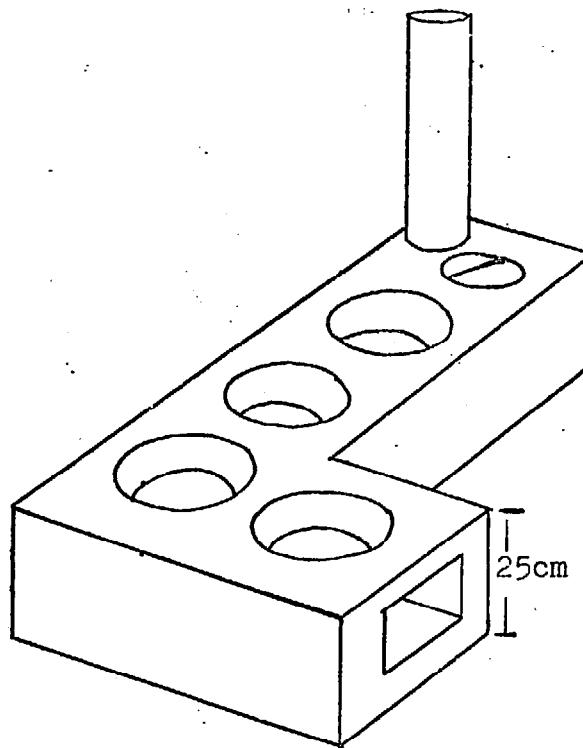
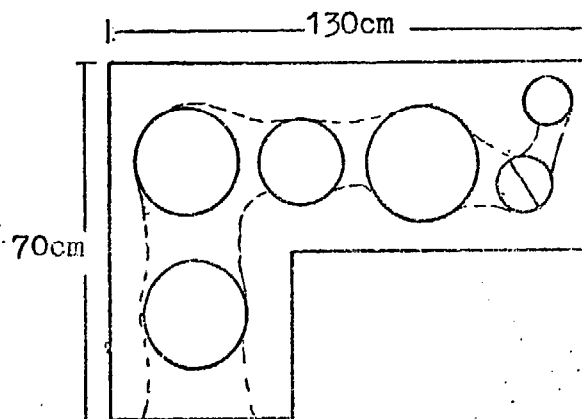
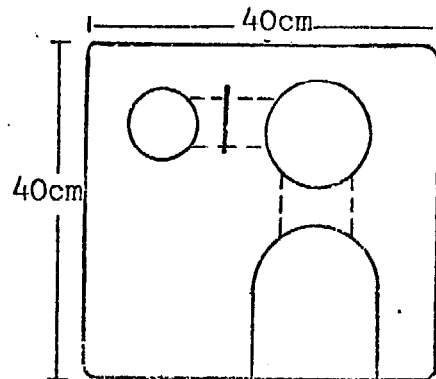
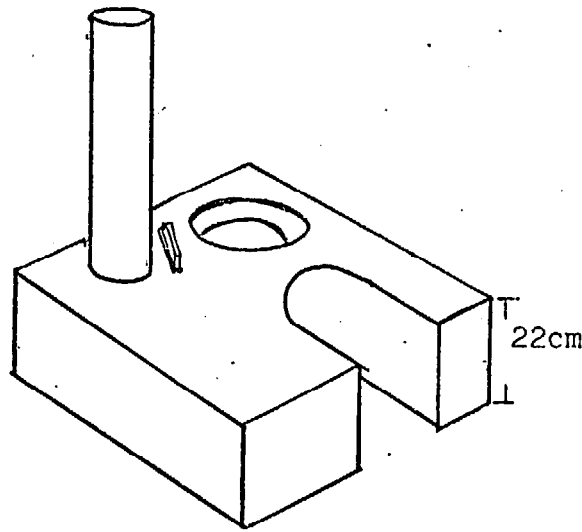


Figure 1: The 4-holed
HERL Chula



The chula is constructed from a block of clay and sand. The most common method of construction is to pack mud around a carefully prepared mould; when dry a tunnel is carved out horizontally through the block and holes are cut to fit the cooking vessels and chimney. The fire is made at the end of the tunnel beneath the first pot; a chimney of clay or sheet metal is fitted at the other end. Hot gases and flames flow through the tunnel, under the pots and up the chimney. A damper provides draught control; the number of pots and the size and height of the stove are adjusted to suit the user's preferences.

Figure 2: The 2-holed PRAI Chula

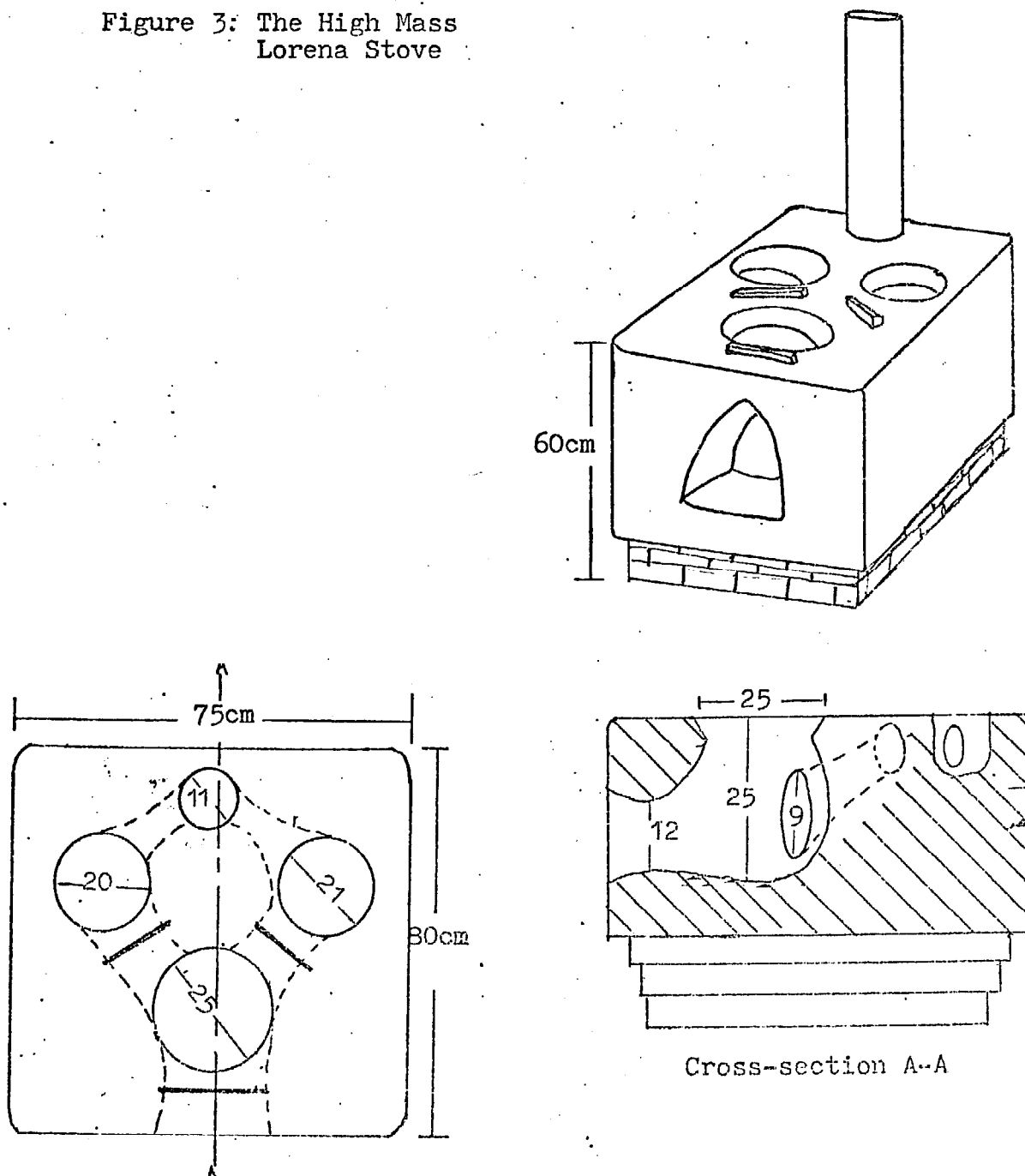


2.2 The Lorena Stove

'Lorena' is a word derived from a combination of two Spanish words, 'lodo' meaning mud and 'arena' meaning sand. The design was developed in Guatemala but it is essentially a modified version of the improved Indian chula.

Like the chula, the stove is made from a block of clay and sand and carved out when dry. Complete blocks may be built with moulds or else a series of mud layers may be plastered on top of each other. The stove can be built in a range of sizes and may accommodate up to four pots (Figs 3-7).

Figure 3: The High Mass Lorena Stove



The unique features of this stove which distinguish it from the chula are:

1. Both the entrance way and combustion chamber have a parabolic cross-section which increases the size from the entrance inwards (Fig 3a). The floor of the chamber slopes inwards to allow for ash formation. The height of the chamber is usually between 20 and 25cm. The pot sits on top of the chamber. In the original design a metal damper was placed between the entrance and the combustion chamber. (Fig 3b).

Figure 3a: The Parabolic Entrance Way

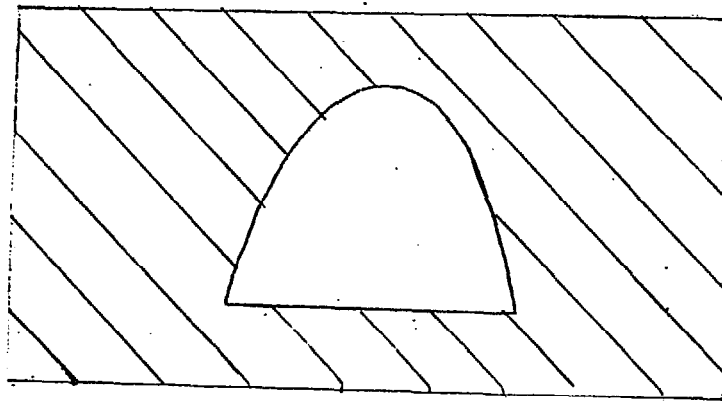
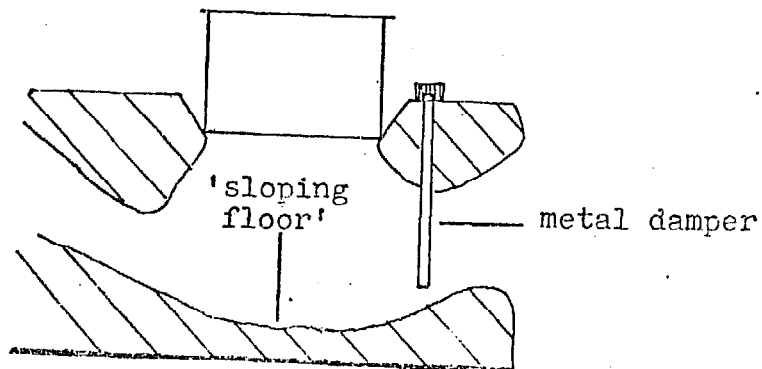


Figure 3b: Cross-section of Combustion Chamber



2. The flues and pot holes - The most commonly used configuration is shown in Fig 3. The flue is taken from the side at the back of the combustion chamber to the second pot hole.

In Figs 4 and 5 two flues run from either side of the combustion chamber to the second and third pot holes. The flues are inclined upwards and meet the pot holes at a tangent. The pot holes are shaped so that the pots sit down into the hole and the gases swirl around the undersides. The exit flue from one of the pot holes leave tangentially and either goes into the next pot hole or out into the chimney.

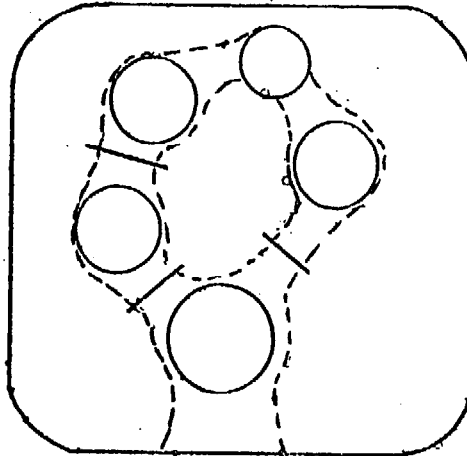


Figure 4 -
Flue configuration
of High Mass Lorena

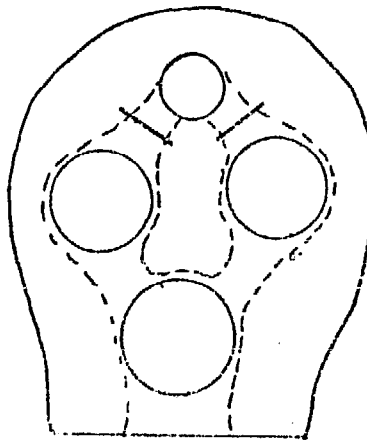


Figure 5 -
Flue configuration
of High Mass Lorena

The flue and pot hole configuration in Fig 6 is similar to that of the Herl Chula (p.3). The flue leaves the back of the combustion chamber, converges and then enters the second pot hole. The hot gases pass round the sides of the pot and enter the next flue, which is slightly narrower than the previous flue. This flue then leads to the third pot hole before joining up with the chimney. The flue and pot hole configuration in Fig 7 is the most compact of the lorenas and will accommodate only 2 pot holes.

Figure 6 - Flue and 3-holed configuration of High Mass Lorena

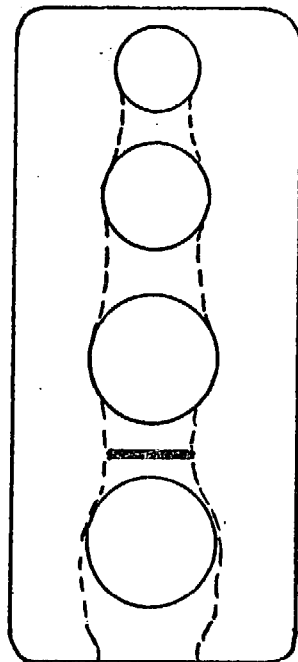
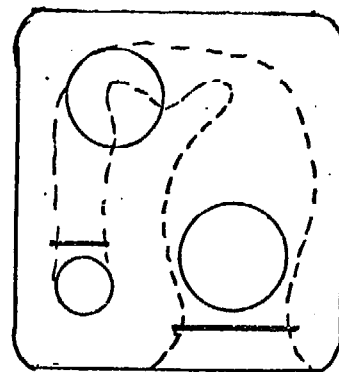


Figure 7 - Flue and 2-holed configuration of High Mass Lorena



3. The use of dampers - These are used to control the amount of air entering the Lorena stove. The designers believed that the control and channelling of the air, combined with careful construction of the combustion chamber and the sitting of the pot in the gas stream, would promote high combustion efficiencies and percentage heat utilisation (Appendix 1) in the cooking process.

In Fig 4 (see p.7) the dampers also allow cooking with only two of the pot holes.

3.

FIELD TESTS

In 1978, Dian Desa began a programme to build high mass Lorena stoves in Indonesian villages. The initial reaction to the stoves was not encouraging. It was found that the high mass stoves were unsuitable for the short cooking times generally required in the preparation of Asian meals. The time taken to cook on the Lorena stove was greater than on the traditional stove and there was no significant saving in fuel. When smaller Lorena stoves were built many more were accepted.

In February 1980, one of the authors (S. Joseph) spent two weeks testing Lorena and traditional stoves in Indonesian villages⁴. A total of nineteen tests were carried out on three different traditional stoves and ten Lorena stoves with three and four pot holes, on stoves constructed on lines similar to those in Figs 4, 5 and 6. Three of the Lorena stoves clearly had a superior performance to the traditional stoves, in terms of cooking time, quantity of wood used, percentage heat utilised and ease of operation. Four of the Lorena stoves were clearly worse than the traditional stoves and were not being used. The remainder had a similar performance to the traditional stoves and were being used when cooking times were longer than the time taken to bring a pot of water to the boil.

The results of the tests indicated that the reasons for poor performance were:

- 1) incorrectly placed chimneys causing inadequate draught;
- 2) flues blocked by ash or pieces of ceramic pots. These pieces had originally been used to raise the pot above the hole to allow more heat to reach the cooking pot. This indicates that either the draft was insufficient or the combustion chamber and flues were the wrong shape or dimensions;
- 3) incorrectly placed flues, resulting in poor heat transfer. The exact reasons for this poor heat transfer are not yet fully understood;

⁴ The testing procedure used is detailed in Interim Report No. 1 ITDG, November 1980

- 4) damaged dampers or damper slots - the users were unable to control the flow of air and hot gases into and out of the stove;
- 5) incorrectly shaped pot holes. The hole over the combustion chamber was too small, thus reducing the heat transferred by radiation. Some of the pots did not sit into the second, third and fourth pot holes. Since only a limited contact with the hot gases could occur, heat transferred to these pots was markedly reduced;
- 6) incorrectly made combustion chamber. Often the combustion chamber was either too small or too large. This led to poor combustion (indicated by low CO₂ levels and high excess air) with a consequent increase in creosote and soot formation.

3.1 Field Test Conclusions

The smaller mass Lorena stoves had consistently better performances than the large mass stoves, which were only more efficient when used constantly throughout the day, e.g. in the chief's household where food is cooked constantly for guests. Stoves constructed along the lines shown in Fig 5 were consistently better than those shown in Fig 6. These results indicate a clear need to investigate in more detail the factors that affect the performance of mud stoves and to consider alternative small mud stoves such as the Indian chula. It is also apparent that the poor performance of Lorena stoves, due to bad construction, incorrect use and insufficient maintenance, indicates the need for the training of stove builders and extension workers.

4.

LABORATORY TESTS

The laboratory test work was undertaken by ITDG in England. The aims were:

- 1) to determine the main variables that affect the performance of mud stoves;
- 2) to establish a procedure for the improvement of mud stove designs in order to extend the lifetime of the stoves, promote greater ease of use over a wide range of cooking practices and to improve performance in terms of the quantity of wood used and the cooking time;
- 3) to compare the performance of the small Chula with the small and large Lorena stoves.

It was also hoped that as a result of these tests a deeper insight would be obtained into the underlying principles of combustion and heat transfer that affect the performance of mud stoves.

The times used were:

- 1) Pot₁ to the boil (BP₁)
- 2) Pot₁ to the boil + ten minutes (BP₁ S₁₀)
- 3) Pot₂ to the boil (BP₂)
- 4) Pot₂ to the boil, plus 30 minutes (BP₂ S₃₀)
- 5) Pot₂ to the boil, plus 60 minutes (BP₂ S₆₀)

The draught was varied by a damper placed in the chimney and by altering the height of the chimney. At medium draught the damper was fully opened and in a nine foot high chimney. A low draft was obtained by closing the damper 80° from the vertical. An extra nine feet was added to the chimney to obtain a high draught

The procedure used for testing the stoves follows that set out in the ITDG Interim Report No. 1. The stoves were placed on a weighing platform (capacity 50kg ± .05) and a flexible stainless steel flue liner was connected between the chimney port on

the stove and a fixed metal-asbestos chimney 274cm high and 12cm diameter. Solid state thermocouples were used to measure temperatures up to 150°C and chrome/alumel thermocouples were used to measure temperatures from 100°C to 1000°C. Gas samples were taken continuously from the flue liner and analysed for oxygen, carbon dioxide and carbon monoxide. Changes in draught were noted using a Baccarach draught gauge. Data on the composition and temperature of the gases were continuously logged into a microprocessor. Changes in wood weight, draught and observations of charcoal formation and flame characteristics were noted by hand. Data was processed at the end of the experiment and recorded.

The test fuels were IROKO (a west African hardwood) and JELATONG (a Malaysian hardwood). These woods have very different burning characteristics, Jelatong being a fast burning wood that produces long flames, and Iroko being a slow burning wood that produces shorter flames. The Iroko had a moisture content of 11.5%⁵ and Jelatong a moisture content of 14.5%. These moisture contents were varied up to 50.0%. Both woods were cut into standard sizes of 2.4 x 15cm long, 2.4 x 60cm and 5.0 x 5.0 x 60cm. The wood was either fed continuously into the stove or in batches. The fire was started with about 5g of paper and about 40g of small kindling.

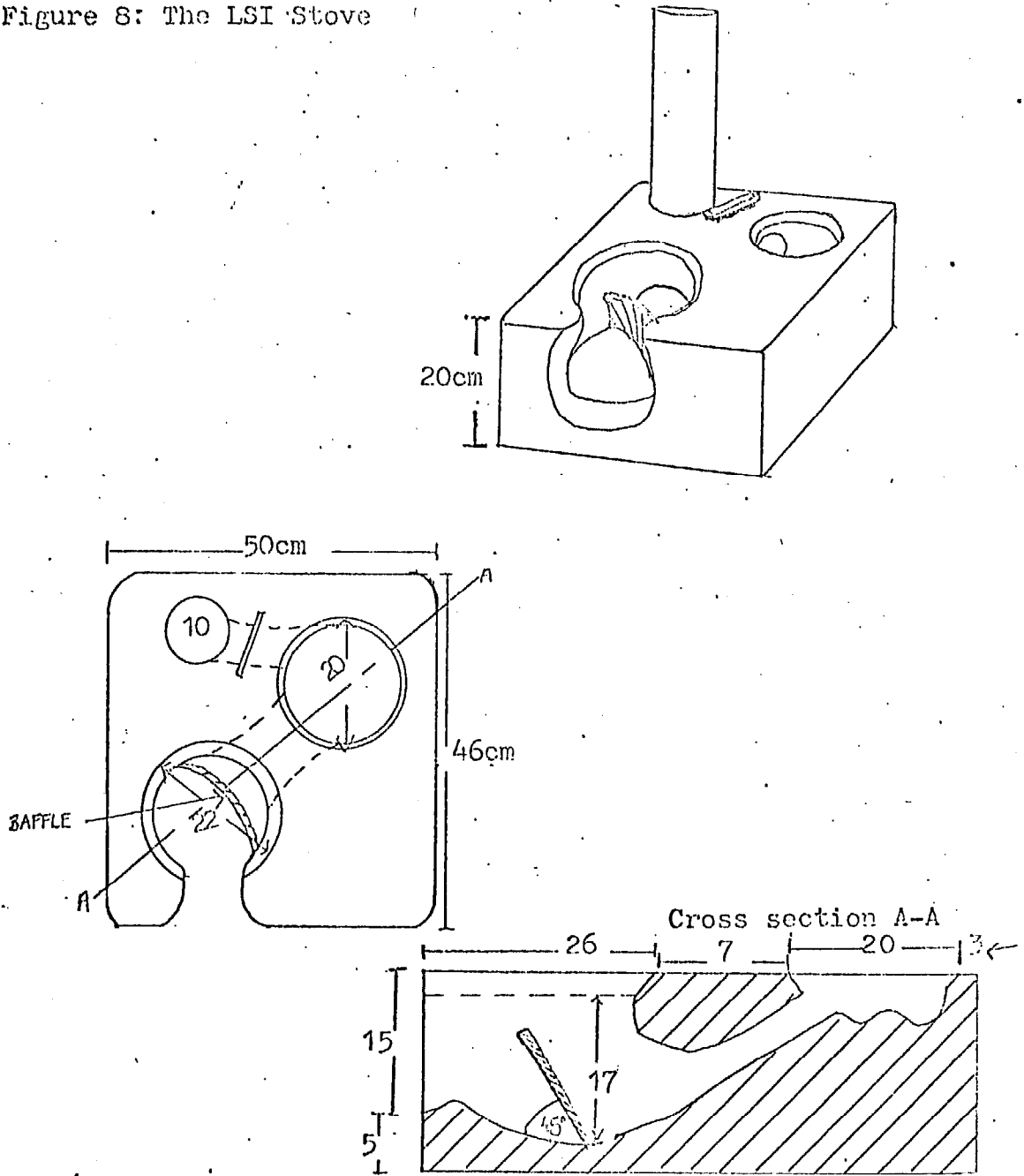
A uniform method of stacking and feeding was used over all the experiments. At the start of a test series on a new stove the laboratory personnel first familiarised themselves with the problems of using the stove and then standardised the method of operation.

Aluminium pots 20cm and 18cm diameter respectively were used in all the experiments. The bigger pot (pot₁) was placed at the front and the smaller pot (pot₂) was placed at the back. Tests were to be carried out with varying types and sizes of pots but severe cracking of the stove prevented this.

Three stoves were tested (see Figs 3, 8 and 9). The stove in Figure 3 has been described earlier (p.5). A small mass version of the Lorena stove (LSI) is shown in Figure 8, while Figure 9 is a version of the two-holed chula (GS).

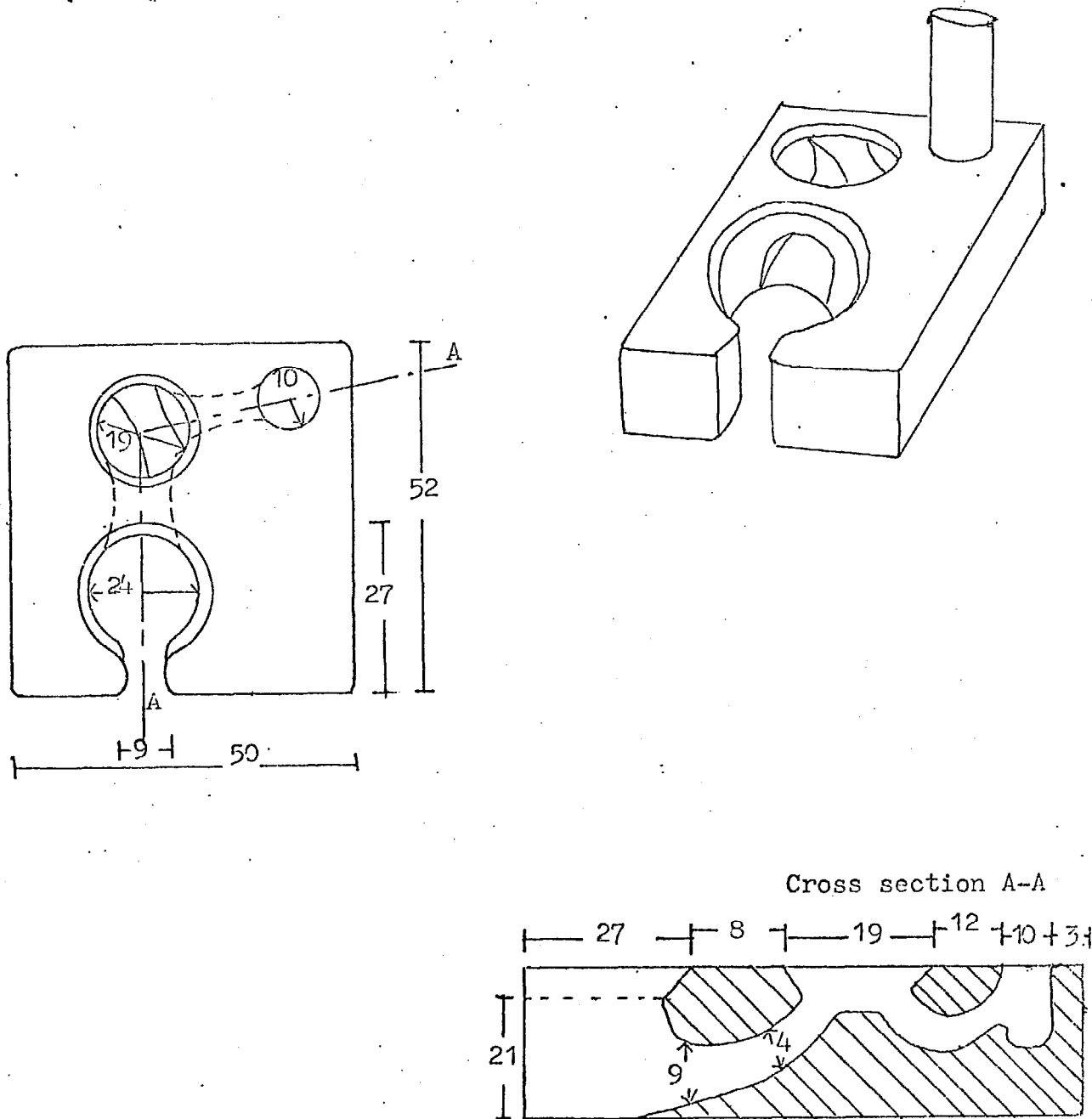
⁵ Dry basis - all moisture contents are expressed relative to the moisture free mass of the fuel.

Figure 8: The LSI Stove



A total of fifty tests was carried out on the stoves, but natural deterioration of the stove body occurred during this time. It was therefore necessary to repeat a standard control experiment periodically in order to monitor the effects of deterioration on the test results. When the results were significantly affected the series of tests was terminated. This occurred after twenty-three tests on the LSI stove and after twenty tests on the GS stove. The LSII stove did not deteriorate significantly over a series of eight tests.

Figure 9: The GS Stove



4.1 General Observations of Laboratory Tests

The results indicated that the most important variable affecting performance of the stoves is the configuration of combustion chamber and the pot holes. Baffles⁶ can measurably decrease the wood use and the time taken to boil. In the GS stove a baffle was placed in the back pot hole (Fig 9, cross section).

⁶ Baffles are obstructions placed inside the stove to redirect the flames and hot gases.

The effect of the baffle was to restrict the burning rate of the wood and force the flames and hot gases to hit the base of the pot at a relatively high velocity (≈ 2.3 m/sec).

In the LSI, a small baffle was placed across the exit from the combustion chamber to the flue at an angle of about 60° to the floor of the stove (Fig 8, cross-section). The effect of this was to concentrate the flames under the base of the first pot.

A change in draught also significantly changes the performance of the stove. A very low draught increases the time taken to boil and the quantity of fuel used to bring the pots to the boil. Under optimum draught conditions an increase in fuel moisture content only slightly changes the percentage heat utilised (PHU) (see Appendix 1) and increases BP_1 . For longer cooking times, an increased moisture content does not significantly affect the performance of the stoves, (up to 40% moisture content d.b.).

As in the field, the small mass stoves performed better than the large mass stoves. The Lorena type stoves were most sensitive to changes in all the variables. The overall performance of the LSI stove was more sensitive to changes in the draught, the moisture content of the wood and quantity of water boiled than the GS stove (see Appendix 2). It was found that the optimum performance of the LSI stove was obtained at approximately $BP_1 S_{10}$, whereas the optimum performance of the GS stove was reached at approximately $BP_1 S_{30}$. The LSII stove reached its optimum at about 2 hours after pot_1 was brought to the boil. These differences can be attributed to the relative masses of the stoves. The larger mass LSII stove appeared most sensitive to changes in operator conditions, especially variations in draught and use of the dampers. The optimum performance of the LSII stove occurred when the stove was hot, only two pots were used, an average burning rate of 22g/min was maintained and air dried wood was used. It was much more difficult to ignite wet wood in the enclosed firebox of the LSII stove than in the open fireboxes of the GS and LSI stoves.

The LSI stove was found to be the most sensitive of the smaller stoves to all variations in operating conditions.

It was particularly sensitive to an increase in the moisture content of the wood, which made the fire difficult to start, produced a lot of smoke and required almost constant attention. The stove was most convenient to use when long pieces of air-dried Jelatong were used, with a medium draught and baffle in the combustion chamber.

The GS stove was less sensitive to an increase in moisture content or a variation in draught. It was also easier to operate at a medium draught with long pieces of air-dried Jelatong.

The results of the cooking tests emphasised the necessity for pot holes which could accommodate more than one size. Although the pot holes of the smaller stoves were not strictly interchangeable, it was possible to swap the pots and thereby use the heat more efficiently.

When only one pot of water was boiled a cold mud stove was not as efficient as a well protected and operated open fire. When a hot mud stove was used the efficiencies were nearly the same (see Appendix 3).

4.2 Discussion of LSI Test Results

4.2.1 Physical Tests

The first two tests were carried out without any baffles. The time to boil 2 litres of water in pot₁ was approximately fifteen minutes and 500g of wood were used, (see Table 1/A). Pot₂ came to the boil soon after. A baffle was placed in the combustion chamber and three further tests were carried out. The time BP₁ remained the same but the wood used decreased to an average of 280g (see Table 1/B). The temperature of the water in pot₂ was only 80° at BP₁, the remaining tests were all carried out with a baffle in place since this increased the PHU.

Tests were carried out to determine the effects of variations in the draught, moisture content, size of wood used and amount of water in each pot. The results of these tests are given in Tables 2.1 and 2.3, Appendix 2. The relationship between the PHU and the burning rate is shown graphically in Tables 2.2 and 2.4, Appendix 2. The burning rate varied from 8-30g/min for cooking times of BP₁ and BP₁ S₁₀.

For the time BP₁ the range of PHU for all experimental conditions was 12-24% with a maximum value reached at a

Table 1: LSI TEST RESULTS

Text Ref.	Defn of Test end point	Testing Conditions	No. of Tests	PHU (%)		Aver. Time Taken (min)	Eff. wt. of wood used (g)	Aver. Burning Rate (g/min)
				Aver.	Range			
A	BP ₁	* a/d Jelatong Medium draught	2	13	12.5-13.5	15	500	30
B	EP ₁	a/d Jelatong Medium draught	3	23.5	23 - 24	15	280	16

* a/d = air-dried

burning rate of 18g/min. The PHU increased after BP₁ and reached a maximum of 26% at the lower burning rate of 14g/min. The maximum PHU does not seem to vary for cooking times of up to 18 minutes, although further experiments need to be carried out to confirm this.

It was also apparent that the type of wood used affected the performance. When air-dried Jelatong was used at optimum draught, the average PHU 23%, under the same operating conditions the average PHU of the slower burning Iroko was only 14%. Short billets of wood did not significantly affect the performance. For cooking times of up to 40 minutes it was observed with both woods that the PHU increased as the moisture content was increased from 12-25%. However, the time to boil was not significantly affected by variations in the moisture content in this range.

Approximately 100-120g of charcoal formed ten minutes after the start when a stove is operating at a burning rate that gives the maximum PHU. The amount of charcoal decreases to 50-60g when burning rates are above or below the optimum. Heat balances were carried out on the results of 7 experiments at times BP₁ S₁₀, BP₂ S₃₀ and BP₂ S₆₀. Three of the balances showed unaccounted losses of 17-20%. Whilst the other four were accurate to within $\pm 6\%$.

Given the inaccuracies inherent in these calculations it can be concluded that the heat losses from the flue gases is approximately 30-40%. This increases to 50% when there is a high draught or wet wood is used. Heat lost from the stove wall was only significant after a cooking time of 60-70 minutes, when the wall had reached an average temperature of 60-80°C. The heat absorbed by the stove accounted for 15-20% of the total loss for cooking times up to 60 minutes. In all cases, the heat lost due to the formation of carbon monoxide was very small. (When the stove is fully sealed the percentage composition of carbon monoxide in the flue gases is less than .4%).

4.2.2 Operator Tests⁷

The time needed to start a good fire was dependent on the draught, moisture content, size and type of wood used and stove temperature. It was found easiest to start the fire when

⁷As described in Interim Report No 1 pp 14-16

the stove was warm and 2.5 x 2.5 x 60 cm pieces of air-dried Jelatong were used.

For both woods Fire attendance (as defined in Interim Report No. 1, p.15) was particularly necessary at high moisture contents. Regular attendance was necessary to maintain the fire and a lot of smoke was produced from the wet wood. For both woods, the frequency of attendance was highest when shorter billets were used. This was due to the need to replenish the fire with separate charges during the test. The use of shorter billets also made it difficult to position the wood. The need for fire attendance was also dependent on the draught, although the nature of this dependence was not the same for both woods. In the case of Jelatong, an increased draught necessitated more attention to the fire but for Iroko, the reverse was true. When the stove was operated without a baffle at a medium draught it was necessary to attend the fire frequently. Under these conditions the fire was drawn into the connecting tunnel and beneath the second pot seat. Regular attendance and manipulation of the wood was needed to help counteract this effect and keep a steady fire under the first pot.

When the stove was used to simmer or steam, there was less need to tend the fire because a bed of charcoals had formed and less wood was required to maintain the fire.

Ease in controlling the fire was affected by all the variations in conditions, described above. It was most notable that the inclusion of a baffle in the firebox significantly improved the ease of control. The baffle re-directed a considerable proportion of the flames back and under the first pot. Control of the fire was most difficult with wet wood, particularly at the beginning of the test when the large volumes of smoke produced were a cause of irritation to the user.

Controlling the fire was made more difficult when short rather than long billets of wood were used. This was especially so when there was a need to decrease the heat output, e.g. after a pot had boiled and only simmering was required. When a bed of charcoal was produced the heat output and direction of the flames could not be manipulated as with wood. At this point the control of the fire was mainly dependent on how much charcoal was in the firebox. Iroko tended to produce larger amounts of charcoals

than Jelatong.

The LSI stove has 2 pot seats which are made to fit specific sizes of flat bottomed pots. The implication of this is that the pots may not be satisfactorily interchanged between the seats. Ideally, when it is necessary to boil two pots of water it should be possible to transfer the second pot to the front after the water in the front pot has boiled. If this is not possible the water in the second pot can only be boiled by keeping the fire well stoked under the first pot. The disadvantages of this are that:

- a) more wood is required to bring the water in the second pot to the boil;
- b) it takes longer;
- c) the first pot is kept rigorously boiling, which may not be required.

These disadvantages are accentuated when a baffle is in place. When the baffle is not used, the heat taken up by the two pots is more even.

4.2.3 Cooking Tests

A standard meal of 500g of rice and 500g of dhal, each with 1000g of water was cooked in aluminium pots with lids. The rice was placed on the front pot hole and the dhal at the back. When the rice was oiled, the pots were changed over, even though the pot holes were not designed for this. The wood was removed when the dhal boiled. Both foods were considered cooked after a total of 18 minutes. The total weight of wood used (after correction for charcoal formation) was 334g.

4.2.4 General Maintenance

It was found necessary to clean out the ashes from the combustion chamber and connecting flue at the beginning of each day. Although the combustion chamber was very accessible it was quite difficult to clean out the flue since it was immediately behind the baffle.

Cracks appeared around the firebox and flue during use. These needed regular repairing as they tended to open up again soon after being plastered up.

4.3 Discussion of GS Test Results

4.3.1 Physical Tests

It was found that under optimum conditions without baffles 2 litres of water in pot₁ could be brought to the boil in a time of 24 minutes with 500g of wood (effective weight), the PHU was 11% (see Table 2/C). When baffles were placed in both the combustion chamber and in the flue underneath the second pot hole the performance improved markedly. However, the best performance was obtained when only a back baffle was used. The time taken to boil 2 litres of water was 12 minutes, the quantity of wood used was 240g and the PHU was 17% (see Table 2/D). The burning rate was 17g/min. It is interesting to note that although the LSI and GS stoves have different shapes, the optimum rate for BP₁ is approximately the same in both cases. Away from this PHU decreases as both burning rate increases and decreases (see Figure 2.6, Appendix 2). With only a back baffle the optimum PHU occurs at a higher draught setting. At the lower draught the flame is drawn up close to the first pot and is then directed down again into the connecting flue.

With a front baffle the PHU is not so affected by high draught but is greatly affected by a low draught (see Table 2/E,F). It is critical that the front baffle is correctly placed. If it is placed too far forward the burning volume is too small and the flames are quenched. On the other hand if the baffle is too far back then the flame is not directed under the first pot.

From the few tests carried out it appears that the front baffle should be placed at an angle of 45° - 50° to the floor of the firebox. The upper edge of the baffle should be halfway across the pot hole.

The front baffle is useful if it is required to cook unequal quantities of food within the same period of time, with say 3kgs of food/water in pot₁, and 1kg of food/water in pot₂ more heat must be transferred to pot₁.

The GS stove appears to perform best when the cooking operation takes about 40 minutes (starting from cold). This is about the time that it takes to bring both pots of water to the boil (2 litres in each pot) and the average PHU observed for this

Table 2: GS Test Results

Text Ref.	Defn of Test End Point	Testing Conditions	No. of Tests	PHU (%)		Aver. Time Taken (min)	Eff. wt. of wood used (g)	Aver. Burning Rate (g/min)
				Aver.	Range			
C	BP ₁	* a/d Jelatong Medium draught No baffles	1	11		24	490	18
D	BP ₁	a/d Jelatong High draught Back baffle	1	19		12	240	17
E	BP ₁	a/d Jelatong High & Med draught Front baffle	4	16.5	16 - 17	14	280	18
F	BP ₁	a/d Jelatong Low draught Front baffle	2	14.1	13 - 15	18	290	13
G	BP ₂	Various conditions 2 baffles	11	20	18 - 22	40	850	15
H	EP ₂ S ₃₀	Various conditions 2 baffles	4	18.5	18 - 21	70	1100	18

* a/d = air-dried

operation was 20% (range 18-22%, 11 tests). When the water in the two pots was simmered for 30 minutes after boiling (about 70 minutes total cooking time) the average PHU was found to decrease slightly to 18.5% (range 18-21%, 4 tests) (see Table 2/G, H).

4.3.2 Operator Tests

The ignition time depended less on variations in draught than for the LSI stove. However, it was adversely affected when wet wood was used and as before Iroko was more difficult to light than Jelatong. The 5 x 5 x 60cm stakes of Jelatong were much harder to ignite (in practice when large pieces of wood are burnt, one or two stakes would be kept smouldering from the previous fire to make ignition easier). When the fire was started in a hot stove using 2.5 x 2.5 x 60cm pieces of air-dried Jelatong, the ignition time decreased.

Fire attendance was particularly important with wet wood and when larger stakes of Jelatong were used. The larger stakes needed very frequent attention to maintain the fire.

A combination of no baffles and a medium draught caused the fire to be drawn sharply into the 2nd pot seat and up the chimney. This meant that regular attendance was needed to keep the wood fed under the first pot seat. Over longer periods of cooking it was found that the fire did not require so much attention, as was observed with the LSI stove. The effects of different operating conditions became less marked as the stove reached a steady temperature.

When the draught was reduced by means of a baffle placed in the combustion chamber, or a damper in the chimney it became possible to control the fire and its direction out of the combustion chamber and hence allow the flames to be delayed under the first pot seat. The combined use of using a baffle and damper can be less advantageous if the objective is to heat up the back pot as well. The use of a baffle when there is a low draught will prevent flames reaching the second pot, so that less heat will be transferred to the pot.

The introduction of a back baffle improved control of the fire underneath the second pot by redirecting any flames under the pot seat.

When a bed of charcoal has been formed it becomes the main source of heat and a front baffle is no longer of any use in controlling the fire.

Wet wood adversely affected control of the fire because of the smoke produced and the shorter flame lengths. This was especially marked at the beginning of a test when the stove was cold. When burning the larger stakes of wood it was difficult to control the fire because of short flame lengths and a decreased volume of flame. In addition the wood could not be manipulated or stacked as with the smaller pieces

4.3.3 Cooking Tests

The same standard meal and procedure was used as in the LSI test. The time taken to cook the meal was 22 minutes and the weight of wood used was 417g.

4.3.4 General Maintenance

The GS stove was no more difficult to clean than the LSI stove. Cracks appeared in the same areas as the LSI stove but the extent and depth of them was not as great as the walls were thicker. The cracks formed along the thinner wall of the firebox and across the bridge between the firebox and second pot seat.

4.4 Discussion of LSII Test Results (Figure 3)

4.4.1 Physical Tests

A total of eight tests were carried out on this stove.⁸ In five of the tests, two pots were used and in the remaining tests three pots were used. The two sets of tests were carried out consecutively. In the first set of tests both pots were brought to the boil. The wood remaining was removed and the pots were refilled with 2 litres of water each at 26°C. The charcoal remaining was used to start the fire for the next test. This procedure was repeated three times and then the cooking time for the fourth test was increased to BP₂ S₃₀, and for the fifth test BP₂ S₆₀. In the second set of tests the cooking times were BP₂ S₃₀. Measurements of the weights of wood used were made at BP₁, BP₂ and at the end of the experiment.

⁸ The number of results was insufficient to plot a graph of PHU versus the Burning Rate.

Much more attention was paid to using the dampers properly in the second set of tests. (The method of using the dampers was altered in the final experiment of the second series of tests).

The range of burning rates obtained was larger than for the lower mass stoves (10-50g/min). The PHU varied from 9 to 17% for BP₁ and from 12 to 17% for BP₂. A variation in the method of operating the dampers changed the performance markedly, (a drop from 17% to 12% in the PHU was obtained when the dampers were used incorrectly).

Adding a third pot to the stove did not improve the performance. In fact unless the dampers and wood were manipulated correctly the performance was poorer (both in terms of wood used and the time taken to boil pots 1 and 2). The time BP₁ ranged from 16 to 18 minutes for a cold stove to 12 to 13 minutes for a hot stove. The PHU increased as the stove body warmed up. After approximately three hours the performance of the stove reached a maximum and then declined slightly for longer burning times.

4.4.2 Operator Tests

The ignition time in the enclosed combustion chamber of the Lorena was most sensitive to a change in draught (wet wood was not used in these tests, experience in the field having proved this to be difficult). Ignition was easiest in a hot stove using long sticks of air-dried Jelatong.

The Fire attendance was adversely affected by a high draught. It was necessary to keep feeding large quantities of wood because of the fast burning rate. When the dampers to pots 2 and 3 were open, the flame envelope was dispersed and drawn away from the bottom of the first pot. Regular attendance and manipulation was needed to keep part of the fire under the first pot. During consecutive tests, when the stove was hot and a bed of charcoals had formed, less wood was required to maintain the fire.

Control of the fire was more difficult when both the dampers were open. (The effect of this has already been explained)

Control of the flames under the first pot was also difficult with a high draught. The flames were swept under the flue exit without being delayed under the first pot seat.

The large Lorena has three pot holes. The second and third pot holes were made to fit flat-bottomed pots. Therefore the pots could not be satisfactorily changed between one pot hole and another.

4.4.3 Cooking Tests

No cooking tests were carried out.

4.4.4 General Maintenance

The combustion chamber and connecting flues of the stove needed to be cleaned out every day.

On account of its large mass the Lorena was found to develop less cracks than the smaller stoves. The first crack appeared across the bridge of the firebox entrance.

The chimneys of all the stoves need cleaning at least three times a year.

5.

CONCLUSIONS FROM TEST RESULTS

The principal characteristics of a mud stove which determine its performance are the mass, overall size and shape (which are in turn governed by the materials and the size and number of pots used), combustion chamber size and shape, length, shape and direction of the connecting flues and diameter and height of the chimney.

These physical characteristics, in turn, will determine the effect which a change in draught, moisture content, size of fuel and cooking times will have on the performance of the stove.

1. Effect of stove size on performance

The optimum performance of larger mass stoves occurs at longer cooking times. Fig 10 indicates the change in temperature which occurs across the walls of large and small mass stoves. It can be seen that small mass stoves heat up more quickly than large mass stoves. However, the final surface temperature of the high mass stove is lower. Thus large mass stoves require more energy initially to reach their steady state temperature. Once they reach this temperature the heat loss from the walls is less (since the wall temperature is lower).

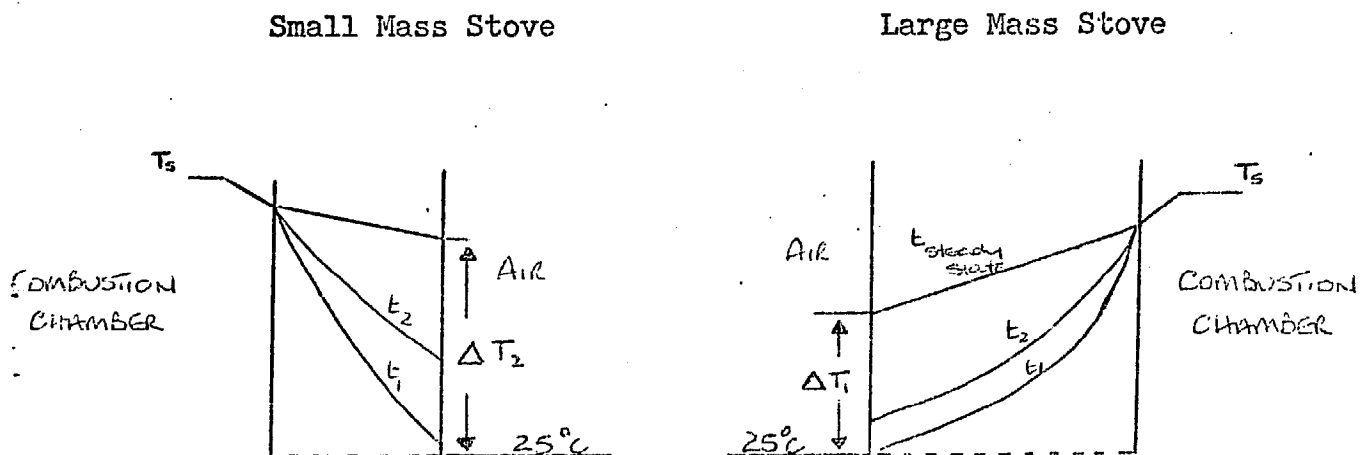


Figure 10: Temperature gradients across the walls of mud stoves at different times (t) ($t_1, t_2 < t_{steady\ state}$)

2. Effect of combustion chamber size and shape on performance

For water to come to the boil efficiently⁹ and quickly in large mass stoves, the heat output must be greater than in smaller stoves (to provide the energy needed to heat up the walls). To obtain higher heat output rates the volume of the combustion chamber must be larger¹⁰. At present there is insufficient data to determine precisely the relationship between the volume of the combustion chamber, the rate of heat release and the optimum rates of heat utilisation by pot₁.

Table 3 indicates the output/volume ratios which were obtained for low and high mass stoves over different cooking times (at optimum performance). The table confirms the general observations that for a given cooking time the ratio is constant for all types of mud stove. This ratio decreases by approximately one third for longer cooking times. It should be emphasised that these conclusions are tentative and further test work is needed. It also appears that this ratio could change when clay pots are used.

Table 3: Ratio of heat output to combustion chamber volume for different cooking times for high and low mass stoves

Stove Type	Ratio for cooking time < 1 hr	Ratio for cooking time > 1 hr
GS and LSI	682 kW/m ³ (2.3kg/min.m ³)	417 kW/m ³ (1.4kg/min.m ³)
High mass Lorena	727 kW/m ³ (2.5kg/min.m ³)	485 kW/m ³ (1.6kg/min.m ³)

⁹ Dutt (1979) has shown that the faster the input of heat into the water the lower are the losses from the pot and the more efficient is the cooking process.

¹⁰ In stoves which have a grate, maximum output is determined by the grate area. In stoves without a grate it would appear that power output is related to combustion chamber volume.

At the optimum volume (and optimum draught setting) it has been observed visually (through pyrex dishes) that the flame envelope just fills the combustion chamber. When the volume is too large it appears that heat is rapidly dissipated away from the burning wood. When the volume is too small the flames impinge on the walls and a great deal of soot is formed.

3. Effect of length and shape of connecting flues, pot hole size and shape and chimney size on performance

It has been observed visually that efficient combustion and heat transfer depend on the flame envelope following a certain path in the combustion chamber. The path of the flame envelope is affected by the physical parameters mentioned above.

There are two main forces that affect the direction of the flame envelope. The first is the convective force drawing the flame towards the cold pot, the second is the buoyancy force (draught) drawing the flame out towards the chimney¹¹. When the chimney and flue passages are large the draught is large. The flame envelope is then drawn along the bottom of the firebox and does not touch the bottom of the pot thus both convective and radiation heat transfer are reduced.

When the buoyancy force is small compared with the convective force the flame envelope is drawn up to the bottom of the pot.

¹¹ The draught (which is related to the gas velocity) can be expressed as:

$$\Delta P_{\text{actual}} = \Delta P_{\text{theoretical}} - \Delta P_{\text{friction}}$$

$\Delta P_{\text{theoretical}}$ is equal to the theoretical pressure drop due to the difference between the outside air temperature and the temperature of the gases at the entrance to the chimney.

$\Delta P_{\text{theoretical}}$ is related to the height and diameter of the chimney.

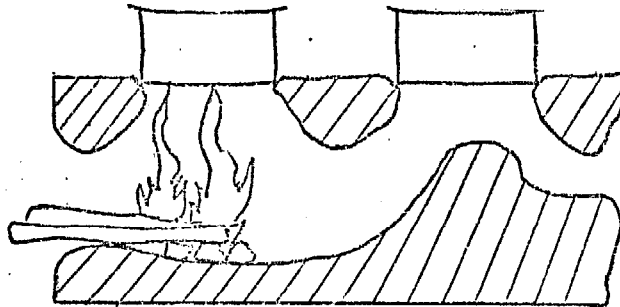
$\Delta P_{\text{friction}}$ is the pressure drop due to the resistance of flow of the gases as they pass through the stove and up the chimney.

A great deal of soot is formed indicating incomplete combustion and low flame temperatures.

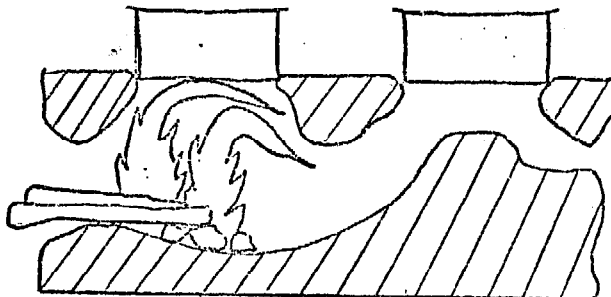
When the draught is correctly adjusted the flame envelope takes the path indicated in Figure 11b.

Figure 11: The path of the flame envelope

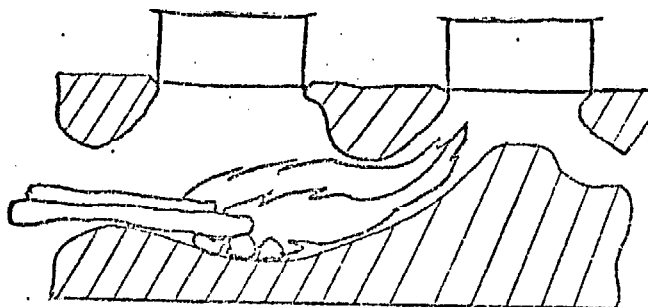
- a. At a low draught the flames impinge on the base of the pot



- b. At the optimal draught the flames lick the base of the pot



- c. At a high draught the flames are drawn into the second pot hole



High rates of heat transfer are attained along with relatively complete combustion. It would appear that positioning the exit flue at the bottom of the combustion chamber has the effect of creating turbulence and increasing the residence time of the volatile gases in the firebox. If the exit flue is not placed

exactly at the rear of the chamber a baffle must be added (as in the LSI stove) (Fig 8) to channel the flame envelope more effectively under the complete area of the base of the pot. Using a baffle in a GS type stove only improves performance when it is necessary to use a large chimney or when the rise in temperature in pot₂ needs to be slower than in pot₁. Front baffles are not recommended as their correct positioning is too critical if maximum performance is to be obtained.

The diameter of the exit flues and the volume of the other pot hole is determined by the total resistance to the flow of the gases that is needed to attain maximum heat utilisation in the cooking process. It is important that the flue holes be large enough to permit cleaning.

The entrance to the flue from the firebox should be slightly wider than the exit with the narrowest point being at the middle of the flue. The flue should angle steeply up to the second pot hole. Unless only one size of pot is to be used in the second pot seat, a GS type design of pot seat should be used. The baffle placed under the pot seat will force the hot flue gases to hit the bottom of the pot, turn sharply and then increase in velocity as they flow parallel to the pot's surface, thus increasing convective heat transfer. The distance between the bottom of the pot and the baffle should be small enough to maximise the convective heat transfer (e.g. in the GS stove 2.5cm was found to be the optimum distance). This optimum distance changes according to the height and diameter of the chimney, the size of stove and width of the pots and shape of the base of the pot.

The exit flue from the second pot hole should start approximately 1.5cm under the lip of the pot seat, and descend sharply to the third pot hole or chimney.

The height of the chimney is determined by:

- 1) the shape of the roof and the position of the stove in the house. If it is to one side the chimney will be short. If it is in the middle of the house the chimney will be high. The chimney should protrude 60cm from the roof;

2) the type of roof used. If the roof is made of flammable material it is preferable to place the chimney through the wall. The chimney should protrude at least 60cm from the wall and should not be close to any other large object (ie another house);

3) the need to use the heat in the flue gas to dry or smoke food or provide heat for the room. Dian Desa and Sarvodaya have found that small chimneys placed inside the room are as effective in improving performance and reducing irritation to the user as large chimneys. However, the smoke must have an exit to escape through the roof or at the top of the walls. Using small chimneys considerably decreases the cost of a stove.

To vary the draught either a damper is placed inside the chimney (not a recommended practice as they deteriorate quickly), or change the size of the chimney. The maximum diameter should not be more than 12cm in order to prevent cold air being drawn in.

It has been the experience of ITDG and its collaborators that a mud stove designed and tested in one country will never be exactly suitable for another cultural setting. It is also probable that no one mud stove design will suit all the different requirements of a region. Thus it is important to develop and test stoves in a regional or local workshop/test centre environment before placing them in the field. In this section an outline will be given of a method that can be used to design and optimise performance of mud stoves.

5.1 Stove Design Guidelines

1. Determine the range of cooking times and amount of food and water cooked.
2. Determine the range of types (and the specific function) and size of pots used;
3. Determine the range of types, sizes and moisture content of fuel available.
4. Determine if it is necessary to have a chimney placed outside or inside and the wind speeds experienced during the year. The former information may be obtained from the users the latter from the local meteorological station. Winds over

10. The results of these tests will indicate whether or not the new stove design is superior to the traditional stove.

Note: The above guidelines have been derived from the results of the work done in the laboratory and the field. The process of improving these guidelines is being continued by ITDG and its collaborators.

Definition of TermsPercentage Heat Utilisation (PHU)

Note: For the cooking time BP_1 , the PHU = PHU_1 and for all other cooking times the PHU = PHU_2 .

$$PHU_1 = \frac{c \sum_{\text{all pots}} W_m (T_f - T_i)}{(E_{fm} W_f - E_{co} W_c)} \times 100 \quad (\%)$$

$$PHU_2 = \frac{c \sum_{\text{all pots}} W_m (T_f - T_i) + lW_e}{(E_{fm} W_f - E_{co} W_c)} \times 100 \quad (\%)$$

where c = specific heat of water = $1 \text{ kcal/kg}^\circ\text{C}$

$$= 4.184 \text{ kJ/kg}^\circ\text{C}$$

(This is equal to the average specific heat between 25 and 80°C)

l = latent heat of water at 100°C = 2.26 MJ/kg

(The latent heat is greater at lower temperatures but the evaporative weight loss at these temperatures is comparatively small).

- W_m = weight of water in pot(s) (kg)
- W_e = evaporative weight loss from pot(s) (kg)
- W_f = weight of firewood burnt in test (including kindling) which is calculated from the initial weight of wood minus the final weight of unburnt wood (kg)
- W_c = weight of charcoal produced in test (g)
- T_i = initial temperature of water in pot ($^{\circ}C$)
- T_f = final temperature of water in pot ($^{\circ}C$)
- E_{fm} = high heat value (gross calorific value) of firewood at moisture content m (dry basis) (MJ/kg)
- E_{co} = high heat value of charcoal at zero moisture content = 29 MJ/kg

Note:
$$E_{fm} = \frac{100E_{fo}}{100 + m}$$

where E_{fo} = high heat value of firewood at zero moisture content = 20 MJ/kg

and for $m = 15\%$ (d.b.), $E_{fm} = 17.4$ MJ/kg

$$\text{Burning Rate (BR)} = \frac{W_f - W_k - W_c}{t} \frac{E_{co}}{E_{fm}} \times 100 \quad (\text{g/min})$$

where W_k = weight of kindling wood used to start fire (g)

t = duration of test from time when main charge of wood has been ignited to the end of test (min)

Cooking Times:

- BP₁ = Time to bring Pot₁ to the boil
- BP₂ = Time to bring Pot₂ to the boil
- BP₁ S₁₀ = Time to bring Pot₁ to the boil and simmer for 10 mins
- BP₂ S₃₀ = Time to bring Pot₂ to the boil and simmer for 30 mins
- BP₂ S₆₀ = Time to bring Pot₂ to the boil and simmer for 60 mins

Table 2.1: LSI TEST RESULTS

Test No. ig 2.1	Defn of test end point	Draught	Moisture % d.b.	Wood Type & Size	Baffles	Hot Stove	Quantity of water		Burning Rate (g/min)	PHU ₁ %
							P ₁	P ₂		
1	BP ₁	Medium	15	Jelatong A	None	x	2	2	30	12
2	BP ₁	Medium	15	Jelatong A	F	x	2	1	30	14
3	BP ₁	High	30	Jelatong A	F	x	2	2	25	15
4	BP ₁	Medium	15	Jelatong A	F	✓	2	2	23	18
5	BP ₁	High	15	Jelatong A	F	x	2	2	22	18
6	BP ₁	Medium	15	Jelatong A	F	x	2	2	19	24
7	BP ₁	Medium	15	Jelatong A	F	x	2	2	18	24
8	BP ₁	Medium	15	Jelatong A	F	x	2	2	18	23
9	BP ₁	Medium	20	Jelatong A	F	x	2	2	18	22
10	BP ₁	Medium	25	Iroko A	F	x	2	2	15	18
11	BP ₁	Medium	15	Jelatong B	F	x	2	2	17	16
12	BP ₁	High	11	Iroko A	F	x	2	2	16	15
13	BP ₁	Medium	30	Jelatong A	F	x	2	2	12	17

A = 2.5cm x 2.5cm x 60cm

B = 2.5cm x 2.5cm x 15cm

F = Front Baffle

Table 2.1: LSI Test Results

Figure 2.2: LSI Stove: Plot of PHU versus Burning Rate at BP₁

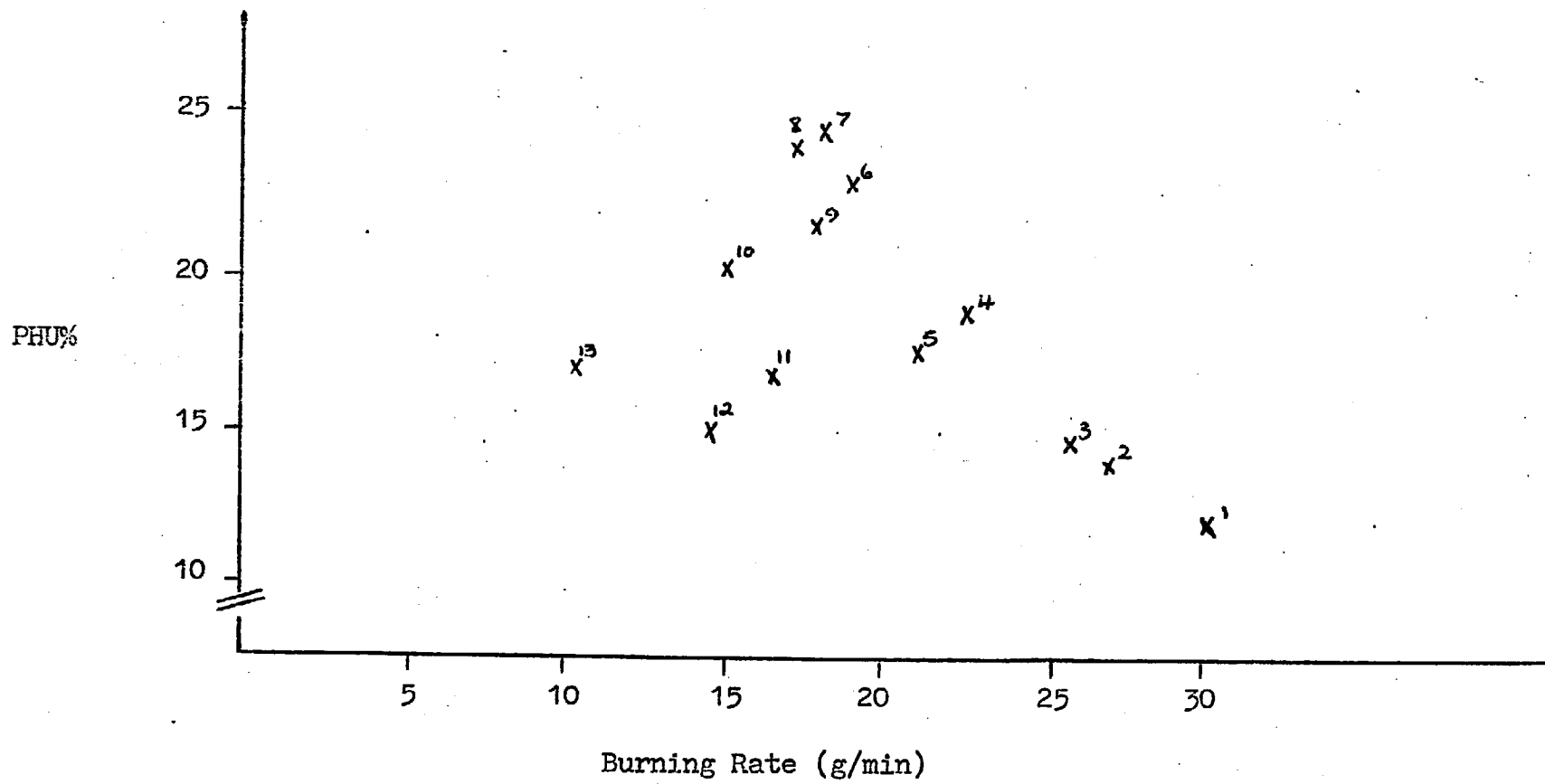


Table 2.3: LSI TEST RESULTS

Test No.	Def ⁿ of test end point	Draught	Moisture % d.b.	Wood Size & Type	Baffles	Hot Stove	Quantity of Water		Burning Rate (g/min)	PHU % ²
							P ₁	P ₂		
14	BP ₁ S ₁₀	Medium	15	Jelatong A	None	x	2	2	28	12
15	BP ₁ S ₁₀	Medium	15	Jelatong A	F	x	2	2	27	13
16	BP ₁ S ₁₀	High	30	Jelatong A	F	x	2	2	25	15
17	BP ₁ S ₁₀	Medium	15	Jelatong A	F	✓	2	2	22	17
18	BP ₁ S ₁₀	High	15	Jelatong A	F	x	2	2	20	14
19	BP ₁ S ₁₀	Medium	15	Jelatong A	F	x	2	2	19	18
20	BP ₁ S ₁₀	Medium	15	Iroko A	F	x	2	2	17	17
21	BP ₁ S ₁₀	Medium	15	Jelatong A	F	x	2	2	17	16
22	BP ₁ S ₁₀	Medium	15	Jelatong B	F	x	2	2	16	22
23	BP ₁ S ₁₀	High	11	Iroko A	F	x	2	2	14	23
24	BP ₁ S ₁₀	Medium	25	Iroko A	F	x	2	2	11	27
25	BP ₁ S ₁₀	Medium	30	Jelatong A	D	x	2	2	9	22

A = 2.5cm x 2.5cm x 60cm

B = 2.5cm x 2.5cm x 15cm

F = Front baffle

Table 2.3: LSI Test Results

Figure 2.4: LSI Stove: Plot of PHU versus Burning Rate at BP₁ S₁₀

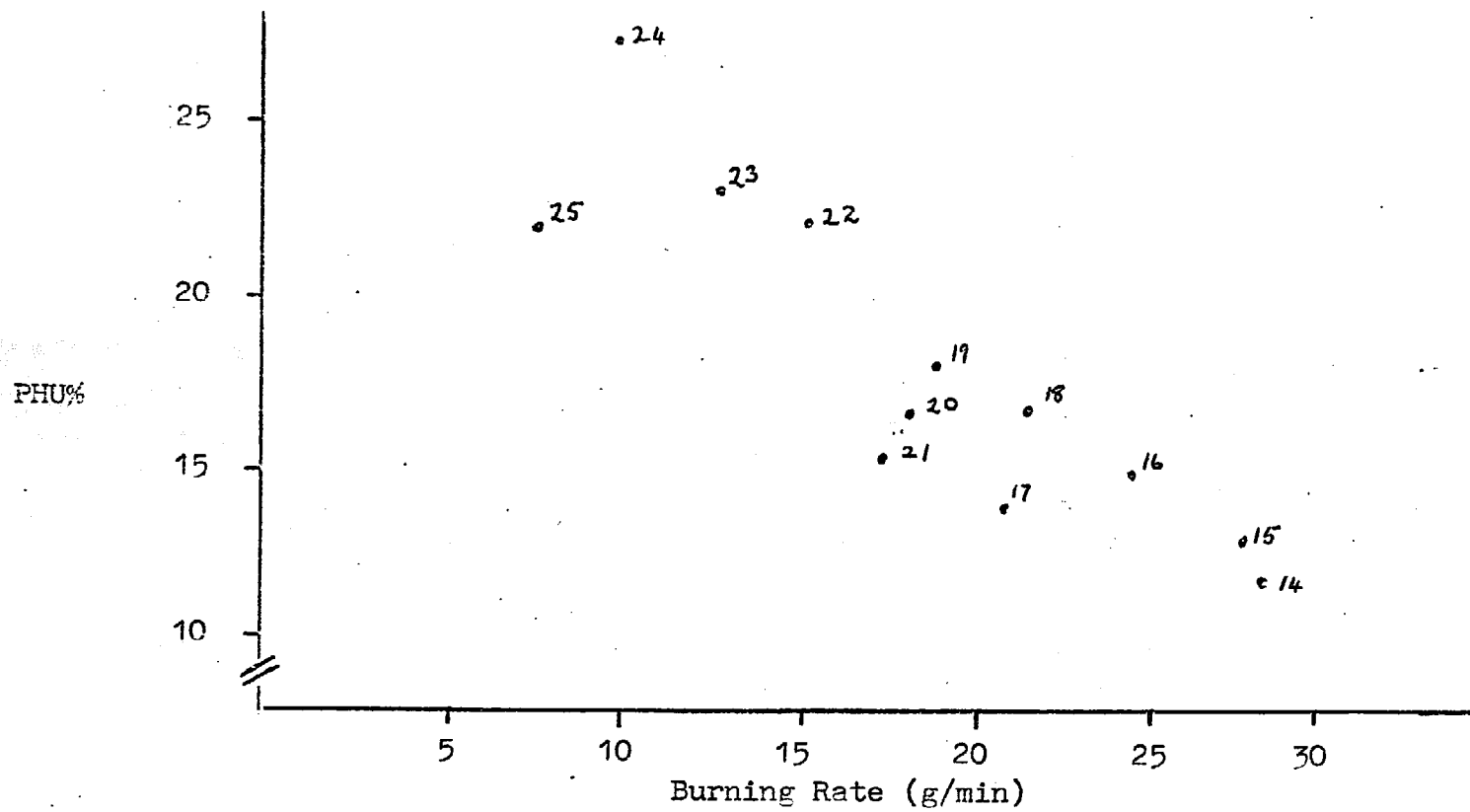


Table 2.5: GS TEST RESULTS

Test No.	Defl of test end point	Draught	Moisture % d.b.	Wood Type & Size	Baffles	Hot Stove	Quantity of Water		Burning Rate (g/min)	PHU * (%)
							P ₁	P ₂		
1	BP ₁	Medium	48	Jelatong A	B	x	2	2	12.0	13.0
2	BP ₁	Medium	47	Jelatong A	B & F	x	2	2	13.0	14.0
3	BP ₁	Medium	15	Jelatong A	B & F	x	2	2	14.5	15.0
4	BP ₁	High	15	Jelatong A	B & F	✓	2	2	14.0	16.5
5	BP ₁	Medium	15	Jelatong A	B & F	x	2	2	16.0	17.0
6	BP ₁	Medium	15	Jelatong A	B & F	x	2	2	18.1	16.5
7	BP ₁	Medium	15	Jelatong A	B	x	2	2	19.0	18.0
8	BP ₁	High	15	Jelatong A	B & F	x	4	2	20.0	16.5
9	BP ₁	Low	15	Jelatong A	B & F	x	2	2	22.0	15.0
10	BP ₂	High	15	Jelatong A	B & F	✓	2	2	22.0	19.0
11	BP ₂	Medium	15	Jelatong A	B & F	x	2	2	21.0	19.0
12	BP ₂	Medium	15	Jelatong A	B & F	x	2	2	21.0	19.0
13	BP ₂	Medium	15	Jelatong A	B & F	x	2	2	20.0	20.0
14	BP ₂	Medium	15	Jelatong A	B & F	x	4	2	17.0	19.0

Table 2.5: GS Test Results

Table 2.5: GS TEST RESULTS (contd)

Test No.	Defn of test end point	Draught	Moisture % d.b.	Wood Type & Size	Baffles	Hot Stove	Quantity of Water		Burning Rate (g/min)	PHU * (%)
							P ₁	P ₂		
15	BP ₂	Medium	15	Jelatong A	B	x	2	2	16.0	21.0
16	BP ₂	Low	15	Iroko A	B & F	x	2	2	15.0	19.0
17	BP ₂	Medium	47	Jelatong A	B	x	2	2	12.0	19.0
18	BP ₂	Low	15	Jelatong A	B & F	x	2	2	11.0	22.0
19	BP ₂ S ₃₀	Low	15	Jelatong A	B & F	x	2	2	18.0	19.0
20	BP ₂ S ₃₀	High	15	Jelatong A	B & F	x	2	2	17.0	18.5
21	BP ₂ S ₃₀	Medium	15	Jelatong A	B & F	x	2	2	16.0	18.0
22	BP ₂ S ₃₀	Medium	15	Jelatong A	B	x	2	2	12.0	21.0

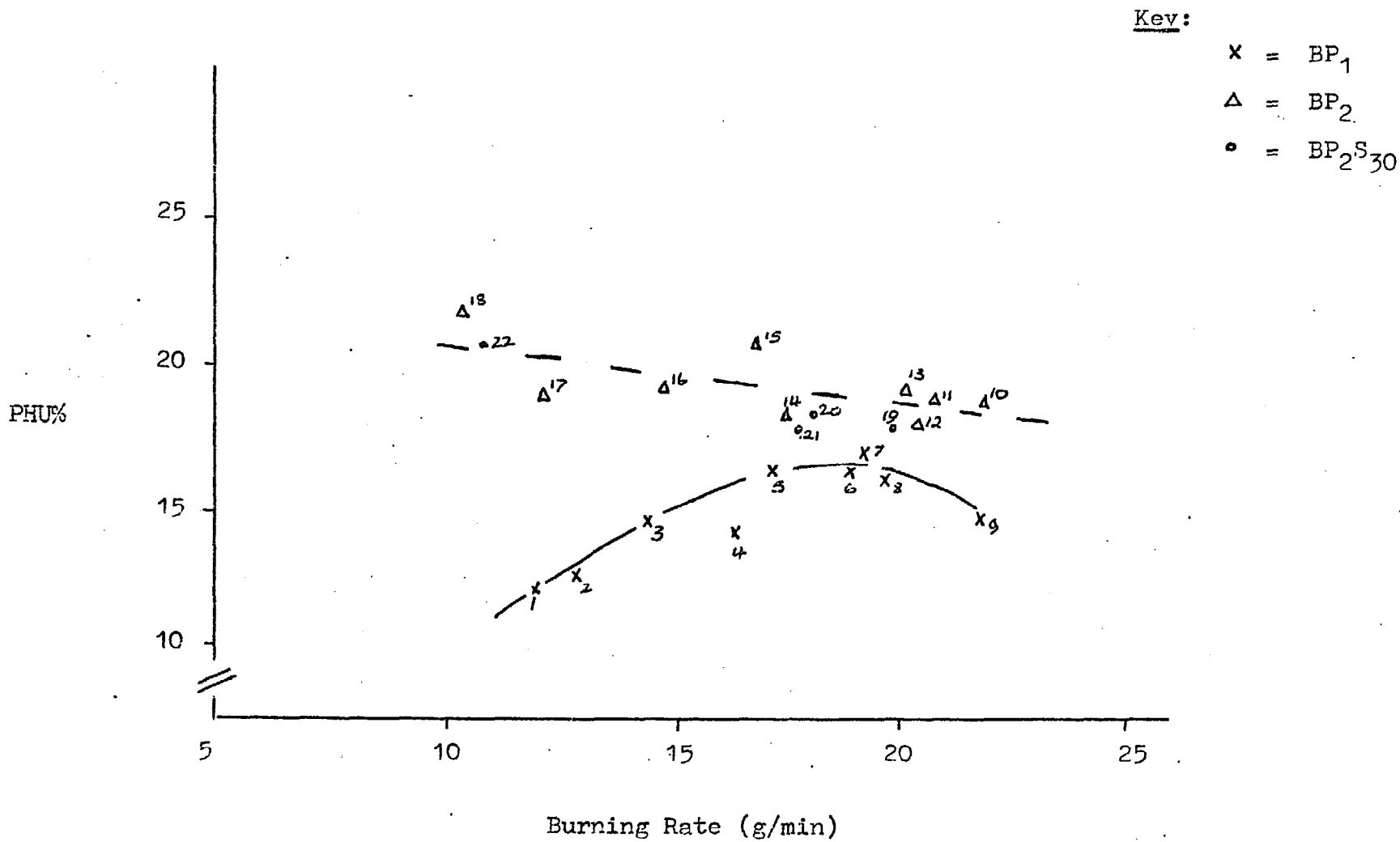
A = 2.5 x 2.5 x 60cm

B = Back baffle

F = Front baffle

* = For BP₁ PHU % = PHU₁ - For BP₂ and BP₂ S₃₀ PHU% = PHU₂

Figure 2.6: GS Stove: Plot of PHU versus Burning Rate at BP₁, BP₂, BP₂S₃₀



-x-

DISCUSSIONS OF TESTS ON THREE STONES FIREPLACE

Introduction

Tests were carried out over the range of cooking times BP_1 , BP_1S_{30} and BP_1S_{60} . The variables examined included wood size, wood type, moisture content, amount of water used and ambient wind conditions (still air, slight draught and gusty conditions, wind speed on anemometer ranged between 5 and 15 mph). The height of the pot above the grate was maintained at approximately 8cm. This corresponded to the suggested optimum height reported by Prasad et al 1980.

It was found that when a three stones fire is carefully controlled and placed away from breeze it performs very efficiently. The average time taken to bring 2 litres of water to the boil was 14 minutes; the wood consumed was approximately 180g (effective weight) and the PHU was 20%.

These are similar to the results found by Prasad et al 1980. Unfavourable operating conditions increased the amount of wood used to 240g (effective weight), the time taken to boil to 18 minutes and the PHU fell to 15%. When boiling double the quantity of water the time and the amount of wood used was also approximately doubled. Under all conditions the PHU increased until BP_1S_{30} , then declined at the time BP_1S_{60} . The moisture content of the wood did not significantly change the performance of the three stones. At 57% moisture content the wood used and time to boil increased by 15-20% and the PHU decreased to 17%. The overall test results suggest that the most important variable to affect the performance was the draught flowing around the fireplace. The relationship between the PHU and the burning rate is shown graphically in Figure 3.1 and Figure 3.2 indicates the scatter in wood used as a function of cooking time.

As the cooking time increased so the variation in performance of the stove increased. At cooking time BP_1 the PHU did not vary over a wide range of burning rates. At BP_1S_{60} the smallest variation due to operating conditions or user inefficiency could affect the stove's performance. This sensitivity could account for the wide variation in the reported efficiencies of open fireplaces.

Figure 3.1: Three Stones Fireplace: Plot of PHU versus Burning Rate at BP₁, BP₁S₃₀ and BP₁S₆₀

Key:
X = BP₁
Δ = BP₁S₃₀
● = BP₁S₆₀

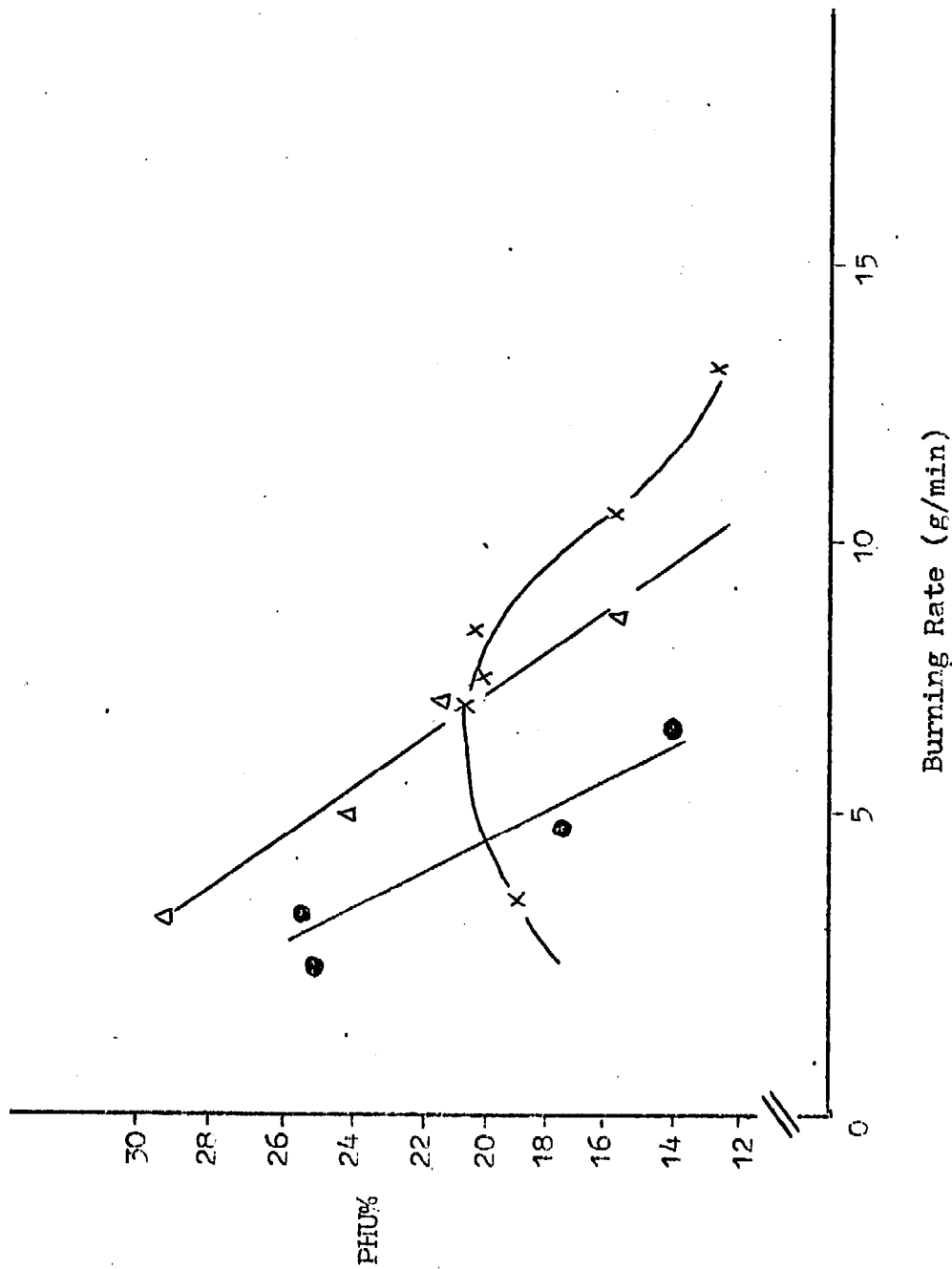
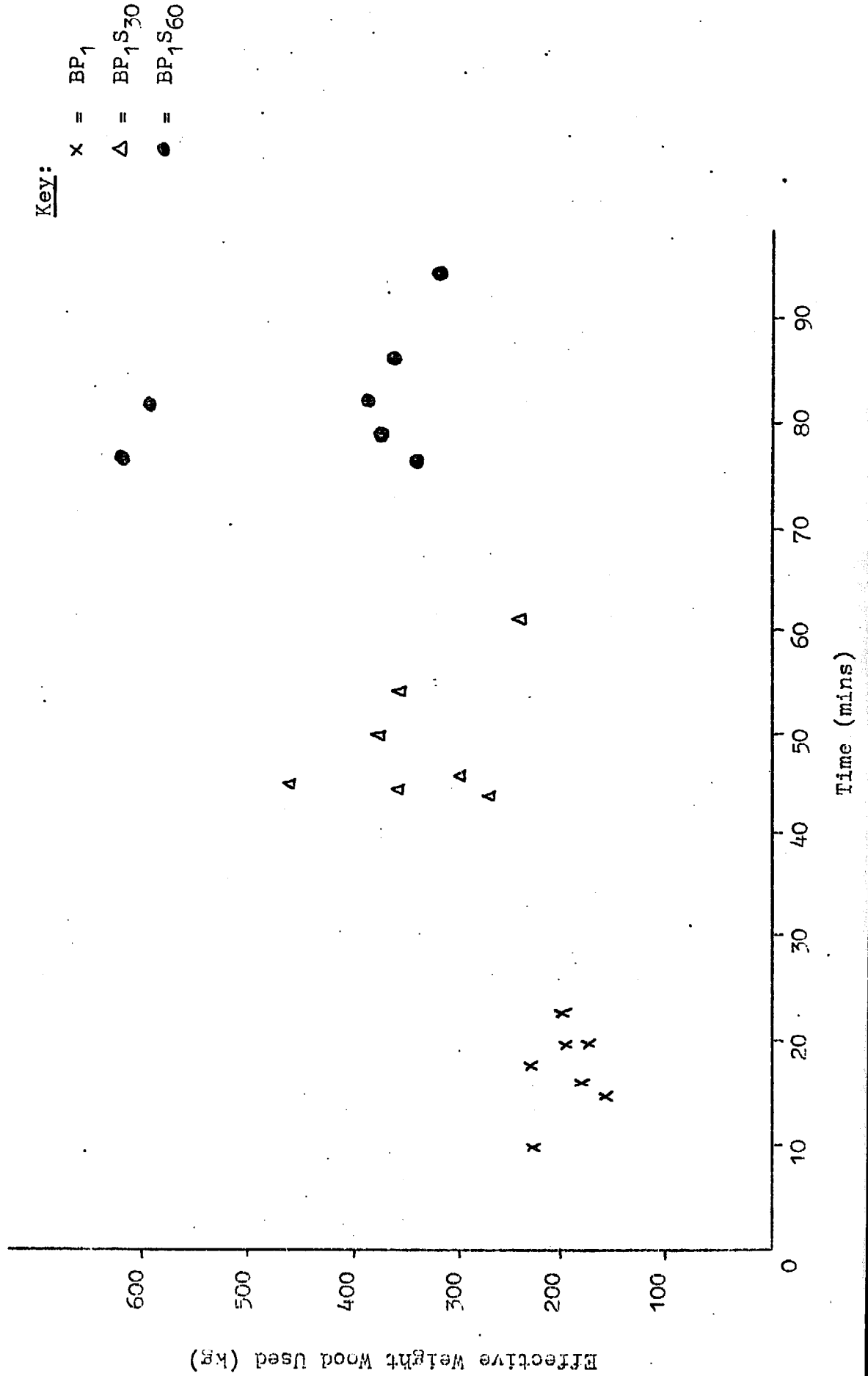


Figure 3.2: Three Stones Fireplace: Plot of Effective Weight Wood used versus Time



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