Designing a Test Procedure for Domestic Woodburning Stoves

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by

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of the

ITDG Stoves Project

November 1980

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1. INTRODUCTION

Over the past 20 or 30 years a number of stove programmes have been established to design and introduce stoves that either alleviate the fuelwood shortage problem or promote kitchen hygiene.

Many of these programmes have failed due partly to the lack of detailed information or suitable laboratory or field testing of particular designs. The aim of this report is to detail:

1. the information needed to provide an initial assessment of the suitability of a stove design; before making and testing;

2. the type of laboratory and field tests required to see that a stove is firstly suited to the required cultural cooking practices and secondly has a better performance than the stoves currently used by the people for whom it is intended.

STOVE PROGRAMME STRATEGY

2. Usually there are two types of people involved in stove programmes, the designers/testers and the programme implementors/ extension workers. Both these groups of people must also interact with the users during all the stages of the programme.

The testing procedure of this report must be viewed within the overall stove programme strategy being developed by ITDG for use by its collaborators. This strategy consists of 7 stages:

1. survey of cooking practices and fuel usage;
2. field testing of stoves already in use in different localities;
3. assessment of other alternative designs to see if they meet requirements found in the initial survey;
4. laboratory testing of suitable alternative designs; construction and testing of completely new designs or modified designs;
5. limited field testing of alternative or modified designs that appear suitable during laboratory tests;
6. extensive field testing of stoves that gain user acceptance;
7. design and execution of extension programmes to facilitate accurate construction and widespread and correct use of the chosen stove in the localities for which it is appropriate. Stimulation of National Government policy development on wood stoves.

2.1 Stage 1

Information on local cooking practices must be obtained if new stoves are to be designed that will perform all the functions of the old stoves as well as using less firewood.

To carry out detailed surveys is a highly skilled, time consuming and expensive operation. In many countries cooking practices and stoves used differ from one area to another. In the future designers will have access to this type of detailed information as more government and research bodies undertake energy use surveys. If this information is not available designers should at least carry out a limited survey in the appropriate area. Visual observations over a period of a few weeks should be taken and a limited number of people interviewed. It is not advisable to use detailed questionnaires or detailed socio-economic studies.

The survey should broadly establish:

1. the local cooking practice (type and quantity of food used, time to cook and method of preparation, where the cooking is done);

2. the cultural rules associated with cooking (eg meal times and any taboos, and sex roles associated with cooking, significance of fireplace);

3. the type and size of pots, stoves and fuel used;

4. who constructs the stove, how it is carried out and time devoted to repair and maintenance;

5. the method of obtaining firewood, (is it gathered in the field or is it obtained from wood dealers? What is the price of the wood or the time required to collect it?)

A literature survey of stove designs should be carried out. Information can be obtained from ITDG (U.K.), VITA (USA) and FAO (Rome).

2.2 <u>Stage 2</u>

Field tests of the stoves currently in use should be conducted to determine the type and amount of wood used in cooking and time taken to cook food or boil water.

2.3 <u>Stage 3</u>

The data obtained from Stages 1 and 2 should be used by the designer to decide whether an alternative stove design will have a better performance than the indigenous stoves and will be culturally acceptable.

Detailed information on other stoves is not often readily available. Designers can send off a questionnaire to be filled in by the persons who have built and tested the stove. This questionnaire, which forms part of the test procedure that has been developed by ITDG in collaboration with the Fiji Department of Forestry (Appendix 1). The questionnaire will help decide the suitability of a particular stove design by providing information on:

1. the dimensions of the stove;
2. the method of construction and type and amount of material needed;
3. the labour required for construction;
4. estimation of lifetime;
5. detailed instructions on how to use the stove efficiently;
6. sort of fuels that the stove can burn and methods of cooking for which it is suitable (e.g. frying, stewing and baking);
7. some estimation of the amount of fuel used in either cooking standardised representative meals or some standardised water boiling experiments;
8. time required to bring different quantities of water to the boil.

2.4 Stage 4

If necessary detailed information cannot be obtained from the questionnaire then laboratory testing will have to be undertaken. If the results of these indicate that the types of stoves tested are not suitable, modification to the indigenous stoves must be undertaken or new stoves designed.

2.5 Stage 5

Having ascertained the possible suitability of a stove design from the results of the laboratory tests, performance data under field conditions must now be obtained. We have found that the best way to do this is to provide a limited number of stoves to families who have had previous interest in development programmes. Ideally one should carry out the following experiments. One group of stoves should be constructed by artisans or field workers who have received extensive training and practice in building the stoves; while the other group would be built by artisans or field workers who have had limited training and practice in building the stoves. For each group of stoves, half the women using them would be trained in using the stoves and half would not be trained.

In some cases it may not be possible to carry out this type of controlled experiment. A larger number of stoves should then be introduced into a few villages that have had previous contact with the extension agency. Performance of these stoves should be measured at the start of the trials, and at periods of three and six months. The results of the experiment should provide information on:

1. user reaction to the new stove;
2. how crucially affected the stove performance is by the accuracy of construction, efficiency of operation and stove deterioration;
3. possible design modifications that could improve the acceptability or performance of the stove.

2.6 Stage 6

The limited field testing is now extended to further villages in the area.

2.7 Stage 7

The likelihood of widespread acceptance should now be assessed on the basis of the previous extension exercise. If the results are favourable, expanded extension programmes can be designed. A National woodfuel policy that involves positive government support is essential to promote widepsread dissemination of stoves.

It is also essential that the women users are involved in all aspects of the stove programmes.

3. LABORATORY TESTING

Although laboratory testing will never indicate whether a stove will be acceptable to users it can give a good indication of the comparative performance of different stoves under specific conditions.

The task of choosing a suitable stove would be made much easier if a standard test were used by all stove designers. In practice this is not feasible because of the difficulties of standardising ambient conditions; test equipment; wood type and moisture content; operation of the stove and cooking procedures.

Since it is impossible to devise a standard test, ITDG has instead evolved a standard test procedure for reporting the methods of testing and results of field and laboratory test work. A record of this detailed information will enable designers to:

1. determine how a test method used by other designers differs from their own;

2. use this test method to compare other stoves with the indigenous design(s) tested. Thus a more accurate assessment between stoves' performance can be obtained.

The test procedure evolved by ITDG and its collaborators will be discussed fully in this report. Our joint experience has shown that this test procedure provides:

1. a comparative assessment of performance between indigenous and alternative stoves;

2. an indication of design modifications required to improve the performance and the cultural acceptability of the stove;

3. a greater understanding of the principles of stove design and a confirmation or rejection of preconceived ideas;

4. identification of the potential problems involved in the extension of the stove(s).

Three types of tests need to be undertaken in the test procedure. These are described here as physical tests, cooking tests and operator tests. We have found that these tests will indicate how the stove performance is affected by changes in the following parameters:

1. type and size of fuel;
2. moisture content of fuel;
3. ambient conditions (such as wind speed);
4. draft;
5. cooking time;
6. type, size and number of pots used;
7. size and shape of combustion chamber.
8. operator skill (such as stacking of wood and the use of dampers.

3.1 Experimental Procedure

In theory experiments are carried out by holding constant all except one of the parameters that affect stove performance. This parameter is then changed and the resultant change in performance is noted. In practice it is very difficult to keep all parameters except one constant over a series of tests. Ambient conditions (wind and temperature) will change causing a difference in the flow rate of air into the firebox. The stove often deteriorates (especially mud stoves) and it is difficult to repair it to its original shape. It is therefore very difficult to get repeatable results to within 10-20% accuracy.

These variations are enhanced if the tester does not operate the stove in the same way for all experiments. Improper stacking of wood and inconsistent attention can make a big difference in the performance figures obtained (up to 100%).

Thus it is important to standardise the method for testing a stove. An example of such a method which can be used for both field and laboratory testing is given in Appendix 2.

The number of species of wood tested should be limited to two or three types. These should represent either the most frequently used or species that have widely differing burning characteristics, (ie, light fast burning wood versus a dense slow burning wood). It is very important to keep a constant check on the moisture content of the wood as a variation can greatly affect the test result. It is also important to be consistent in feeding the wood into the stove during the experiments.

It must be emphasised that the experiments can be carried out using only thermometers, scales, clocks and a drying oven (to standardise moisture content of the wood). The more sophisticated test beds used by some laboratories consist of the following measuring and/or recording instruments:

1. a set of sclaes on which the stove sits, or some other arrangement that enables the weight of wood to be measured continuously as it is burnt;

2. a series of thermocouples placed inside and at the stove walls to measure the flow of heat into and out of the stove body;

3. a pipe to take off a sample of the gases leaving the stove. This pipe leads to instruments measuring volume percent of carbon dioxide and carbon monoxide, water, and in some cases unburnt hydrocarbons and solid carbons in the gases;

4. thermocouples that continuously read the temperature of the water in the pots;

5. a draft gauge or pitot tube to measure velocity of the gases in the chimney.

3.2 Physical Tests

Physical testing essentially involves the measurement of the flow of heat (energy), generated from the burning wood, into and out of the stove and into the cooking pots. The object of these tests is to be able to maximise the flow of heat into the cooking process.

Physical tests are carried out using pots filled only with water; these tests are generally described as 'boiling water' tests. There has been a great deal of controversy on the way these tests should be carried out. It has been found that a number of methods are being used all of which will give different results. The methods are:

1. a fixed charge of wood is burnt. The time taken for the amount of water evaporated when all the wood is consumed is recorded;

2. a fixed charge of wood is burnt and the number of times a fixed quantity of water can be brought to the boil is recorded;

3. a fixed quantity of water is completely evaporated off and the time taken and the amount of fuel used is recorded;

4. a cooking time is set after a fixed amount of water is brought to the boil then the amount of wood used, charcoal remaining and the quantity of water evaporated off is recorded.

In our physical testing we have opted for method number 4 as it is most closely related to the way people cook. For meals that involve boiling, the usual procedure is to stoke up the fire in order to bring the water to the boil as quickly as possible. The fire would then be controlled to allow gentle simmering. At the end of cooking the wood would be removed. Usually the charcoal remaining is used for roasting or baking or for cooking the next meal.

We have based the time length of the experiments on this simple cooking procedure. Thus times considered are:

1. Time to boil pot 1
2. Time to boil pot 1 + 10 minutes
3. Time to boil pot 1 + 30 minutes
4. Time to boil pot 1 + 60 minutes
5. Time to boil pot 2
6. Time to boil pot 2 + 30 minutes
7. Time to boil pot 2 + 60 minutes
8. Time to boil pot 3
9. Time to boil pot 3 + 30 minutes

3. Processing Results of Physical Tests

At the end of an experiment the raw data is collected on a Data Sheet (Appendix 3). A summary of results will give:

1. weight of wood used and charcoal remaining;

2. time taken to boil different pots or final temperature in pots 2, 3 ....

3. the amount of water evaporated from the different pots;

4. the average stack temperature, composition of the flue gas and temperature of stove body.

This data forms the basis for comparison between different experiments on the same stove and between different stoves. To further aid in comparing stoves a so called 'efficiency' figure is usually calculated. This efficiency figure takes into account the quantities of charcoal formed and water evaporated when the experimental conditions are changed, and the different types of wood used. Calculation of efficiency is based on the method used in evaluating the performance of a boiler.

3.3.1 Heat Utilised

Since cooking is a quite different process than raising steam in a boiler we have preferred to calculate a factor which we term 'Heat Utilised'. Heat utilised is simply the heat absorbed by the water, divided by the heat liberated from the burning wood. There are a number of different ways that can be used to calculate the heat utilised. Two of these are given in Appendix 4. They are presented as percentage figures HU_1, and HU_2

It is recommended that both the heat utilisation figures are calculated in order to provide a guide on how cooking procedures change the value of HU_2. HU_2 includes the heat used in evaporating water. This may be considered as useful heat absorbed when the evaporation of water is a necessary part of the cooking process (eg in stewing or steaming). Alternatively it may be considered as a loss of heat when the object is to conserve water (eg vegetable cooking).

It needs to be emphasised that the cooking procedure, ie, the time taken and method of operation should mirror that used in the village as closely as possible. The authors have found that a deviation from village practice will distort the heat utilisation figures. We found that in one experiment where we wanted to bring 2 pots of water to the boil, if we interchanged the second pot with the first at the boil, we used 700gms of wood, took 24 minutes and calculated an HU_1 of 12.34%, and an HU_2 of 13.2%. When we did not interchange the pots, we used 1014gms of wood, took 42 minutes and calculated an HU_1 of 8.1%, and an HU_2 of 18.8%.

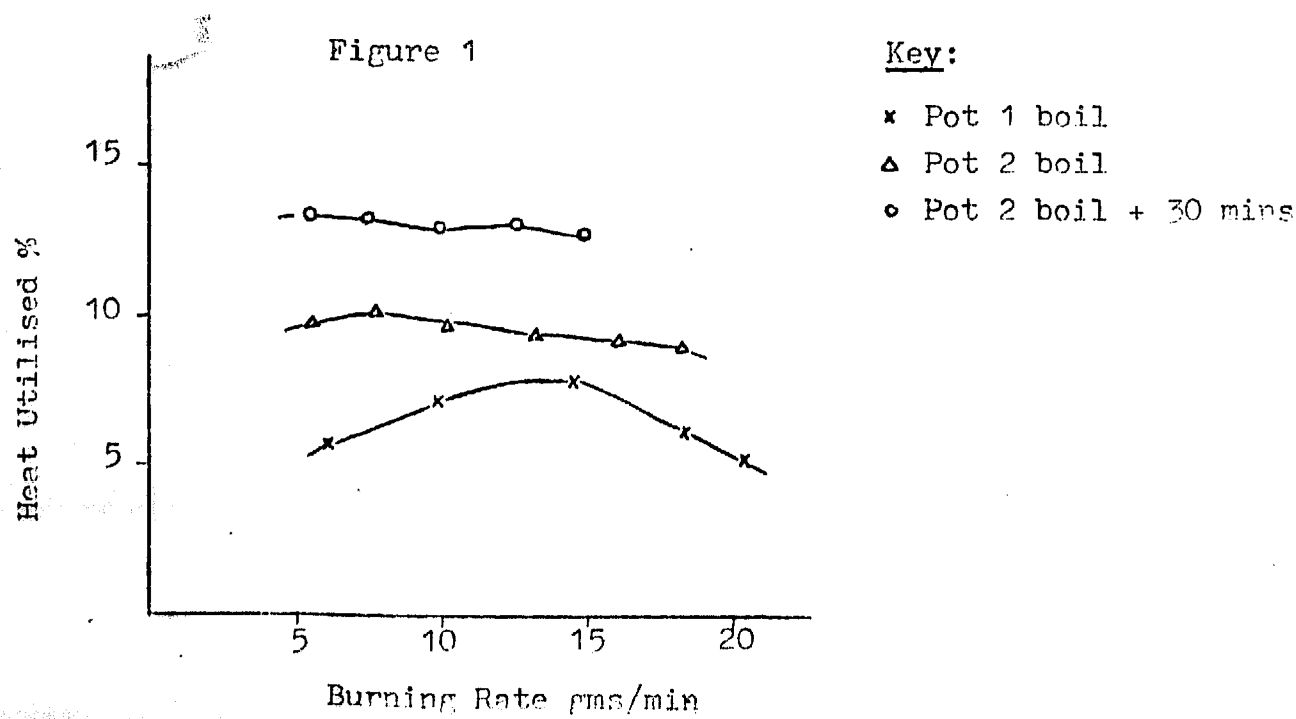
3.3.2 Burning Rate

As well as calculating heat utilisation figures, the burning rate of the wood is also calculated. Burning rate is defined as the amount of wood burnt in the experiment, divided by the duration of the experiment. It is expressed as gms/min. The method of calculation is given in Appendix 3.

The burning rate changes as the different stove parameters are changed, eg, large pieces of wood burn more slowly than small pieces.

Burning rates are calculated over a range of cooking times. HU_2 (or HU_1 if no water is evaporated) is plotted against the burning rate (see Fig 1).

Figure 1



The heat utilised is a function of the burning rate. Ideally, the stove's performance should not vary over a wide range of burning rates. The degree to which a stove performance does vary with burning rate gives an indication of how important it is to train people to use the stove correctly.

The time taken for a stove to become insensitive to changes in burning rate also indicates the type of cooking that it is best suited for. This will be discussed in a subsequent report.

We feel that it is more important to compare the variation in heat utilisation for differing burning rates between stoves than the actual heat utilisation figures alone. Thus to say one stove utilises 14% of the wood's energy as compared with 20% in another has little value.

3.3.3 Heat Balances

The next series of calculations that may be carried out are heat balances. Since accurate heat balances are difficult to perform the reader is advised to turn to Appendix 5 for a full discussion.

Ideally, heat balances should give an indication as to the effect on heat transfer to different parts of the stove and on combustion (burning) efficiency as the different experimental conditions are changed. Due to various difficulties this has not yet been realised.

3.4 Cooking Tests

Cooking tests carried out in the laboratory measure the amount of wood used and the time taken to cook a variety of standard meals under controlled conditions. In the field (see p. 17) it is often very difficult to carry out a controlled cooking test to produce repeatable results, so the value and necessity of laboratory cooking tests are obviously complimentary to the physical and operator tests also carried out in the laboratory.

The principle objective of cooking tests is to determine the influence of the stove design on the amount of wood used and time taken to cook a meal. To do this it is necessary to develop a standard test procedure to minimise any variations in the results due to differences in:

1. variety, size and wetness of wood;
2. the sequence of cooking operations;
3. type and quantity of food.

The information gathered in the field survey of cooking practices should be used as the basis for development of standard cooking test procedures. The survey should have provided a profile of the type and quantity of food cooked for each meal throughout the day. For the purposes of the test, it is best to focus on the main meal of the day. To obtain repeatable results, it is desirable that the sequence of cooking operations be as simple as possible without losing its authenticity.

Before undertaking a series of cooking tests it is necessary to ensure that sufficient test fuel and all food items will be available over the period of time and will not be subject to drastic seasonal changes in quality. This needs to be carefully watched especially when fresh produce is used in standard tests. This is because food quality, and especially that of meat, will affect the time taken to cook it, and hence the amount of wood used. Judgement of the 'doneness' of food also presents a problem in testing due to it being largely a subjective assessment, which will vary from cook to cook. Ideally one person should carry out the tests to introduce some consistency and should have experience of the tastes of potential stove users.

3.5 Operator Tests

These tests enable an assessment to be made of the demands upon the user (operator) when operating a stove which is subjected to a range of conditions. The tests concentrate on the main components of operation, ie, starting a fire, attending it, controlling it and maintaining the stove.

The objective of the tests are to evaluate the ease of user operation and ascertain the conditions for optimum ease of use. All problems associated with the operation of the stove should be identified. The basic test method will follow that of the physical testing.

The main areas of investigation are:

1. Ignition - this is recorded as the time needed from the point of lighting the kindle to a steady burning of the test wood.

2. Fire Attendance - this is the frequency and degree of attention needed to keep a steady fire going or a bed of charcoals glowing.

3. Fire Controlability - this is assessed as the ease or difficulty in lowering or increasing the level of heat output from the fire.

4. Operator convenience and maintenance - observations should be made on the interchangeability of pots in the pot seats; the ease and frequency of cleaning necessary and the type and extent of regular maintenance needed.

It is considered that the ignition, fire attendance and fire controlability are the most important factors in evaluating the ease of user operation. Hence if these are affected by a change in operating conditions, it follows that the operative demands upon the user will also be affected. In order to assess these demands, a range of different conditions should be investigated in the stove's operation. These are variations in the type, size and wetness of wood; the draft of air through the stove; positioning of baffles; starting of fire in a hot/cold stove and operating for short and longer periods.

It must be stressed that these laboratory tests are only complimentary to and not a substitute for field trials in which the opinions of a number of users are sought on the operation of the stove.

3.6 Processing Results of Operator Tests

Obviously direct measurements of ignition, fire attendance and fire controlability cannot be made, so it is necessary to develop a rating scale for each of these components. The following scales are considered to be a reasonable and convenient means of indicating the effects of the different variables on the operative performance.

A 5 point rating scale may be used in each case as follows:

1. Ignition	5	- less than 1 minute
	4	- 1 - 2 minutes
	3	- 2 - 3 minutes
	2	- 3 - 4 minutes
	1	- 4 - 5 minutes
2 Fire Attendance	5	- every 8 - 10 minutes
	4	- every 6 - 8 minutes
	3	- every 4 - 6 minutes
	2	- every 2 - 4 minutes
	1	- every 1 - 2 minutes

3. Fire Controlability

5	-	Immediate
4	-	Good
3	-	Fair
2	-	Poor
1	-	Very poor

(A rating of 5 would indicate a control of heat output comparable with a gas burner)

4. FIELD TESTING

Cooking is part of the socio-cultural fabric of any society. Thus user reaction and test results must be related to this fabric. Before embarking on any tests the basic information of a village's social and political structure, economic base, ecological profile and the cultural forces associated with cooking must be ascertained from key members of the village and from the local stove project officer, (See Appendix 6 for example of a survey carried out in Indonesia).

4.1 Experimental Procedure

A survey is conducted on the range of stoves used in the village. Cooking tests are then devised to either simulate or mirror local cooking practices. Under ideal conditions a number of tests should be carried out in each household to cover the range of meals cooked and the types of wood used. In practice it is not possible to:

1. disrupt the routine of the families for more than one meal;

2. keep ambient conditions constant from one day to the next (especially wind which affects draft);

3. obtain a large quantity of wood of the same type and moisture content;

4. obtain the same type and size of cooking pots. (Mud stoves are often constructed so that only a certain size of pot can be used in the cooking holes).

In addition it is sometimes difficult to obtain enough food for extensive series of tests and then the following procedure is used:

Tests are first carried out on indigenous stoves using the chosen standardised meal. The time taken is noted and amount of wood used is recorded. This experiment is repeated three times and the results averaged. Using the same wood, same cooking time and replacing the quantity of food used (on weight basis) by water, the test is repeated. If the amount of wood used does not differ by more than 15% then all other tests in that village can be carried out using water instead of food. Tests are then carried out on the new stoves.

At the end of the test run the household owners are asked if:

1. They liked the new stove and why?

2. Does the new stove use more or less wood than the traditional one, by how much?

3. Does the new stove cook faster or slower than the traditional stove?

4. How often do they use the new stove and what for?

(For those people who have removed the traditional stove question 4 need not be asked as they have obviously found the stove acceptable under all cooking situations)

The final questions that are asked are:

5. What improvements would you like to see in the new stove?

6. Would you prefer a different type of stove? Outline the design.

The answers to questions 1-4 can be checked against the results of the tests. If the stove is warm at the start of the experiment and there is accumulated ash in the firebox then it is obviously being used. If the test results do not tally with the answers to question 2 the stove interviewer can try to discern if the stove performs better at longer or shorter cooking times. If the response is inconclusive and if the traditional stove is still in use the interviewer can either conclude that:

1. People do not wish to offend the interviewer;

2. the stove does not perform to the satisfaction of the user (we have found that a user who has an exceptionally good stove will usually enthuse about it).

4.2 Processing Results of Field Tests

At the end of each test the heat utilised (using an estimated moisture content) and the burning rate should be calculated.

The initial conclusions of the test results and answers to the questionnair should then be reported to members of the household in terms which they can understand with an explanation of why the stove is working or not working. They should then be told how the stove performance could be improved and asked whether they wish to make the improvements or whether they want a different stove.

Later on, graphs should be plotted of CO_2, O_2, stack temperature and pot temperatures as a function of time. Comparison is made between the stove under test and other stoves that have been tested. Quantities compared are the wood used, the time to boil, the time to form charcoal and the heat utilised.

4.3 Example of Interpreting Field Test Results

The example has been taken from field test work carried out in Indonesia on a traditional stove and two examples of Lorena mud stoves. The results are given in Table 1 below.

Table 1 - Results of Tests on 3 Indonesian Stoves

Stove Type	Wood Type & moisture content (% dwb)	Wt Wood used (gms)	Wt Charcoal remaining (gms)	Time to boil (mins)	HU_1 (%)
1 Traditional 2 cooking holes	Acacia 18	1070	120	25	6
2 Lorena 3 cooking holes	Leucena 22	710	200	15	22
3 Lorena 3 cooking holes	Kopah 24	1180	290	20	13

Comments: Three litres of water were brought to the boil in pot_1, .5 kg of corn was roasted in pot_2. In stoves 2 and 3, nine litres of water were heated up in pot_3. HU_1 included the heat absorbed in pot_3 as well as pot_1.

It is seen from Table 1 that the performance of stove number 2 is superior to 1 and 3. Figure 2 shows that after an initial starting period the temperature of the gas leaving the stove number 2 rises very steeply along with the carbon dioxide, while the oxygen composition decreases. Once a bed of charcoal is formed the stack temperature and the CO_2 composition fall to around 200°C and 6-7% respectively. This stack temperature and composition remains constant as long as some wood is burning on the bed of coals. These are the optimum conditions for simmering or roasting. It should be noted that for rapid heat transfer to take place a high flame temperature must be achieved (radiation being the predominant mechanism of heat transfer in the combustion chamber). High flame temperatures are indicated by low excess air (low percentage oxygen) and high carbon dioxide content.

For stove number 3, the rate of heat transferred to pot_1 is a lot slower. The stack temperature and CO_2 rises very slowly and the composition of oxygen in the chimney gases is high (Figure 3). On careful examination of this stove it was found that the chimney was not placed high enough above the roof thus reducing the draft. The damper slots were misaligned which rendered them ineffective. The overall performance of this stove was not significantly better than the traditional stove.

It should also be noted that the burning rate for stoves 1 and 3 was much higher than for stove number 2. It has been found that for all Lorena stoves the optimum burning rate to bring pot 1 to the boil is between 15-18gms/min, (the measurement of burning rate is a useful means of checking if a stove is running efficiently when a set of scales and a watch are tge only instruments available).

It would appear from these tests that the accurate construction of the Lorena stove is important if its performance is to be much better than a traditional stove. Thus stove builders must be given adequate training and extension workers should check for stove faults (see Appendix 7 for an example of a check list for ascertaining stove faults).

Figure 2. Stove No. 2

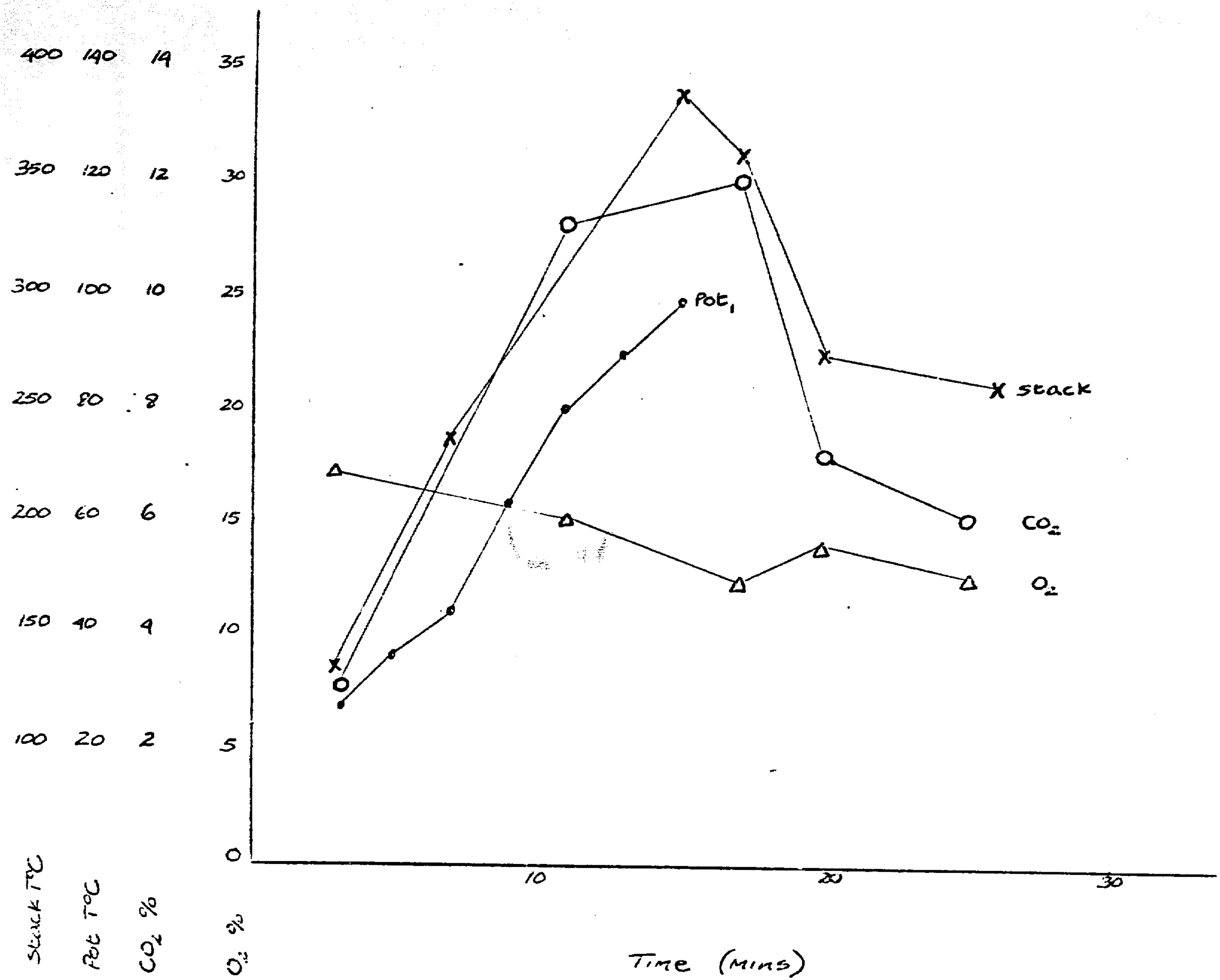
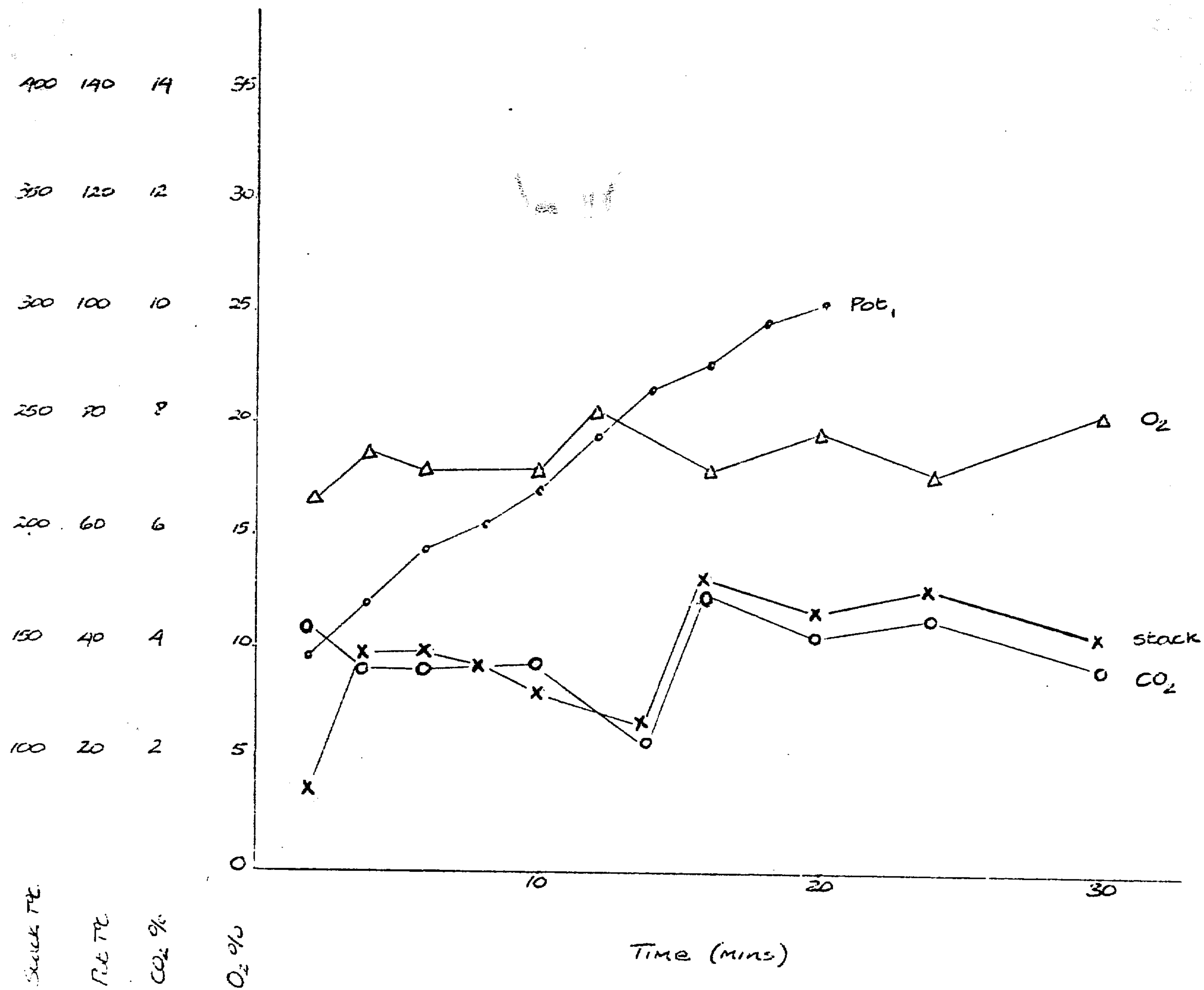


Figure 3. Stove No. 3



5. INTERIM CONCLUSION

The test procedure detailed in this report has been tried out over the last year by ITDG and its collaborators. In general, we have found the procedure to be satisfactory but we intend to continue improving it and to publish details periodically. We would welcome any comments and criticisms of the test procedure.

STOVE QUESTIONNAIRE

1. General Information

1.1 Name of stove ....

1.2 Origin:

a. Country ....
b. Region ....
c. Organisation ....
d. Designer ....

2. Construction Information

2.1 Date of construction ....

2.2 Construction by:

a. Artisan Yes/No
b. Stove owner Yes/No
c. Small Rural Industry Yes/No

2.3 Construction Materials:

	Weight	Cost	Local	Import
a. Mud (sand and clay)				
b. Mud and additives				
c. Clay bricks, sun dried				
d. Clay bricks, fired				
e. Ceramic				
f. Ceramic and additives				
g. Portland Cement				
h. Refractory cement				
i. Cement-crushed fire-clay				
j. Steel sheet (gauge....)				
k. Steel plate (thickness...mm)				
l. Cast iron				
m. Other (specify)...........				

2.4 Construction time:

a. Skilled labour .... (person hours)
b. Unskilled labour .... (person hours)
c. Owner's labour .... (person hours)

2.5 Construction Detail:

Give brief description of construction and the tools and equipment needed.....................................
....
....

2.6 Total construction cost (in courrency of country)......

2.7 Estimated Lifetime ....

a. Has the stove been used continuously? Yes/No
b. How often is the stove used........(times a day)
c. By whom?..

3. <u>General Design Information</u>

3.1 Overall dimensions:

a. Length ....cm b. Width ....cm
c. Depth (or height from ground) ....cm
d. Attach sketches

3.2 What type of fuel can the stove burn?

a. Charcoal Yes/No
b. Wood Yes/No
c. Rice husks Yes/No
d. Straw Yes/No
e. Others (specify)..................................

3.3 What type of domestic cooking is the stove used for? Give details of meals and method of preparation.

....
....
....
....
....
....

3.4 Does the stove have any other functions?

a. Space heating Yes/No
b. Food processing (eg smoking) Yes/No
c. Water heating Yes/No
d. Baking Yes/No
e. Others (specify)................................

3.5 Maintenance Requirements:
What type of maintenance is carried out?

a. Cleaning of flues Yes/No How often?.......
b. Replacement of flues Yes/No How often?.......
c. Repair of main body Yes/No How often?.......

Give a brief description of how main stove body repairs are carried out:

....

....

....

d. Any other regular maintenance?...................

....

3.6 Safety:

a. Has the chimney caught fire? Yes/No
b. Does ash or coal fall out of the stove Yes/No
c. Others (specify)..................................

4. Detailed Design Information

4.1 Number of holes for pots ....

4.2 Are these holes designed to accommodate:

a. Flat bottomed pots Yes/No
b. Round bottomed pots Yes/No
c. Both types Yes/No

4.3 Can the pots be inserted in flue gas stream Yes/No
How far do they sit inside? ....cm

4.4 Oven included Yes/No
Inside dimension: Length ....cm Width ....cm
Depth ....cm

4.5 Hot water boiler Yes/No
Inside dimensions: Length ....cm Width ......cm
Depth ....cm

4.6 Chimney

a. Materials ....

b. Height ....cm Diameter inside.......cm

c. Damper Yes/No

d. Rain arrestor Yes/No

4.7 Primary Air control Yes/No

4.8 Secondary Air control Yes/No

4.9 Hearth size: Length ....cm Width ....cm
Depth ....cm

4.10 Hearth Door Yes/No

Size: Length ....cm Width ....cm

4.11 Grate Yes/No
Size: Length ....cm Width ....cm

4.12 Type of air flow through the combustion chamber:

a. Downdraft
b. Updraft
c. Cross draft
d. Diagonal draft
e. S-draft

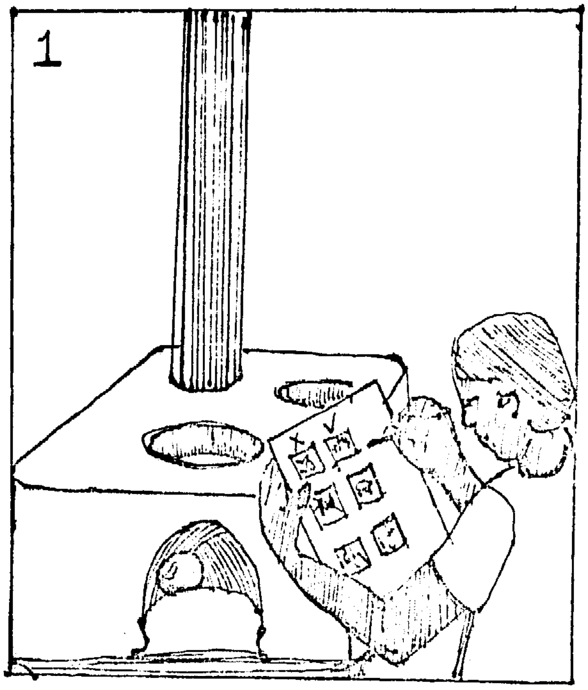
4.13 Baffles: Yes/No
Number .... Materials ....

5. <u>Test Information</u>

5.1 Has the stove been tested Yes/No

Give details of tests carried out.......................
....
....
....
....
....
....

STANDARD TEST METHOD

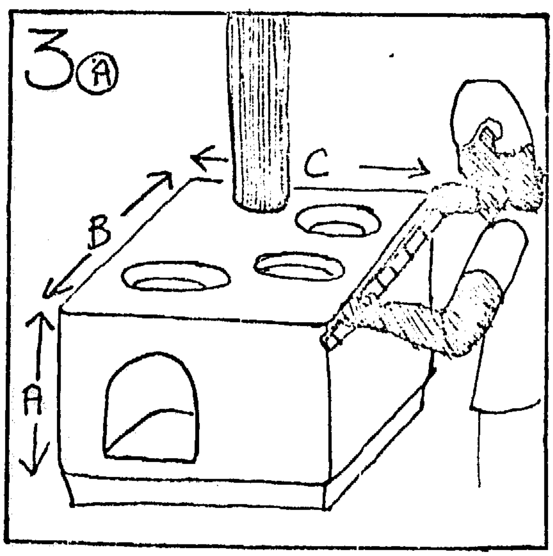


Examine stove for faults using check list.

2

1) Type of food ....
2) Quantity ....
3) How long was it cooked for? ....
4) How was it cooked? ....
5) How did you tell when it was cooked? ....

Note down cooking procedure.

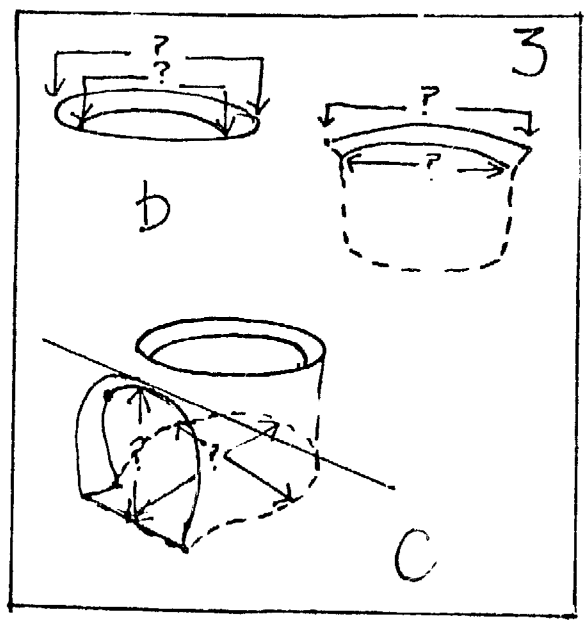


Measure the size of the stove walls:

A:

B:

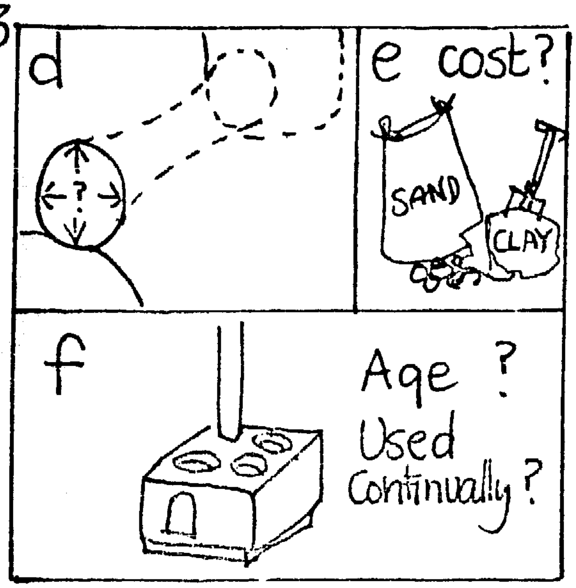
C:



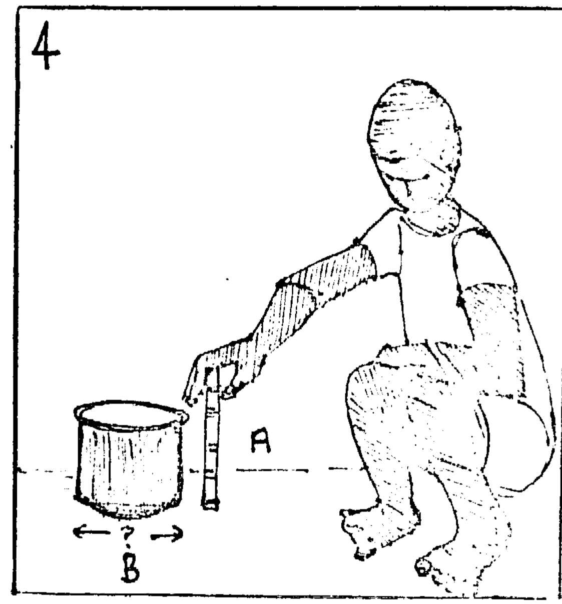
b. measure size of pot holes — hole diameter and lip diameter.

C. measure depth and width

3

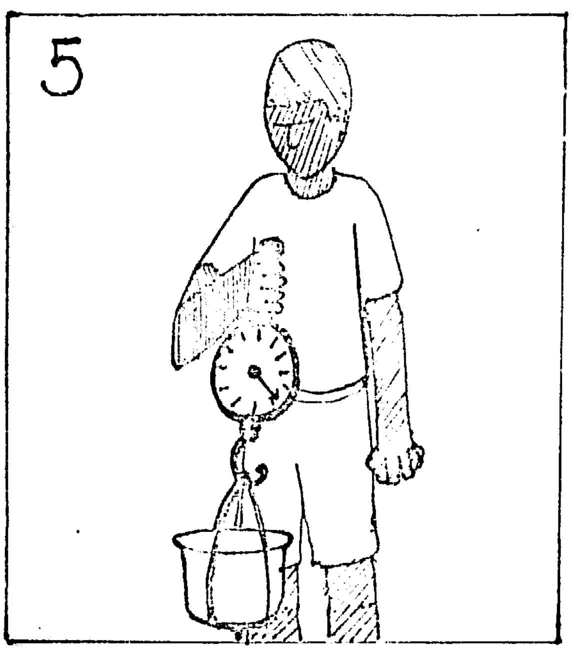


d. entrance way dimensions.
e. materials used and cost.
f. age of stove? Has it been in continual use?

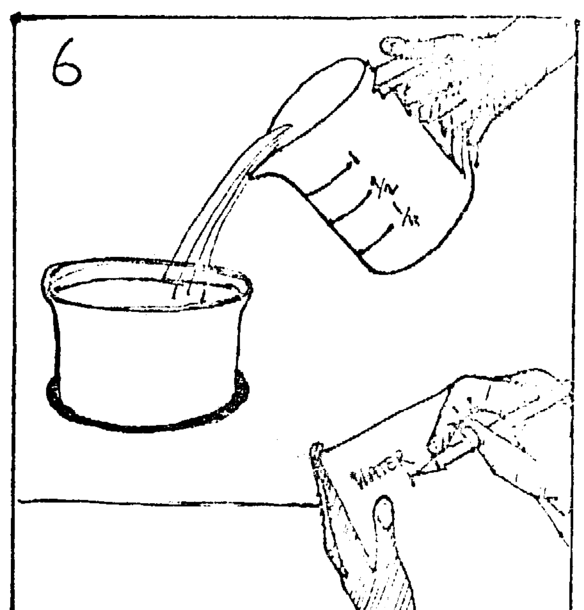


Measure size of pots: width and height.

Pot 1 A.... B....
Pot 2 A.... B....
Pot 3 A.... B....

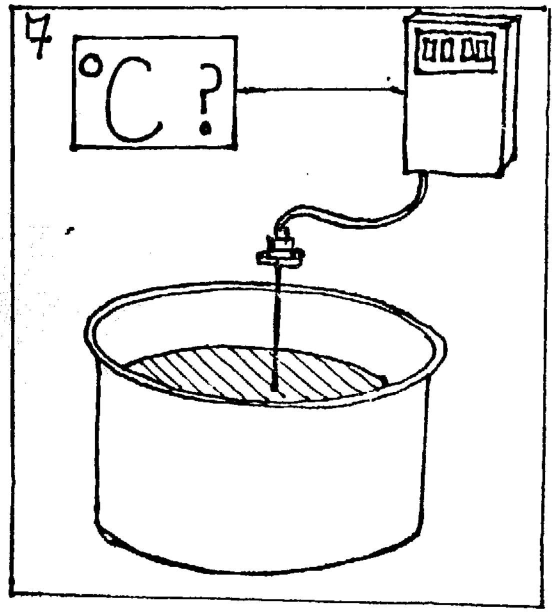


Weigh pots.

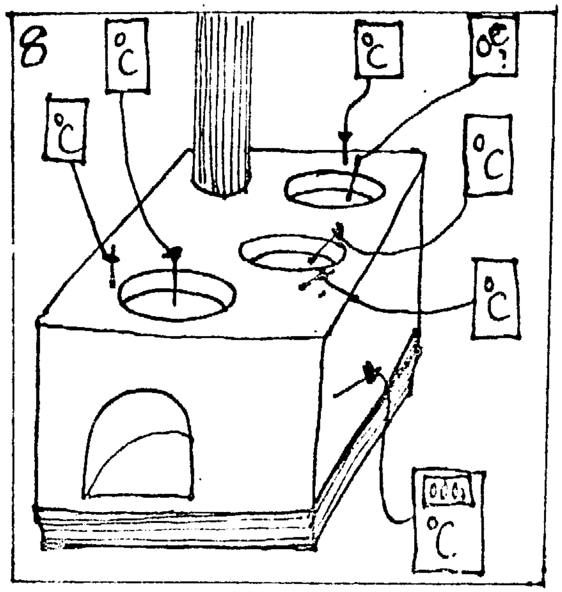


Put in the required amount of water and record it.

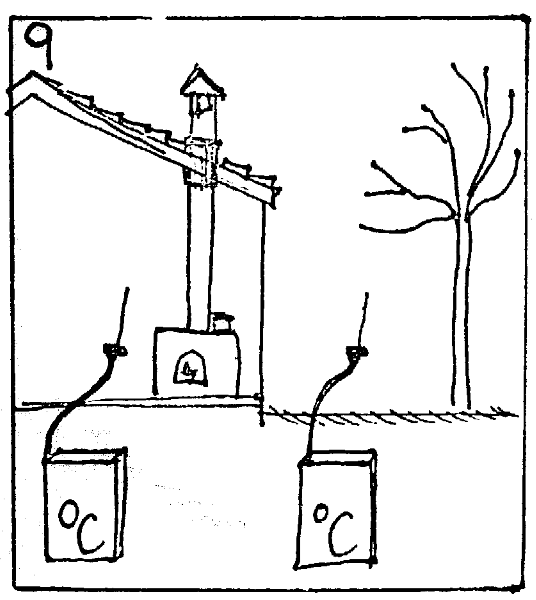
Pot 1.....
Pot 2....



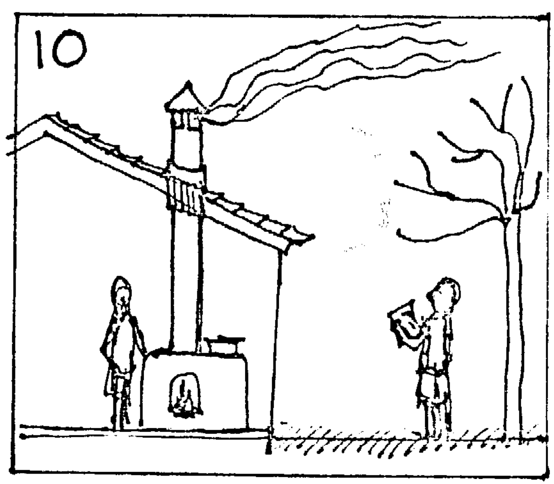
Record the temperature of the water.



Record the stove wall temperature: for each hole record the temperature of the inner and outer wall.

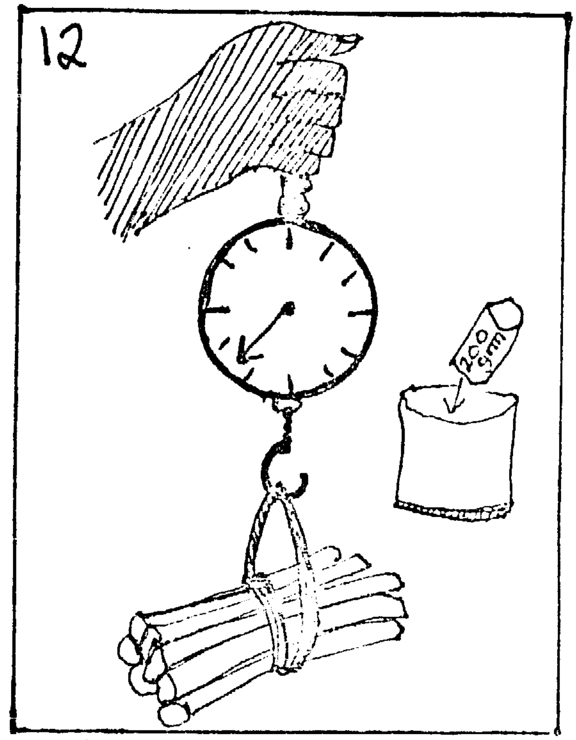


Record the temperature of the air inside and outside the kitchen.

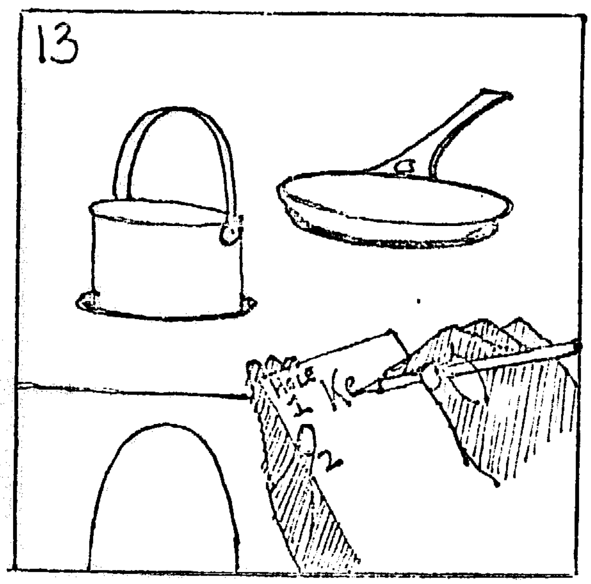


Note if it is windy inside or outside the kitchen.

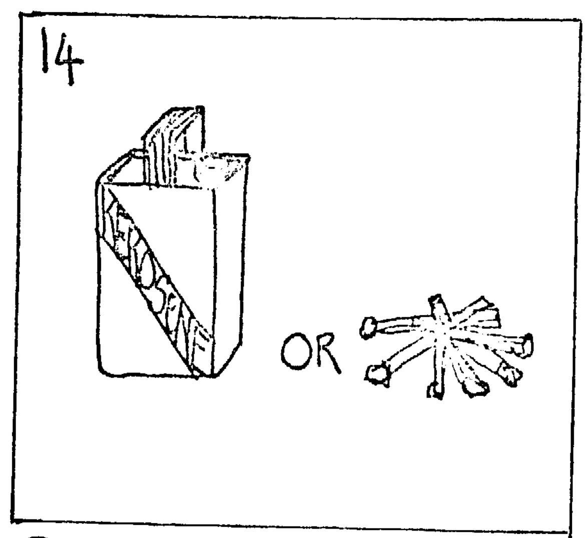
Weigh out food.



Weigh out wood of known variety, note this. Keep 200 grm. sample for moisture content analysis.

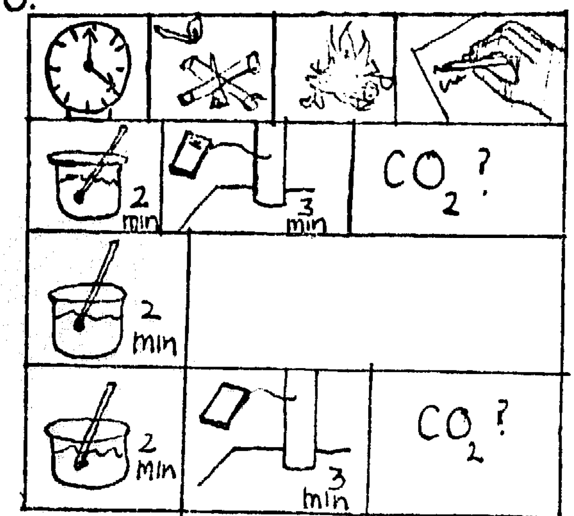


Specify where each pot is placed eg. kettle-hole 1 wok-hole 2.



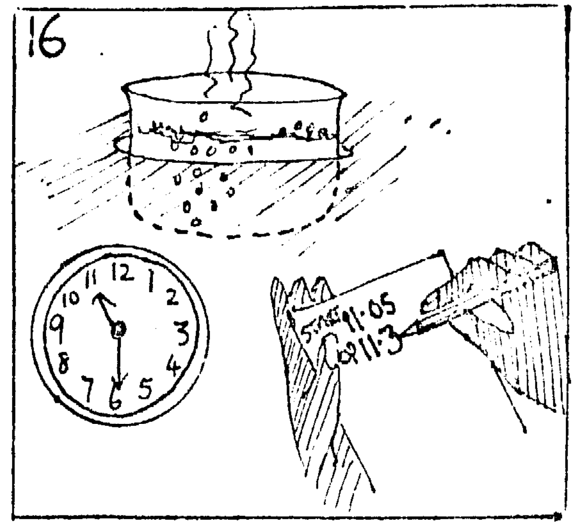
Decide which way the stove is to be lit for all tests eg.
Kerosene or
Kindling – what type ?

15.



Note-time of lighting.
time when fire burning

Take water temperature reading, stack reading, CO_2 analysis. Take water reading again. Repeat until experiment is finished.

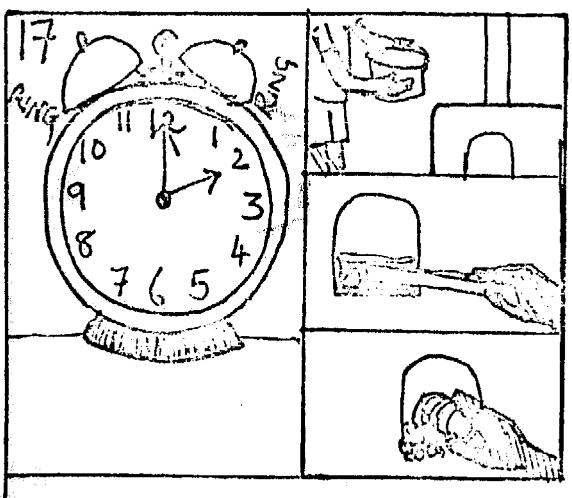


For each pot note time at which water boils.

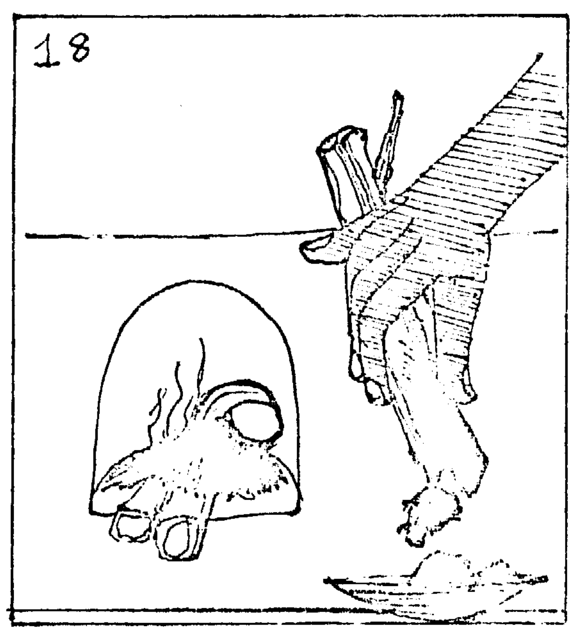
Pot 1 ....

Pot 2 ....

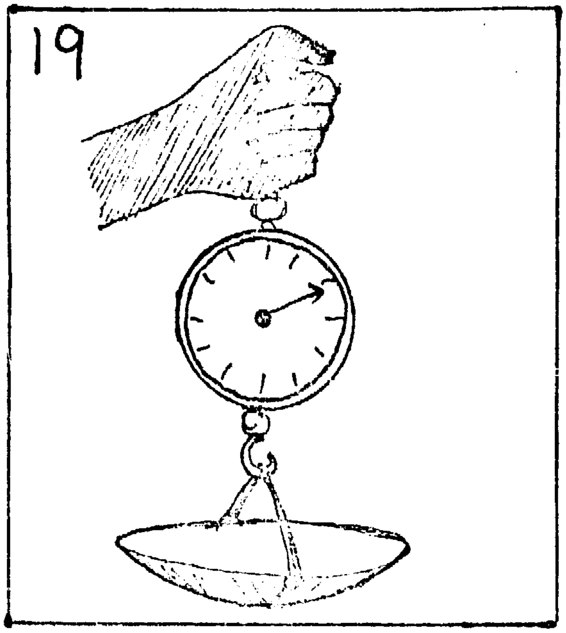
Pot 3 ....



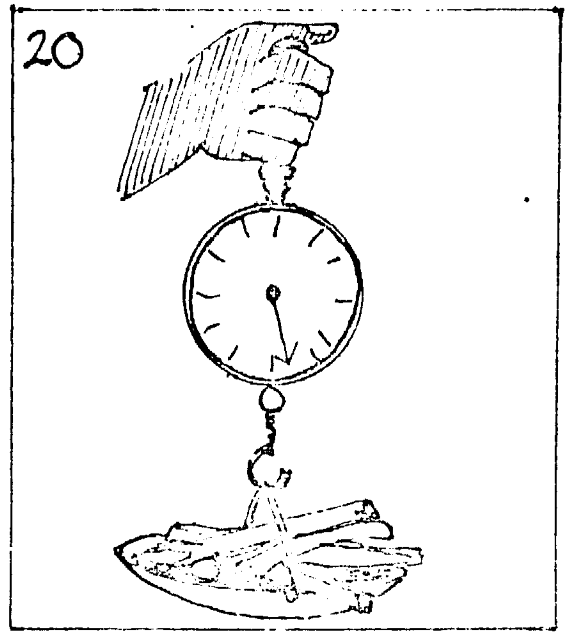
Terminate experiment after specified time has elapsed.



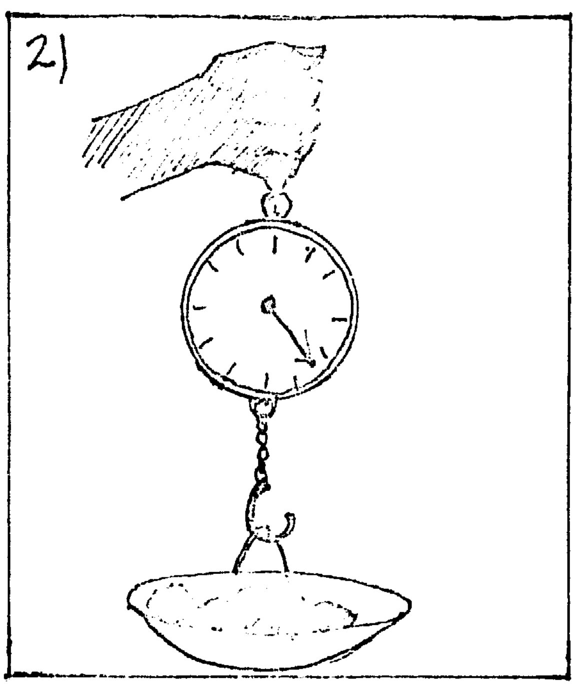
Take out wood and knock off charcoal.



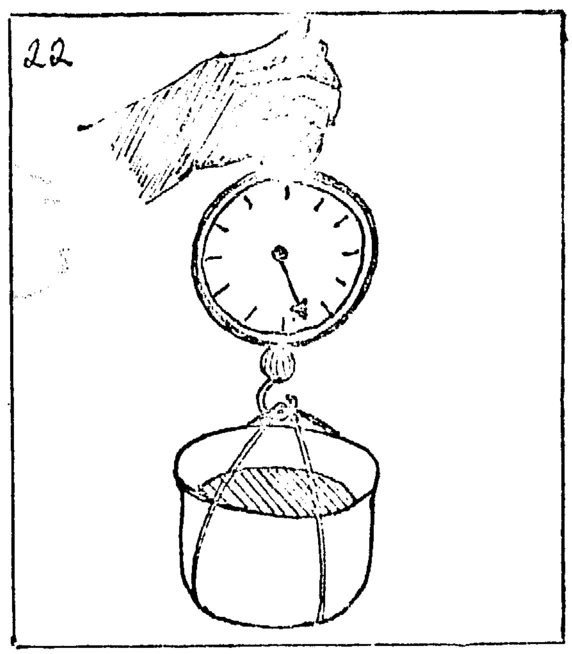
Using container of known weight.



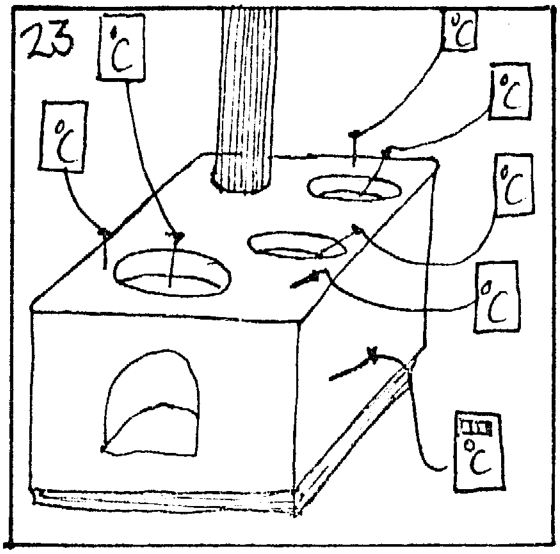
Weigh wood and container.



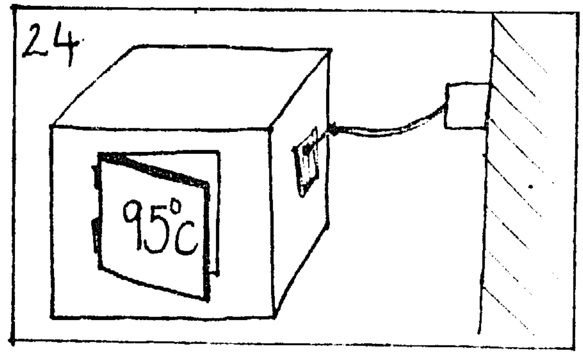
Weigh charcoal and container.



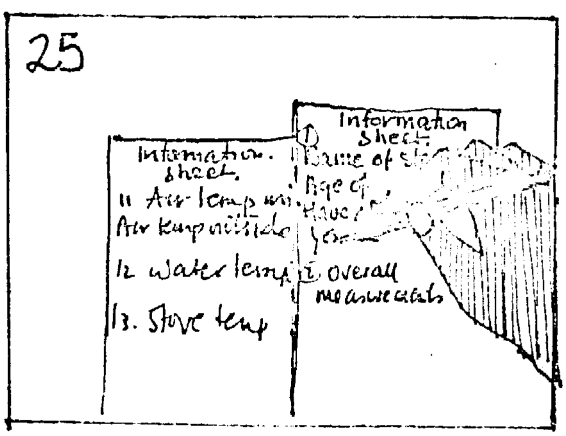
Weigh each pot with water to determine how much has evaporated.



Record the stove wall temperature: for each hole record the temperature of the inner and outer wall.



Moisture Analysis
Cut 200 grams into small pieces. Leave in slightly open oven set at at 95°C for 24 hours. Weigh wood



Fill out other Data Sheets.

LABORATORY TESTS DATA SHEETS

Sheet A

Test No: .... Name of stove: ....

Date: .... Operator: ....

Location: ....

Weather conditions: ....

	Initial	Final
Time:	....	....
Ambient temperature (°C)	....	....
Humidity (% RH):	....	....

Stove: Material: ....

Approx date of manuf: ....

Condition: ....

Chimney: ....

Wood: Type: ....

Condition (wet/dry): ....

Approx. dimns. of each piece: ....

Arrangement in stove: ....

Heat valves (E_{hp}): Wood: .... Charcoal:........

Ignition material (excl. kindling): ....

Pots:	Material	Code	Contents
1)	....	....	....
2)	....	....	....
3)	....	....	....

Description of test procedure: Period 1 ....

Period 2 ....

Period 3 ....

Sheet B

Test No: .... Data for period: ....

Time to ignite wood: .... min

Duration of test period (excl. ign.): .... min

Wt. wood left from previous test/period: .... gm

Wt. kindling wood added: .... gm

Wt. wood added: .... gm

Total init. wt. wood (incl kindl): .... gm

Init. wt. charcoal: .... gm

Final wt. wood: .... gm

Final wt. charcoal: .... gm

Wt. wood used (incl. kindl.) .... gm

Net wt. charcoal produced: .... gm

Effective wt. wood used (incl kindl.)* .... gm

Effective wt. wood used (excl. kindl)* .... gm

Time (min)	Pot 1 (°C)	Pot 2 (°C)	Pot 3 (°C)	Stack (°C)	CO (%)	CO_2 (%)	O_2 (%)

* According to ratio of heat values of wood and charcoal

Sheet B (contd)

	Pot 1	Pot 2	Pot 3	Total
Init. temp. test substance (°C)				
Final temp. (°C)				
Temp. increase (°C)				
Init. wt. pan + test substance (g)				
Final wt. pan + test substance (g)				
Wt. loss (due to evap) (g)				
Init. wt. test substance (g)				
Test substance enthalpy increase (MJ)				
Evaporative heat loss (MJ)				
Total energy utilised (MJ)				

Energy used (incl. kindling) ________ MJ

Sheet C

Summary of results from Test No: ....

Period								
Water boil eff. (%) Total eff. (%)								
Duration (min) Burning rate (g/min) Burning rate (KW)								
Wt. wood used (g) Wt. char prod. (g)								
Pot 2 temp. incr. (^oC) Pot 3 temp. incr. (^oC)								
Mean stack (^oC) Mean CO (^oC) Mean CO_2 (^oC) Mean O_2 (^oC)								

Draft: ....

Comments: ....

....

....

....

....

....

....

HEAT UTILISED (HU)

$$HU_1 = \frac{S_w \sum_{\text{all pots}} W_m \; (T_f - T_i)}{(E_{fm} W_f - E_{co} W_c)} \times 100 \qquad (\%)$$

$$HU_2 = \frac{S_w \sum_{\text{all pots}} \left[W_m \; (T_f - T_i) + l \, W_e \right]}{(E_{fm} W_f - E_{co} W_c)} \times 100 \qquad (\%)$$

$$\text{Burning Rate (BR)} = \frac{W_f - W_k - W_c \dfrac{E_{co}}{E_{fm}}}{t} \times 1{,}000 \quad \text{(g/min)}$$

where S_w = specific heat of water = 1 kcal/kg°C

= 4.184 kJ/kg°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)

= initial weight of unburnt wood minus final weight of unburnt wood (kg)

W_c = weight of charcoal produced in test

= final weight of charcoal minus initial weight of charcoal (kg)

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

T_i = initial temperature of water in pot (^oC)

T_f = final temperature of water in pot (^oC)

E_{fm} = high heat value (gross calorific value) of firewood at moisture content m (dry basis), measured in MJ/kg

E_{co} = high heat value of charcoal at zero moisture content = 29 MJ/kg

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

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

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

For m = 15% (d.b.), E_{fm} = 17.4 MJ/kg

APPENDIX 5 (1)

CALCULATING HEAT BALANCES

When wood burns in a stove it liberates energy in the form of heat and light. Some of this energy is absorbed by the pot wall and the water in the pot and some is absorbed by the stove wall. The remainder is lost up the chimney either through the incomplete burning of the wood (the formation of soot or carbon monoxide) or through the sensible heat of (the energy in) the hot flue gas. The hot stove and pot walls also loose heat to the surrounding air by radiation and convection.

The first law of thermodynamics states that the energy liberated during combustion must equal the energy taken up by the pot and the stove and the flue gases. This relationship can be expressed mathematically.

Eq (1) Q wood = Q stove + Q Pot + Q Flue Gas

Q is the term denoting a quantity of energy (heat) and is measured in Mega joules.

Heat balances can be calculated either at the end of an experiment (this is termed an overall heat balance) or at regular intervals during the experiment (often termed instantaneous heat balance).

There are a number of ways of calculating this energy or heat balance. The preferred method is given below. Each of the four terms will be examined in turn.

1. Q wood

Wood is composed of carbon, hydrogen and oxygen atoms. When wood burns completely in air the carbon reacts with oxygen to form carbon dioxide and the hydrogen reacts with oxygen to form water vapour. Heat is also liberated. The amount of heat liberated (if none of the water vapour condenses) is termed the Gross Calorific Value (GCV). This is measured in megajoules/kilogram

During the cooking process charcoal invariably remains. This charcoal also has a Gross Calorific Value. Whereas the (GCV) of any type of wood does not vary significantly the GCV of charcoal for the same type of wood does. We have found from tests than an average value of 29.3 Megajoules/kg can be used for the GCV.

The GCV is measured in a bomb calorimeter.

To calculate Q wood the following formula can be used:

Eq(2) 1. $Q_{wood} = E_{fm} \cdot W_f - E_{co} \cdot W_c$

W_f is the weight of wood as fired (this weight includes the moisture in the wood)

2. Q_{stove} = this term incorporates the heat actually absorbed in the stove body and the heat lost from the stove walls.

2(a) $Q_{in\ stove}$ - Heat taken up by the stove Q is calculated by multiplying the average increase in temperature of the stove body times the weight of the stove times its specific heat (S_s). The specific heat is the amount of energy absorbed by a kilogram of the stove material when it is raised by one degree centigrade. Thus mathematically:

Eq (3) $Q \text{ in stove} = S_s \cdot W_s \cdot (T_f - T_i)$

where T_f is the average stove temperature at the time of calculating the heat balance, T_i is the average temperature at the start of the experiment.

S_s for mud stoves is .85 kjoules/kg^{o}C

2(b) $Q_{out\ stove}$ - heat is lost from the stove wall both by radiation and convection. The convective heat lost can be calculated using a parameter known as a natural convection transfer coefficient. For convective loss

Eq(4) $Q \text{ out stove} = h_{nc} \cdot A\ (T_{fav} - T_a) \cdot t$

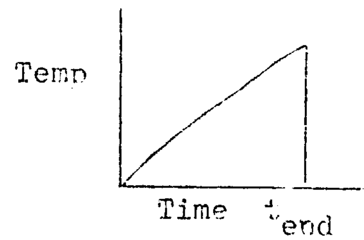
h_{nc} = the natural convective heat transfer coefficient. This can be calculated using standard nondimensional correlations.

However, when there is little draft around the stove walls and the final average temperature is less than 100^{o}C h is approximately equal to 9 watts/m^{2} ^{o}C (one watt is a joule/sec). For a stove wall at an average temperature of 200^{o}C h = 13 watts/m^{2} ^{o}C. If a strong breeze is blowing around the stove an additional forced convective heat transfer coefficient must be calculated and added to the natural convective term.

It is very difficult to calculate accurately and it is much better to conduct experiments away from substantial ($>$ .5m/sec) drafts.

A is the area of the stove walls in square metres (m^2)
T_{fav} = the time average temperature of the stove wall over the period for which the heat balance is being calculated. This is calculated by plotting the average wall temperature as a function of time. The time average temperature is the area under the curve divided by the time. Mathematically this can be expressed as:

$$T_{av}\ fin = \frac{\int_0^{t_{end}} T(t)\, dt}{t_{end}}$$



T_a = ambient air temperature

t = is the time in seconds

For loss due to radiation for the heat lost is

Eq(5) $Q = \epsilon \times \sigma A \times (T^4_f - T^4_a) \times t$

of the stove wall material

ϵ = emissivity (a fraction of 1)

σ = Stefan Boltmanns constant 5.67×10^{-8} watts/m^2 K4

The temperatures are in degrees Kelvin ($273 = x^oC$)

3. Q_{pot} = this term can be divided into the heat taken up by the water and the pot wall and the heat given out by the pot wall.

3(a) $Q_{in\ water}$ - this is calculated using the following expression:

$$Q_{in}W = \left[\sum_{\text{all pots}} (W_m \cdot (T_f - T_i) \cdot S_s) \right] + L \cdot W_c$$

3(b) $Q_{in\ pot}$ - this is equal to the specific heat of the pot wall multiplied by the weight of the pot multiplied by the increase in temperature of the pot wall (to the water temperature).

Eq (6) $Q_{in\ pot} = S_p \cdot W_p \cdot (T_f - T_i)$

W_p = weight pot

S_p = specific heat of pot

For clay S_p = 1 kjoules/kg°C and for Aluminium S_p= .85 kjoules/kg°C.

3(c) $Q_{out\ pot\ wall}$ - this is calculated using the formula given in 2(b) namely:

Eq (7) $Q_{out\ pot\ wall} = h_{nc} \cdot A_{pw} \cdot (T_{avf} - T_i) \cdot t$
$+ \epsilon_{pw} \cdot \sigma \cdot A_{pw} (T_{avf}^4 - T_i^4) \cdot t$

pw = pot wall

It should be boted than when a lid is used the losses from this lid must be calculated.

4. $Q_{flue\ gas}$ - this term includes:

1. The energy required to evaporate the moisture from the wood and the energy lost to evaporate the water formed in the combustion reaction is not condensed.

2. The energy of the hot gases leaving the stove.

3. The energy lost by incomplete combustion of the wood.

Q_{evap} - this term can be calculated using the formula:

Eq (8) $Q_{evap} = \left(\frac{M_f}{100} + .59 \right) (2521 + 1.9\ T_{ave_g} - 2.23\ T_{af}) \times W_{df}$

where M_f = the moisture content (on a dry weight basis) of the wood

T_{aveg} is the average temperature of the flue gas

T_{af} = ambient temperature of fuel

W_{df} = the dry weight of wood

Q_{stack} - this is given by the expression

Eq (9) $Q_{stack} = S_{stack} \cdot W_{dg} \cdot W_{df} \cdot (T_{aveg} - T_a)$

where S_{stack} = the specific heat of the flue gas and is approximately .24 kilocalories/kilogram/°C.

W_{df} = dry weight of wood

T_a = ambient temperature

T_{avg} = average flue gas temperature

W_{dg} = weight of dry gas produced per kilogram of fuel burnt and can be calculated using the expression

Eq(10) $$W_{dg} = \frac{4\ CO_2 + O_2 + 700 \times C_{ab}}{3\ CO_2 + CO}$$

where $$C_{ab} = \frac{.5 \cdot W_{df} + .9 \cdot W_{tac}}{W_{df} + W_{tac}}$$

W_{tac} = the time average weight of charcoal produced for the time under consideration.

CO_2, O_2, CO are the volumetric composition of the flue gas.

W_{dg} can only be calculated approximately unless very sophisticated equipment is installed to accurately determine the mass flow of gas.

If air enters at any point other than the firebox opening the gas samples taken normally in the chimney for analysis will give a false indication of the amount of gas produced for a kilogram of wood burnt.

Gas readings taken elsewhere in the stove may also give false readings. Combustion often occurs throughout the length of the passageways in the stove.

$Q_{incomplete\ combustion}$ - some of the carbon in the wood will not completely react with oxygen to form carbon dioxide. Instead carbon monoxide creosote and soot will be formed. The heat given out when these substances form is less than when carbon dioxide forms.

Normally only the energy loss due to carbon monoxide formation is considered. However, soot and creosote formation is often quite considerable. To measure the amount of these elements formed is difficult and requires sophisticated equipment.

To account for the energy loss due to carbon monoxide formation the following formula is used:

Eq(11) $$Q_{CO} \text{ (in kilojoules)} = 22{,}250 \times \frac{CO}{CO_2 + CO} \times C_{ab} \times W_{df}$$

22,250 kilojoules/kilogram is the difference in energy released due to burning carbon to carbon monoxide rather than carbon dioxide.

Unaccounted for Losses and Gains

The term one should equal the sum of terms two, three and four (Eq 1). Often due to inaccuracies in measurement this does not occur. It is more usual to find that the sum of terms 2, 3 and 4 are less than term 1 and the energy difference is then called unaccounted for losses.

However, we have observed that terms 2, 3 and 4 can be greater than term 1. This difference is termed an unaccounted for gain.

APPENDIX 6 (1)

EXAMPLE OF AREA PROFILE

Ngestirejo lies within the region of Gunungkidul, a hilly region south-east of Yogyakarta. Most of the top-soil has been removed due to deforestation which has been occurring over the past 100 years. The soil is very clayey, and sits over a limestone rock base with volcanic outcrops on the surface. The main crop is cassava with some corn, peanuts and potatoes being grown. The two main problems in the area are water and firewood. During the wet season ponds fill up and people walk between ½ - 2 km to fetch water. In the dry season the smaller ponds quickly dry up and the large ones often contain no water by the time the first rains appear. People are often forced to walk 10km to fetch water.

Gunungkidul is economically and infrastructurally isolated from the rest of Java. This limits any type of economic development and the economy is mainly self contained. Most money comes from former residents with government jobs.

Firewood

Women selectively prune the acacia trees that grow on the edge of the terraces. This is a high value wood but is not nearly sufficient to meet their needs so they supplement it with twigs and rubbish. Children often collect twigs coming to and from school or while in the fields. This fuel is considered to be inferior and is usually wet. Men do the felling of larger trees usually leucena, jack fruit, kopah and mlungding (a local fruit tree) and teak. This wood is only used for special occasions or for use in construction of houses or furniture.

Social Structure

Ngestirejo lies in the region of Wonasari. Within the region there are a number of districts with a government district head. The district is divided into a number of villages each with an elected head (lurah), treasurer, and secretary. The village is divided into hamlets consisting of 8-20 households each. The lurah is responsible for all community affairs. This includes reporting to the government on the state of development, passing on official decrees, assisting government officials in their work, entertaining visitors and heading cultural activities.

Other important members of the community include hamlet heads, foremen of cooperative work groups, extension people from family planning boards, teachers, traditional doctors. People farm their land without communal assistance. However, reaforestation, road building, maintenance of public buildings and places, and the cassava mills are all cooperatively worked This organisational structure is the same at the other two villages.

Cultural setting with relevance to fuelwood use

Cooking is done by all members of the family. Boiling water and simple tasks such as frying or roasting are done mainly by the children. Preparation of food and cooking of other dishes is done by the wife when not involved in other tasks. The kitchen is one of the largest rooms in the house. In the kitchen are large clay water jars, cooking utensils and a number of stoves. Above the stoves are drying racks for food. Smoke from the fire drifts through the tiled roof and through small posts at the top of the end walls.

Cooking practices vary over the seasons depending on what crops are being harvested. Usually most of the cooking is done in the afternoon, after siesta time (3 - 5 o'clock). However, in larger households cooking is also done early in the morning. Even if no food is being cooked water is boiled in the morning.

Traditional stoves are made by teenage men in the village. They are constructed from mud and from a slightly metamorphosed siltstone referred to as Padas. The stoves take half a day to build and have either 2 or 4 holes, depending on the size of the family. In the lurah's house a four and a two holed stove are always found, the larger stove being used when guests are to be entertained. The lifetime of this stove ranges from 1 and 3 years.

Cooking pots are elevated off the holes by pieces of broken ceramic pots. This allows the flame and hot gases to escape around the pot.

APPENDIX 7 (1)

CHECKLIST FOR ASCERTAINING FAULTS FOUND IN MUD STOVES

1. Kitchen

Is there a means to dry out wood? Yes/No

Is the old stove still being used? Yes/No

2. The Entrance Way

Is the entrance way properly shaped? Yes/No

a. Take measurements ....cm
b. Make a sketch
c. Compare with the original plan

3. The Firebox

Is the firebox:

a. the right shape? Yes/No
b. too deep? Yes/No

Are cracks visible? Yes/No

Have any cracks been repaired? Yes/No
(State reasons why ....
....)

Is there any ash or any other solid material blocking the firebox?
Yes/No

Describe ....
....

Is the pot seat lip the right shape for all utensils? Yes/No

Describe ....

4. Connecting Tunnels

Are the connecting tunnels:

a. clear and clean? Yes/No
b. the right size? Yes/No
(take measurements ....cm)
c. sloped enough? Yes/No

5. Cooking Hole Design

Are the pots inserted properly? Yes/No

Is there space for the hot gases to flow up the sides of the pot? Yes/No

(Take measurements...............cm)

Does the hill support the pot? Yes/No

(Take measurements ....cm)

6. The Dampers

Are the dampers long enough to close the tunnel? Yes/No

(Describe ....)

Do the dampers need replacing? Yes/No

Do the dampers fit nearly into the slots? Yes/No

(Describe ....)

7. The Chimney

Is the chimney:

a. clear of obstruction? Yes/No
b. clean? Yes/No
c. touching inflammable materials? Yes/No
d. worn out? Yes/No